%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5!
ReVolver/C40 $N
<BAu$H@-G=I>2A

5HC+D><y

J?@.11G/27n12F|

Abstract

3<!856u4V$KB8:_$9$kJ*BN$r!"C10IN)J}BN(%\%/%;%k$H8F$V)$N=8$^jG9=@.5l$F$$$k$H9M$(!"3N6u4V$r%\%j%e!<%`%G!<%?$N$^$^2<!85$N%9%/%j!<%s$KEj1F$9$k$3$H$K$h$C$F!">pJs$N2D;k2=$r9T$&5;K!$r%\%j%e!<%`%l%s%@%j%s%0$H8F$V!#%\%j%e!<%`%l%s%@%j%s%0GO!"FbIt>pJs$r;}$D%G!<%?$N2D;k2=$,9T$($k3H$+$i!"J*BN$NI=LL$@1GJ/!"$=$NFbIt$dGX8e$N>u67$b2hA|$H7FI=8=9k3H$,$G$-$k!#$=$N$?$a!"0eNEJ,LnK*1k?MBN%G!<%?$N2D;k2=!"9=B$2r@O$dN.BN7W;;$rO8aH9k2J3X5;=Q7W;;$N7k2L$N2D;k2=JI$N<jCJ$H7F=EMW;k5l$F$$$k!#3N<jK!$N<B8=$K$O85Mh!"KDBg$J%G!<%?$r5-21$7F*$/$?aN5-21MFNL$HB?Bg$J7W;;NL$,I,MW$G$"$C$?!#$=N?$aEv8&5f<<$G$O@lMQJBNs7W;;5! *ReVolver*/C40 $r3+H/$9k3HKhC$F!"$3$NLdBj$KBP=h9k3H$r9M$($?!#

%\%j%e!<%`%l%s%@%j%s%0=hM}$O!"3<!85$N%\%j%e!<%`%G!<%?$r2<!85$K<M1F9k2hA|@8@.=hM}$H!"$=$N<M1F7k2L$K1"1FrD1k%7%'!<%G%#%s%0=hM}$KJ,$1il$k!#*ReVolver*/C40 GO3liN=hM}$r;k@~@8@.%9%F!<%8(Ray Casting Stage:RCS)!"%T%/%;%kCM7W;;%9%F!<%8(Pixel Calculation Stage:PCS)!"%7%'!<%G%#%s%0%9%F!<%8(Shading Stage:SS)!"$H8F$Plk3DN%9%F!<%8$G9T$JCF$$$k!#;k@~@8@.%9%F!<%8GO!";kE@$+$i%9%/%j!<%s>e$N%T%/%;%k$rDL$k;k@~$K4X9k%G!<%?$r@8@.$7$F$$$k!#%T%/%;%kCM7W;;%9%F!<%8GO;k@~@8@.%9%F!<%8$G@8@.$5l?;k@~$K4X$9$k%G!<%?$rbH$K%\%/%;%k$NCMrFI_=P$7!"%T%/%;%k$NF)L@EY$dRGB CM$r5aak!#%7%'!<%G%#%s%0%9%F!<%8GO%T%/%;%kCM7W;;%9%F!<%8$G@8@.$5l?2hA|$K1"1F$rD1!"8=<B46N"$k2hA|$rCRT $K=PNO$9$k!#$^$? *ReVolver*/C40 A4BN$N@)8f$O%7%9%F%`%3%s%H%m!<%k%f%K%C%H(System Control Unit:SCU) $,9T$C$F$*$j!"%[%9%H%^%7%s$+$iAw$i$l$?%3%^%s%I/%G!<%?$K=>$C$F!"3F%9%F!<%8$X$N%G!<%?$d%W%m%0%i%`$NE>Aw$r9T$C$F$$$k!# *ReVolver*/C40 $H%f!<%6$N%$%s%?%U%'!<%9$rHkNb%7%9%F%`%3%s%H%m!<%k$NLrL\$G$"$k!#

K\9FGO3liN9=@.MWAG$N<BAu4pHD$rMQ$$$F!" *ReVolver*/C40 $N@-G=I>2A$r9T$$!"$=$N7k2L$K4p$E$$$?9M;!$r=R$Y$k!#

ReVolver/C40 $N@-G=I>2A$O!" *ReVolver*/C40 $N%5%V%;%C%H$rbA$$$F9TC?!#$=$N7k2L!"2hLL@8@.B.EY$O%T%/%;%kCM7W;;%9%F!<%8$N%9%T!<%I$K0MB8$9k3H,o+$j!"%\%j%e!<%`6u4V$NBg$-$5$r$512^3$voxel!"%U%l!<%`$NBg$-$5r512^2$pixel !"%T%/%;%kCM7W;;%9%F!<%8$N%W%m%;%C%5Bf?t$r512BfH7$?$H$-$K!"%7%9%F%`%<~GH?t25MHz $G1.16frames/s $H$$$&7k2L$K$J$C$?!#$^$?3F%9%F!<%8$4$H$K$b@-G=I>2A$r9T$J$$!";k@~@8@.%9%F!<%8$O%U%l!<%`NBg-5r512^2pixel H7$?$H$-$K!"%7%9%F%`%<~GH?t25MHz GG2.21frames/s!"%7%'!<%G%#%s%0%9%F!<%8$O@h$[IHF1MM$N>r7o$G1.55frames/s $N@-G=$rbC$F$$$k3H$,$o$+$C$?!#

ReVolver/C40 $N@_7WEv=i$O!"%T%/%;%kCM7W;;%9%F!<%8$,>e=R$N>r7o$HF1$8G"$k>l9g$K5.30frames/s $N@-G=$,$@$;kHM=B,5l$F$$$?!#8=:_$N *ReVolver*/C40 $N2hLL@8@.B.EY$O3N@-G=$,=P$;$F$$$J$$!#$=$NMW0xH7FO!"3F%9%F!<%8GN%W%m%0%i%`$NA}Bg$H%T%/%;%kCM7W;;%9%F!<%8$N3F=hM}C10L4V$NDL?.;~4V$NA}Bg$,$"$k!#DL?.;~4V$NA}Bg$N860x$rD4$Y$?7k2L!"4pHD4V(Nc$($P!"%l%$

%-%c%9%F%#%s%0%9%F!<%8$H%T%/%;%kCM7W;;%9%F!<%8$N4V)$NDL?.;~4V$,%T%/%;%kCM7W;;%9%F!<%84pHDFb$NMWAG4V$NDL?.;~4VhjD9$/$J$j!"$=$NCY1d$,%7%9%F%`$N%Q%$%W%i%$%s$rEAHB$7$F$$$k$3$H$,$o$+$C$?!#%W%m%0%i%`$K4X$7FOJBNsL?Na$r;HMQ$9k3HG2~A1$NM>CO$,$"$k$,!"DL?.;~4V$K4X7F$O%T%/%;%kCM7W;;%9%F!<%8$N4pHD$N0lIt2~NI$r9ToJ1lPJiJ$$!#

ReVolver/C40 $G;HMQ$5lF$$$kMWAG%G%P%$%9$O!"6aG/GOhj9bB.2=$+$D>.7?2=$,?^$ilF$$$k!#3liNMWAG%G%P%$%9$rMQ$$$k3HKhCF!" *ReVolver*/C40 $N@-G=$r0];}7D$D>.7?2=$,?^k3H,9M$($ilk!#3N>l9g%a%b%j%"%/%;%9;~4V$,<gMW$JLdBjHJ$k!#

Abstract

Volume rendering is a technique that is developed to visualize information by projecting a three dimensional space on a two dimensional screen. Objects in this space with volume data can be regarded as a group of unit cubes (called voxels). Not only the surface of objects but also the inside and rear side of objects can be projected by using volume rendering, because data have internal-information which can be visualized. So it is an important technique for medical images of the human body and the results obtained by scientific computation such as the computation in fluid dynamics and structure analysis. Enormous amount of storage and long computation time is needed for this method. Thus it was considered that this problem can be solved efficiently by developing Parallel Volume Rendering Machine '*ReVolver*/C40'.

Volume rendering consists of two processes. One is creating images which are visualized information by projecting the three dimensional space on a two dimensional screen, and the other is shading projected objects. This machine executes them with three independent stages. The Ray Casting Stage (RCS) creates view data from view point and screen coordinates. The Pixel Calculation Stage (PCS) calculates voxels addresses from view data generated by the Ray Casting Stage to get their values which are needed to calculate pixel values (colors and transparent values). The Shading Stage (SS) shades images generated by the Pixel Calculation Stage and displays them on the CRT. All these stages are controlled by the System Control Unit (SCU). The System Control Unit receives commands and data from the host machine, and transmits data and programs to each stage by following them. The System Control Unit also provides a user interface.

This paper describes structure and performance evaluation of *ReVolver*/C40.

Only subsets of *ReVolver*/C40 were used for evaluation of the whole system. As a result of performance evaluation, it was found that the Pixel Calculation Stage determines the speed of image generation. *ReVolver*/C40 with 512 processors on the Pixel Calculation Stage can generate images of 512^2pixels from 512^3voxels volume in 1.16frames/s under system clock frequency of 25 MHz. Each stage of *ReVolver*/C40 was also evaluated. The Ray Casting Stage can generate images of 512^2pixels in 2.21frames/s under system clock frequency of 25 MHz. The Shading Stage can generate images in 1.55frames/s in the same conditions.

When *ReVolver*/C40 was designed, it was estimated that the Pixel Calculation Stage can generate images in 5.30frames/s in the same conditions. *ReVolver*/C40 can't actually generate images at this speed. This resulted from an increase of program size at each stage and of communication time in the Pixel Calculation Stage. We find that board to board (for example, from the Ray Casting Stage to the Pixel Calculation Stage) communication time is longer than communication time within the Pixel Calculation Stage board, and that causes communication time increase in the Pixel Calculation Stage. Program can be improved by using parallel instructions, but a new Pixel Calculation Stage board design

is needed to speed up communication.

Recently the devices used on *ReVolver*/C40 are available in a miniaturized form and can be controlled under higher clock frequency. By using such new devices, at least equivalent performances could be reached, and even improved. However, memory access time becomes a main problem in such miniaturized system.

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1 O8aK

%\%j%e!<%`%1%s%@%j%s%0$O!"3<!856u4V$rC10LN)J}BN(%\%/%;%k$H8F$V) $G9=@.$5$l$F$$$k$H9M$(!"$3$N6u4V$r2<!85$N%9%/%j!<%s$KEj1F$7$F2hA|$rF@$k5;K!$G$"$k!#%\%j%e!<%`%1%s%@%j%s%0GO!"FbIt>pJs$r;}$D%G!<%?$N2D;k2=$,9T$($k3H$+$i!"U*BN$NI=LL$@1GJ/!"U*BN$NFbIt$dGX8e$N>u67$b2hA|H7$FI=8=$9k3H,G-$k!#$hCF3N5;K!$O!"=>Mh0eNE2hA|J,Ln$K$*$$$F?MBNFbIt$N2D;k2=$r9T$&>e$G=EMWH5lF$-$?!#5i$K6aG/$G$O!"%9!<%Q!<%3%s%T%e!<%?$JIN9bB.$J7W;;5!$rMxMQ7?2J3X5;=Q7W;;$N7k2L$N2D;k2=Kh$k2r@O<jK!$H7F$b=EMW;k$5lF$-$F$$$k!#$=$3$GEv8&5f<<$G$O0eNE2hA|@8@.$@1GJ/!"2J3X5;=Q7W;;$N7k2L$N2D;k2=rb9T$($kh&$J?7$7$$@lMQJBNs7W;;5!*ReVolver*/C40 $r3+H/$9k?aK!"@_7W!"<BAu$r9T$CF-$?!#$=$N7k2L!"8=:_*ReVolver*/C40 O=$N%5%V%;%C%H$,F0:n7F$$$k!#$=$3$G!"$=$N%5%V%;%C%H$rMQ$$$F *ReVolver*/C40 $N@-G=I>2A$r9TC?!#

@-G=I>2A$O!"$^$:3F%9%F!<%8C1BN$G2hLL@8@.B.EY$rN'B.$9kh$&$J=hM}KD$$$F2hLL@8@.B.EY$rI>2A$7!"$=$N8e3F%9%F!<%8$r@\B3$7!"*ReVolver*/C40 $N%W%m%H%?%$%W$r<B:]F0:n$5$;$kNH$[$\F1$8>r7o$G!"2hLL@8@.B.EY$rI>2A$7$?!#$?$@!"0lItI10BDj$JF0:nr*$3$9$H9M$(ilkH3m$O!"$^$:F0:n$9k3HrG0F,K*$$$?@_7W$r9T$C$F$$$k!#

K\9FGO%5%V%;%C%H$rMQ$$$? *ReVolver*/C40 $N@-G=I>2A$K$D$$$F=RYk!#Bh2>OK*$$$F$OGX7J$H7F *ReVolver*/C40 $N35MW$K$D$$$F=R$Y!"Bh3>O$G$O *ReVolver*/C40 $N3F%9%F!<%8$*hSA4BN9=@.KD$$$F=RYk!#Bh4>OGO *ReVolver*/C40 $N3F%9%F!<%8$G$N<BAu$K$D$$$F=R$Y!"Bh5>O$G$O *ReVolver*/C40 $N3F%9%F!<%8$N@-G=I>2A!"$=$7F=lK4pE/ *ReVolver*/C40 A4BN$N@-G=I>2A$K$D$$$F=R$Y!"9M;!$r9T$&!#Bh6>O$G$O *ReVolver*/C40 A4BN$K4X9k9M;!$r9T$&!#$=$7$FBh7>O$G$^$Hak!#

2 *ReVolver*/C40 $N35MW

2.1 %\%j%e!<%`%1%s%@%j%s%0

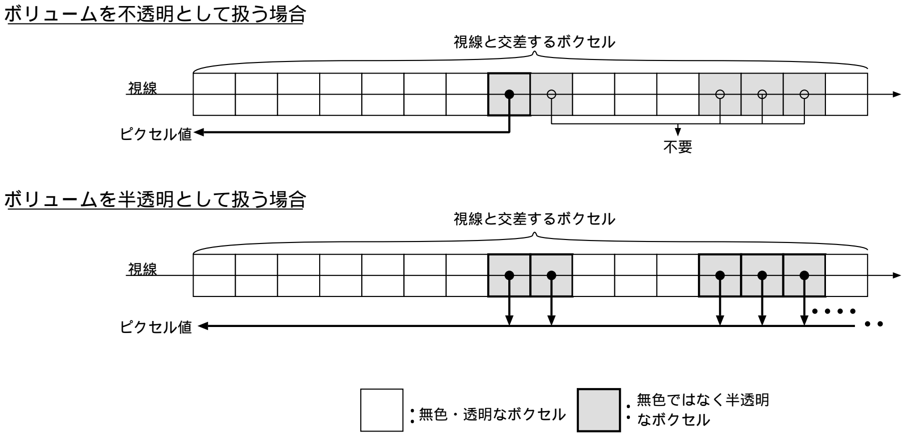
%\%j%e!<%`%1%s%@%j%s%0$O!"%\%j%e!<%`6u4V$+$i%5!<%U%'%$%9$r;;=P7F%1%s%@%j%s%0$r9T$&%5!<%U%'%$%9%1%s%@%j%s%0$H$O0[$J$j!"%\%j%e!<%`$N?'$dF)L@EY$rD>@\%9%/%j!<%s$K<M1F$9$k<jK!$G$"$k[1]!#%\%j%e!<%`%1%s%@%j%s%0K*$$$F!"2D;k2=$NBP>]$HJk6u4V$r%\%j%e!<%`6u4V$H8F$V!#%\%j%e!<%`6u4V$K$O!"2J3X5;=Q7W;;$N7k2L$d<+A38=>]$JIN%G!<%?%;%C%H$,H>F)L@$N%\%j%e!<%`H7$F?'$dF)L@EYJI$KJQ49$5lFCV$+$l$k!#

ReVolver/C40 GO!"%\%j%e!<%`6u4V$ON)J}BN$G$"$j!"$"$"$kD:E@$r4^$`3JU$,%o!<%k%I:BI87O$K$*$1$k3F:BI8<4 (x,y,z <4) $N@5$NJ}8~K"kh$&$K@_Dj5l$k!#$3$N%\%j%e!<%`6u4V$rC10IN)J}BN$KJ,3d$7!"N%;6E*$K%G!<%?$rM?$($?bN$r%\%/%;%k$H8F$S!"3F%\%/%;%k$K$O?'$dF)L@EY$NCM(%\%/%;%kCM) $,M?$(il$k!#$^$?!"%9%/%j!<%s$O%T%/%;%k$H8F$PlkC10L@5J}7A$N=89g$H7FB*$($ilk!#

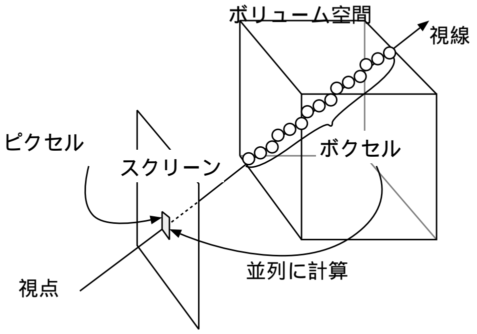
2.2 *ReVolver*/C40 $NFCD'

ReVolver/C40 $O1>O$G$b=R$Y$?$h$&$K!"0eNE2hA|@8@.$@$1GJ$/!"2J3X5;=Q7W;;$N2r@O$dN.BN$N2D;k2=rb9T$($k@lMQJBNs7W;;5!G"$k!#$3$NL\E*$rC#@.9k$?$aKO!"H>F)L@%\%j%e!<%`$NI=<(!"1s6aK!$K$h$k2hA|@8@.!"9bB.IA2h$H$$$&3$D$NMW7o$rK~B-$9$kI,MW$,$"$k!#%\%j%e!<%`$rH>F)L@$JbNH7$F07$&KO!"?^1Nh$&$K%T%/%;%kCM$r7W;;$9$k:]$K;k@~$H8r:9$9$kL5?'F)L@$G$J$$A4%\%/%;%k$r=g$K%"%/%;%9$9$kI,MW$,$"$k!#$^$?1s6aK!$r:NMQ9k>l9g!"G$0UJ}8~$N;k@~$,H/@8$9k?$a!"%a%b%j%"%/%;%9$,5,B'E*GOJ/!"%a%b%j%P%s%/XN%"%/%;%96%9g$N2DG=@-$,9b$/$J$j!"JBNs=hM}$X$N>c32$HJk!#$3$3GO!"$=$liNLdBj$r2r7h$7!"9bB.IA2h$r9T$&$?$a$K *ReVolver*/C40 $,;}$C$F$$$kFCD'$r=R$Y$k!#

%1%$%-%c%9%F%#%s%0K!$N:NMQ ;kE@$+$i%9%/%j!<%s>eN"$k%T%/%;%k$NCf?4XH8~$+$&%Y%/%H%k$N3$H$r;k@~%Y%/%H%k$H8F$S!";kE@$r0lC<H7%T%/%;%k$NCf?4$rDL$kH>D>@~$r;k@~$H8F$V!#?^2$K<($9h&$K%1%$%-%c%9%F%#%s%0K!



?^1: ;2>H9k%\%/%;%k$N0c$$



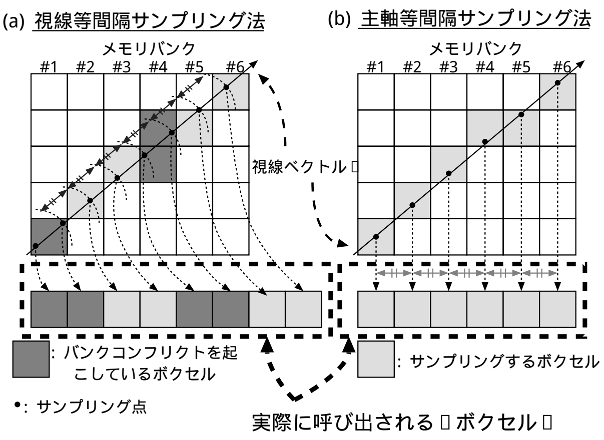
?^2: %1%$%-%c%9%F%#%s%0K!

GO%9%/%j!<%s>e$N%T%/%;%k$4HK!";k@~$,$I$N%\%/%;%k$rDL2a7F$-$?N+$rDI@W$7$F!"%T%/%;%k$N?'$dL@$k5r7hDj$7!"%9%/%j!<%s$KEj1F9k!#

%5%s%W%j%s%0J}K!$NC1=c2= $ReVolver/C40$ GO!";k@~%Y%/%H%k$N@.J,$N@dBPCMN&$A!":GBgCM$rbD:BI8<4$r<g<4$HDj$a!"$3$N<g<4$NJ}8~KBP7$FEy4V3V$K%\%/%;%k$r%5%s%W%j%s%0$9$kJ}K!$r:NMQ7F$$$k!#3NJ}K!$r<g<4Ey4V3V%5%s%W%j%s%0K!$H8F$V(?^3(b);2>H)!#3NJ}K!Kh$j!"<!$K=RYk%P%s%/%3%s%U%j%/%H$,@8$8$J$$!#

$?$@3NJ}K!GO!";k@~$,<4$HJ?9TGJ$$;~$K%5%s%W%j%s%04V3V$,=>Mh$N;k@~Ey4V3V%5%s%W%j%s%0K!(?^3(a);2>H) HHfYFBg-$/$JkH$$$&@-<A$,$"$k!#$3$N%5%s%W%j%s%04V3V$NJd@5$O%T%/%;%kCM$N7W;;;~$K9T$&3H$GBP=h$9$k!#

%P%s%/%3%s%U%j%/%HNJ$$%a%b%j9=@.<g<4Ey4V3V%5%s%W%j%s%0K!GO!"$"$k:BI8<4$K?bD>$J slice $K%\%j%e!<%`%G!<%?$rJ,3d7F%a%b%j%P%s%/$K3JG<$9lP!"$=$N:BI8<4$r<g<4$H7F;}$D;k@~$K4X7F$O%P%s%/%3%s%U%j%/%H%U%j!<HJ$k!#$7$+$7!"G$0UJ}8~$N;k@~$N<g<4$,!"3N:BI8<4$r<g<4$H7F;}DH$O8B$i$J$$!#$=$3$G!"x,y,z <4$N$$$:lK$b?bD>$J slice $,B8:_$9kh$&$KJ,3d9lPG0UJ}8~$N;k@~$KBP7F%P%s%/%3%s%U%j%/%H%U%j!<H9k3H,G-$k!#



?^3: %5%s%W%j%s%0J}K!$NOc$$

ReVolver/C40 $N3 <!85%a%b%j9=B$$G$O!"?^4 Nh$&$K%\%j%e!<%`%G!<%?$r;0=E2=$7!"<g<4Ey4V3V%5%s%W%j%s%0$r9T$&3HKh$j!";k@~$,G$0UJ}8~$G$"$CFb!"%P%s%/%3%s%U%j%/%H$,@8$8$J$$$3HrJ]>Z9k!#

2.3 *ReVolver*/C40 $N=hM}

%\%j%e!<%`%l%s%@%j%s%0=hM}$O!"Bg$-$/$o$1$F;k@~@8@.!"%T%/%;%kCM7W;;!"%7%'!<%G%#%s%0$N3 $D$N=hM}$K$o$1$i$l$k!#*ReVolver*/C40 $G$O$3$l$i$N3 $D$N=hM}$KFC2=$7$?4pHD$r@_7W5Z$S<BAu$7!"$=$l$i$r@\B3$9$k$3$H$G%\%j%e!<%`%l%s%@%j%s%0=hM}$r9bB.$K9T$&$3Hr9M$($?!#0J2<$K*ReVolver*/C40 $,9T$&3F=hM}KD$$$F=RYk!#

2.3.1 ;k@~@8@.=hM}

;k@~@8@.=hM}HO%T%/%;%kCM7W;;KI,MWJ;k@~$K4X$9$k%G!<%?$r@8@.9k=hM}G"$k!#;k@~@8@.=hM}$K$O0J2<$K=RYkh&$J=hM}$,$"$k!#

- ;k@~%Y%/%H%k$N@8@.
  %9%/%j!<%s:BI8K*1k?eJ?$*$h$S?bD>J}8~$NC10L%Y%/%H%kr=l>$l%o!<%k%I:BI87O$GI=7?bNr\vec{S}_h$!"$\vec{S}_v$!";kE@$+$i%9%/%j!<%s$N:8>e(%9%/%j!<%s:BI8$N86E@)$K8~$+$&%Y%/%H%k$r $\vec{S}_b$ H9$k(?^??;2>H)!#$3$3$G!"%9%/%j!<%s:BI8$,$(\mathrm{s_x},\mathrm{s_y})$$G$"$k%T%/%;%kKBP9$k;k@~%Y%/%H%k$r$\vec{R}$$H9k$H!"$\vec{R}$$O<!<0(1)$GI=$5lk!#

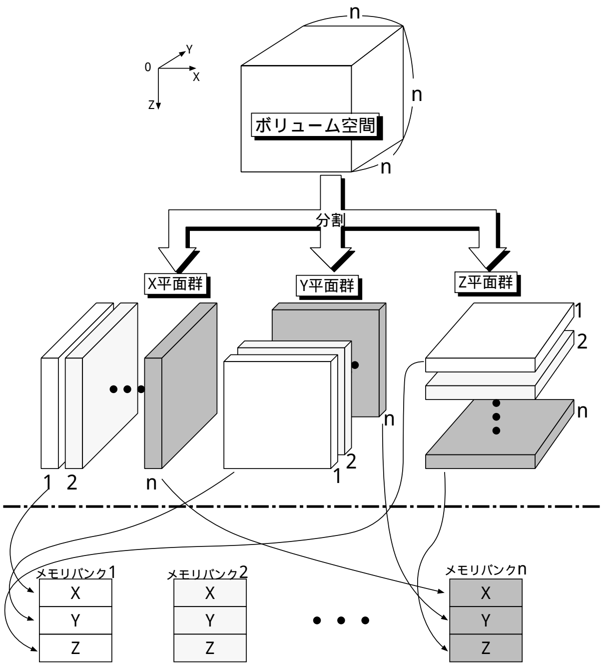
$$\vec{R} = \vec{S}_b + \mathrm{s_x} \times \vec{S}_h + \mathrm{s_y} \times \vec{S}_v \tag{1}$$

  0J2<GO;k@~%G!<%?$NAj8_4X78$r<(7??^??$rE,59;2>H$7Fb$i$$$?$$!#

- <g<45Z$S<g<4J}8~$NH=Dj
  ReVolver/C40 GO<g<4Ey4V3V%5%s%W%j%s%0K!$r:NMQ$9$k!#$3$N<jK!$G$O!"@8@.$5l?;k@~%Y%/%H%k$N@.J,$NCf$G@dBPCM$,:GBgG"kbNrA*$S!"$=$N:BI8<4$r<g<4$HDj5A$9$k!#$=7F!"?^??(b)Nh$&$K!"3N<g<4$NJ}8~$KBP7FEy4V3V$K%5%s%W%j%s%0$r9T$&!#

  ReVolver/C40 $GJ];}$7$F$$$k%\%j%e!<%`%G!<%?$O!"<g<4$,x, y, z <4$N$$$:lG$"$CFbBP1~G-kh$&$K3 =E2=5l!"$=$l$>$l$N<4$KBP7F%P%s%/J,$1$5lF$$$k!#$=$N$?$a!"%\%/%;%kNFI_=P7N:]KO!"<g<4L>$,I,MW$HJk!#$^$?!";k@~%Y%/%H%k$N<g<4@.J,$NId9fKhCF%T%/%;%kCM$N7W;;J}K!$,0[JkNG!"<g<4J}8~bI,MWG$"$k!#$\vec{R}$ $N@.J,$NCf$G@dBPCM$,:GBgNbN,<g<4HJ$j!"$=$NId9f$,<g<4J}8~HJ$k!#

- 4pK\%Y%/%H%k$N7W;;
  ;k@~%Y%/%H%k$N<g<4@.J,$r1 K7$?$bNr4pK\%Y%/%H%k$\vec{B}_v$$H8F$S!"$\vec{R}$ $N<g<4@.J,$,R_i $(\mathrm{i} \in \{\mathrm{x,y,z}\})$$G$"$kH-!"$\vec{B}_v$ $O<!<0(2)$GI=



?^4: %\%j%e!<%`%G!<%?$N3JG<J}K!

5l$k!#

$$\vec{B}_v = \frac{1}{\mathrm{R_i}}\vec{R} \qquad (2)$$

$^$?!"%7%'!<%G%#%s%0=hM}$KMQ$$$ilk4pK\%Y%/%H%kNBg-$5(BLEN H9$k) $O!"$\vec{B}_v$ $NHs<g<4@.J,$rBV1!"BV2 H9kH!"<!<0(3) Kh$j5a$^$k!#

$$\mathrm{BLEN} = \sqrt{1 + \mathrm{BV1}^2 + \mathrm{BV2}^2} \qquad (3)$$

- ;k@~$H%\%j%e!<%`6u4V$N8r:9H=Dj

  %\%j%e!<%`6u4V$rA4$/DI2a$7$J$$;k@~$K$D$$$F$O!"%T%/%;%kCM7W;;$r9T$&I,MW$,$J$$$?$a!";k@~%G!<%?$K$=$N;]$r2C$($FEA$($kI,MW$,$"$k!#$=$3$G!";k@~$,%\%j%e!<%`6u4V$rDI2a$9k+H]$+$NH=Dj$,I,MW$HJk!#3NH=Dj$O!"0J2<$N2E@KD$$$F9T$&!#

  1. ;k@~J}8~Kh$kH=Dj

     ;kE@:BI8$N<g<4@.J,$,Ii$G<g<4J}8~$,Ii$N>l9g!"$*hS<g<4@.J,$,%\%j%e!<%`6u4V$N1JU$ND9$5(0J2<VSIZE $H$9$k) $h$jBg$-$/<g<4J}8~$,@5$N>l9g$O!";k@~$,%\%j%e!<%`6u4V$H8r:9$7$J$$!#

  2. %\%j%e!<%`6u4V$N<g<4@.J,$K$*$1$kC<E@$N:BI8Kh$kH=Dj

     $^$:!";k@~>e$NE@$G<g<4@.J,$N:BI8$,%\%j%e!<%`6u4V$NN>C<$KEy$7$$E@ $\vec{R}_0,\ \vec{R}_{VSIZE}$ $N:BI8$r$=$l$>$l5aak!#$3$3GO!"NcH7$F<g<4$, x G"$k>l9g$r9M$($F!"$\vec{R}_0 = (0, \mathrm{R_{y0}}, \mathrm{R_{z0}})$, $\vec{\mathrm{R}}_{\mathrm{VSIZE}} = (\mathrm{VSIZE}, \mathrm{R_{yVSIZE}}, \mathrm{R_{zVSIZE}})$ H9$k!#*Re-Volver*/C40 GO!";k@~$N@dBPCM$N:GBg@.J,$r;}$DbN$r<g<4$H7F$$$k$?$a!";k@~$NJ}8~$H<g<4$,$J$93QEY$O45° 0J2<G"$k!#%\%j%e!<%`6u4V$ON)J}BN$G$"$k$3$H$rA0Ds$K$7$F$$$k$N$G!";k@~$,%\%j%e!<%`6u4V$rDI2a9k$?$aKO!"$\vec{R}_0$ $^$?$O $\vec{R}_{VSIZE}$ $,%\%j%e!<%`6u4V$NNN0hFbKJ1lPJiJ$$!#9JoA!"

     $0 \le \{\mathrm{R_{y0}}, \mathrm{R_{z0}}\} \le \mathrm{VSIZE}$ $^$?$O $0 \le \{\mathrm{R_{yVSIZE}}, \mathrm{R_{zVSIZE}}\}$ (4)

     $,@.N)$7J1lP!";k@~$,%\%j%e!<%`6u4V$rDI2a7J$$$HH=CGG-$k!#

- =i4|:BI8!"=i4|5wN%$N7W;;

  ReVolver/C40 GI,MWJ%\%/%;%kCM$N%"%I%l %97W;;$N=i4|CMHJ$k=i4|:BI8(;k@~>e$NE@ N&$A!"<g<4@.J,$,0 HJ$kE@$G!"Hs<g<4@. J,$rIN1,IN2 H9$k) r\vec{R}_0$!";kE@$N0LCV%Y%/ %H%kr\vec{E}$!"$=$N<g<4@.J,$rE$_i$ H9kH!"F~<M 5wN%(=i4|5wN%ILEN $H8F$V3HK9$k) $O<! <0(5) $GI=$5lk!#

$$\mathrm{ILEN} = |\vec{E} - \vec{R}_0| = |\mathrm{E_i}| \times \mathrm{BLEN} \qquad (5)$$

- %5%s%W%j%s%03+;OOLCV$N7W;;

  ;kE@$,%\%j%e!<%`6u4VFb$K$"$k>l9g!";kE@$h $j<jA0(%9%/%j!<%s$HH?BPB&) $N%\%/%;%k$,%T %/%;%k$KE}1F$5lJ$$$h$&$K9k$?$a!"$=$N %\%/%;%k$rF)L@$H$_$J$9%^%9%/=hM}$r9T$&I, MW$,$"$k!#$=$3$G!"?^??$Nh&$K!"FI$_=P$9 %\%/%;%k$,I3+$i5lEY7W;;$KI,MWHJk+ $r%5%s%W%j%s%03+;OOLCV MASK KhjCNk 3H$,$G$-$k!#

ReVolver/C40 GO;k@~@8@.=hM}$r;k@~@8@.%9 %F!<%8(RCS) $G9T$C$F$$$k!#

2.3.2 %T%/%;%kCM$N7W;;

ReVolver/C40 $G9T$&%T%/%;%kCM$N7W;;$O!"l $D $N%T%/%;%k$N5lEY$N7W;;$rJ#?t$N%W%m%;%C5$G=h M}9k%\%/%;%kJBNs=hM}$H$$$&J}<0$r:NMQ$7$F$$ $k!#$3$NJ}<0$O%1%$%-%c%9%F%#%s%0$"%k%4%j%:%` $r;k@~J}8~$KJBNs2=7?bNG"$k(?^2;2>H)!# 3NJ}K!GO!"%9%/%j!<%s>e$N3F%T%/%;%k$4HK H/@8$9$k;k@~$K1h$C$F!";k@~$H8r:9$9$k%\%/%;%k $r;kE@$K6a$$=g$K%5%s%W%j%s%0$7$F$$$/!#3l$r ;k@~>e$N%\%/%;%k$,$J$/$Jk^G/j+$($7!"%T %/%;%kCM$r5a$a$k!#$3$N;~$N%5%s%W%j%s%0$5$l$? %\%/%;%k?t$r N H9kH!"BP1~9k%T%/%;%k$NCM $O!"0J2<$N<0(6) $rI>2A$7$?CM$HJk!#

$$\text{%T%/%;%kCM} = \sum_{i=0}^{N} (1 - \alpha_i) c_i \prod_{j=0}^{i-1} \alpha_j \qquad (6)$$

$?$@$7!"%\%/%;%kCM v_t $O!"?' c_t $HF)L@EY α_t $rI=$9 %G!<%?G"$j!"%5%s%W%j%s%0$7$?%\%/%;%k$NCM$O ;kE@$K6a$$=g$+$i!"$v_0, v_1, \cdots, v_{N-1}$ H9$k!#$3$3 $G!"<0(6) $O<0(7) Nh$&$JA22=<0$KJQ7AG-$k!#

$$\begin{cases} C_k &= C_{k-1} + (1 - \alpha(v_k)) \cdot c(v_k) \cdot A_{k-1} \\ A_k &= \alpha(v_k) \cdot A_{k-1} \end{cases} \qquad (7)$$

$?$@$7!"$c(v_i), \alpha(v_i)$ O=l>$l%\%/%;%kCM v_i $r ?'!"F)L@EY$KJQ49$9$7$?CM$G$"$k3H$r<($7$F$$$k!#

%5%s%W%j%s%0$9$k%\%/%;%k?t$, N $N>l9g!"<0(6) KhCF5aailk%T%/%;%kCM$O<0(7) $N C_N $H F10l$NCMHJ$k!#$D$^$j C_N $r5a$ak3HKhC $F!"%T%/%;%kCM$r5aak3H$,=PMh$k!#

<0(7) $N C_k, A_{k-1} $O $C_{k-1}, A_{k-1}, c(v_k), \alpha(v_k)$ $+ $i5a$ak3H,G-!"$c(v_k), \alpha(v_k)$ $O v_k $rJQ49$9$7 $?CM$G$"$k$+$i!"7k6I C_k, A_k $O C_{k-1}, A_{k-1}, v_k $+ $i5a$ak3H,G-$k!#

hC$F!"2.2@a$G=RY?<g<4Ey4V3V%5%s%W%j%s%0 K!$rMQ$$!"i HV$(i = 0, 1, \cdots m)$ $N%W%m%;%C%5$K C_k, A_k $N7W;;$r9To;kH!"3F%W%m%;%C%5$, 2.2 @a$G=RY?%a%b%j%P%s%/$N1 Dr%m!<%+%k%a%b%j H7Fb$A!"%W%m%;%C%5$r0l<!85$K@\B3$7$?9=@. rHk3H,G-$k!#$3NH$-%W%m%;%C%5?t$O!"%\ %j%e!<%`!&G!<%?$, N^3 voxel $N>l9g N BfHJ$k!# 3N9=@.Kh$j!"%W%m%;%C%5$r%Q%$%W%i%$%sF0:n 5;k3HG!"%T%/%;%kCM7W;;$N9bB.2=$rO+$k 3H$,=PMh$k!#

H3m,;k@~$N<g<4@.J,$,@5(0J2<!"!Ý;k@~J}8~ $,@5!W$H8F$V) $N;~$H!";k@~$N<g<4@.J,$,Ii(0J2<!" !Ý;k@~J}8~$,Ii!W$H8F$V) $N;~$HGO!"=hM}$N9T$& J}8~$,5U$HJk!#hC$FN>$($P;k@~J}8~$,@5$N%T %/%;%kCM$N7W;;$r9T$C$F$$$k:GCf$K!";k@~J}8~$, Ii$N%T%/%;%kCM7W;;$r9T$*$&H9kH!"=hM}$N>W FM$,5/3j@-G=$,Dc2<$9$k!#

$=$3$G!">o$K=hM}$NJ}8~$r@5H9k3Hr!"<! Nh$&$K7F<B8=7?!#

<0(6) $r<0(8) $KJQ7A$9$k!#

$$C'_{k-1} \;=\; C'_k \cdot \alpha(v_{k-1}) + (1 - \alpha(v_{k-1})) \cdot c(v_{k-1}) \qquad (8)$$

<0(6) KhCF5aailk%T%/%;%kCM$O!"<0(8) $N C'_0 $HF10l$NCMHJ$k!#<0 (8) $N C'_{k-1} NCMO $C'_k, c_{k-1}, \alpha_{k-1}$ $+$i5aak3H$,$G$-$kNG!"7k 6I C'_k, v_{k-1} $+$i5aak3H$,$G$-$k!#

hC$F!";k@~J}8~$,Ii$N>l9g$K i HV$N%W%m%;%C%5 $K<0(8) $N C'_{N-i} $N7W;;$r9To;kH!"%\%j%e!<

%`!&G!<%?$, $N^3 voxel$ H9kH!"$0, 1, \cdots, N$ HV$N %W%m%;%C%5$N=g$G=hM}$,9T$($k!#

0J>ehj!";k@~J}8~$,@5$N;~$O<0(7) $r7W;;$7!";k@~J}8~$,Ii$N;~$O<0(8) $r7W;;$9k3HG!">o$K=hM}$NJ}8~$rC1J}8~$H9k3H$,2DG=$G$"$k!#

ReVolver/C40 GO3liN=hM}$r%T%/%;%kCM7W;;%9%F!<%8(PCS) $G9T$C$F$$$k!#

2.3.3 %7%'!<%G%#%s%0=hM}

%7%'!<%G%#%s%0HO!"N)BN$r9=@.$9$k3FLL$KBP7F!"8w8;0LCV$d<~0O$N4D6->r7o$r9MN8$7$FL@$k5r7hDj9kJ}K!G"$k!#%7%'!<%G%#%s%0$Khj!"hj8=<BE*$JN)BN$NI=8=$,2DG=$KJk!#

N)BN$r9=@.$9$k3FLL$NL@k5$N7hDj$K$O!"8w8;$N0LCV$d<~0O$NL@k5!"N)BNNLLN3QEYJI$NB?$/$N%Q%i%a!<%?$,4XM?7F$$$k!#?^??ObCH$b0lHLE*$J1"1F$N7hDjJ}K!$G$"$k!#J*BN>eN"$k0lE@P $NL@$k$5(51EY)$L$ $r!"L58B1sE@$K$"$k8w8;$+$i$NF~<M8w$N;6MpKh$k51EY L_d!"F~<M8w@5H?<MKh$k51EY L_s!"N)BNFbIt$+iNF)2a8w$Khk51EY L_b!"$*hS<~0O4D6-$N;6Mp8wKh$k51EY L_e $N;M$D$NMWAG$NOBH7$F5a$a$k!#

$$L = L_d + L_s + L_b + L_e \tag{9}$$

3Nh&$J!"J*BN$N$"$kE@$N51EY$r5aak3HKh$j!"%7%'!<%G%#%s%0%b%G%k$,:n@.5l$k!#

L58B1sE@K"$k8w8;$+$i6/EY I_p $N8w$,E@P $KF~<M$9$k>l9g!"E@P K*1kJ*BNI=LL$NK!@~$HF~<M8wHN3QEY$r i!"BP>]H9$kN)BN$NH?<M78?t$r R_p H9kH!"F~<M8w$N;6Mp$Khk51EY L_d $O

$$L_d = R_p I_p \cos i \tag{10}$$

$GM?$(il$k[9]!#

%\%j%e!<%`%l%s%@%j%s%0$K$*$$$F$O!"%\%j%e!<%`%G!<%?$=$NbN$OI=LL$NK!@~%Y%/%H%k$K4X$9$k>pJs$r;}$?$J$$$?$a!"<~$j$N%\%/%;%k$N>uBV$+$iK!@~>pJs$r?dDj$9kI,MW,$"$k!#3N>l9g%\%j%e!<%`$NI=LL$H$O!";k@~>e$N%\%/%;%kCM$r;kE@$K6a$$$B&$+$iD4$Y!"$O8a$KL5?'F)L@$G$J$$%\%/%;%k$H8r:9$7$?=j$G$"$kH_J9$3$H$,$G$-$k!#%9%/%j!<%s$+$i3NI=LL$^$G$N5wN%$r3F%T%/%;%k4H$K5a$a$?CM$rdepth CM$H8F$V!#3Ndepth CM$+$iI=LL$NK!@~$r6a;w7W;;$7!"%T%/%;%kCM$HK!@~%Y%/%H%krbHK3F%T%/%;%k$N51EY$rJd@5$9$k<jK!$,!"depth gradient shading G"$k!#$3$N<jK!$G$O!"K!@~%Y%/%H%k$r5aak$?$a$K;HMQ$9$k%T%/%;%k$NHO0O$r7h$akI,MW,$"$k$,!"?^??$K<(9h$&$K!"5aak%T%/%;%k<+?H$r4^$`>e2<:81&$"$o$;$F 13 %T%/%;%kr=$NNN0h$H9kN,E,EvH5lF$$$k[11]!#

$"$kE@P K*1kK!@~%Y%/%H%k$r5a$a$k>l9g!"X J}8~$K$D$$$F$O?^??$N(a) Nh$&$Kdepth CM$,C1D4A}2C$9$k>l9g!"<P@~6h4V$NN>C<%T%/%;%kKD$$$F depth CM$r<h$j=P$7!"depth CM$N:9$H:BI8$N:9$r;H$C$F8{G[$r6a;w9k!#$^$?!"?^??$N(b) Nh$&$K depth CM$NA}2C$,JQ2=9k>l9g$O!"(a) $N>l9g$HF1MM$K:9$r<hkH8{G[$,J?C3$KJjFM5/$,:F8=$5lJ$$$N$G!"6a;w$KMQ$$$k6h4V$rA*Br$9$k!#Y J}8~$K$D$$$F$bF1MM$K8{G[$r6a;w$7!"2 DN8{G[$+$iK!@~%Y%/%H%k$r5a$a$k!#

ReVolver/C40 GO3liN=hM}$r%7%'!<%G%#%s%0%9%F!<%8(SS) $G9T$C$F$$$k!#

2.3.4 *ReVolver*/**C40** GNJBNs=hM}

%\%j%e!<%`%l%s%@%j%s%0=hM}$OB?Bg$J7W;;NL$,I,MW$G$"$k$?$a!"JBNs=hM}$,IT2D7g$G$"$k!#3N$?$a *ReVolver*/C40 GOMM!9$J5,LO!"7A$NJBNs=hM}$r9T$C$F$$$k!#

$^$:*ReVolver*/C40 GO%U%l!<%`C10L$G!"2hA|@8@.!"%7%'!<%G%#%s%0!"2hA|=PNO$rFHN)$K=hM}9k3HKhCF%^%/%m%Q%$%W%i%$%s$r7A@.$7!"9bB.$JI=<($r2DG=H7$F$$$k(?^??;2>H)!#

5i$K!"2hA|@8@.$K$*$$$F$O%T%/%;%kC10L$N%Q%$%W%i%$%s=hM}$,9T$olF$$$k(?^??;2>H)!#$^$?!"2.3@a$G=R$Y$?3 DN=hM}O=l>lN=hM}$NFCD'$r9MN8$K$$$l!"0J2<$K<($9h&$JMM!9$JJBNs=hM}KhCF9Tol$F$$$k!#

;k@~@8@.=hM}GNJBNs=hM} %T%/%;%kCM7W;;=hM}$NB.EY$K8+9gC?B.EY$G;k@~%G!<%?$r@8@.9k$?$a!"%U%l!<%`$r%9%-%c%s%i%$%sC10L$KJ,3d$7$F!"8 Bf$N%W%m%;%C%5$GJBNs=hM}$r9T$C$F$$$k!#%T%/%;%kCM7W;;=hM}$N$?$a$K$O;k@~%G!<%?$rC`<!E*KAwi1l$P$$$1$J$$$,!"E>Aw=hM}$OB>$N%W%m%;%C%5GN;k@~@8@.=hM}$K1#JC$5lk!#

%T%/%;%kCM7W;;=hM}GNJBNs=hM} 0lDN;k@~$K

BP9k%\%/%;%kJBNs$N%T%/%;%kCM7W;;=hM}$O 0l<!85$N%Q%$%W%i%$%s9=@.$rHk3HKh$C F=$N=hM}$rJBNs2=9k3H$,2DG=G"$k!# $=$l$>$l$N%W%m%;%C%5$O;kE@$K6a$$%\%/%;%k $+$i=g$K%T%/%;%kCM$r7W;;$7!"<+J,$N=hM}$, =*$okH<!$N%W%m%;%C%5$K7W;;7k2LrEO9!# %W%m%H%?%$%W$G$O%W%m%;%C%5$O128 Bf!":G=* 9=@.$N%U%k%7%9%F%`$G$O512 Bf;HMQ$9$k!#

%7%'!<%G%#%s%0=hM}GNJBNs=hM} %7%'!<%G%#%s%0 =hM}GO!"%9%/%j!<%s$r16 8D$NFs<!85b7 $/$O0l<!85$N%V%m%C%/$KJ,3d$7!"$=l>lr 0lDN%W%m%;%C%5$K3d$jEv$F!"%7%'!<%G%#%s %0=hM}$rJBNs$K9T$&!#

%7%'!<%G%#%s%0=hM}$r9T$&$?$aKO!"%T%/%; %kCM7W;;=hM}$N7k2L$,I,MWG"$k!#$7$+$7@h $[$I=RY?h&$K!"%T%/%;%kCM7W;;=hM}$O0l <!85$N%Q%$%W%i%$%s9=@.$rHC$F$$$k!#$=$3 $G!"1) %Q%$%W%i%$%s$+$iC`<!E*$KAwilF/ $k%G!<%?$N<u$1<h$jH=lr16 Bf$N%W%m%;%C %5$G=hM}9k$?$a$NJ,G[!"2) %7%'!<%G%#%s%0!" 3) %7%'!<%G%#%s%0$5$l$?%G!<%?$N<}=8$H2hA| =PNO!"$H$$$&3 CJ$N%Q%$%W%i%$%s=hM}$r9T$C $F$$$k!#

>e=RNDLj;k@~@8@.=hM}$H%7%'!<%G%#%s%0=hM}$O!" =hM}9Y$-%G!<%?$KBP7F6u4VE*$JJBNs=hM}$r!" $^$?%T%/%;%kCM7W;;=hM}$O;~4VE*$JJBNs=hM}r= l>$l9T$C$F$$$k!#3Nh&$K!";k@~@8@.=hM}$H %T%/%;%kCM7W;;=hM}HN4V!"%T%/%;%kCM7W;;=hM} $H%7%'!<%G%#%s%0=hM}$H$N4V$G$OJBNs=hM}$N7ABV $,0[$Jk?$a!"*ReVolver*/C40 GOJBNs=hM}8zN($rDc2<$5$;$:K3li$N:90[$r5[<}9k$?$a$NA< CV$,9V8ilF$$$k!#

3 *ReVolver*/**C40** $N9=@.

ReVolver/C40 $O?^??$K<(9h$&$K!";k@~@8@. %9%F!<%8(RCS)!"%T%/%;%kCM7W;;%9%F!<%8(PCS)!" %7%'!<%G%#%s%0%9%F!<%8(SS) $H8F$Plk3 DN%9 %F!<%8KhCF9=@.5lF*$j!"$3li$,FHN)$K =hM}$r9T$&3HKhCF!"JBNs=hM}$r<B8=$7$F$$ $k!#$3$N3 DN%9%F!<%8r^Ha$F@)8f$r9TCF $$$kN,!"%7%9%F%`%3%s%H%m!<%k%f%K%C%H(SCU) G"$k!#

ReVolver/C40 GO$=$l$>$l$N%9%F!<%8$HSCU KBP9$k4pHD$r@_7W$7!"<BAu$r9TC?!#0J2<!"$= l>lN9=@.KD$$$F=RYk!#

3.1 SCU $N9=@.

SCU $O!"*ReVolver*/C40 %7%9%F%`A4BN$N@)8f$r 9T$$!"%[%9%H%^%7%s$+$i$N;X<($K7?$,$$$C$F!"B> $N9=@.MWAG$KBP7F%3%^%s%I/%G!<%?$rE>Aw$9$kLr L\$r2L$?$9!#

SCU $N9=@.MWAG$O<g$K0J2<$N2 DG$"$k!#

SCU %a%$%s%\!<%I SCU %a%$%s%\!<%I$O *ReVolver*/C40 $N9=@.MWAG$H@\B3$9$k%3%M%/%? $H!"Xilinx <R$N Field Programmable Gate Array:FPGA(XC4013E) $G9=@.$5lF$*$j!" %[%9%H%^%7%s$N PCI %9%m%C%H$K@\B3$9$k!# SCU %a%$%s%\!<%I$N4pHD>e$N9=@.$r?^17$K <($9!#

SCU %5%V%\!<%I SCU %5 %V %\ !< %I $O !" *ReVolver*/C40 A4BN$K%/%m%C%/?.9f$H%j%;%C %H?.9f$r6!5k9k4pHDG"$j!"<g$K%/%m%C%/ %8%'%M%l!<%?!"Phase Locked Loop(PLL) $J IG9=@.5l$F$$$k!#3N%\!<%I>e$GPLL $N @_Dj$rJQ$($k3HKhCF!"3F4pHDKAwk%/ %m%C%/$N0IAj:9$rJ/$9!#SCU %5%V%\!<%I$N 4pHD>e$N9=@.$r?^18$K<($9!#

3.2 RCS $N9=@.

RCS $OSCU $+$i;kE@$H%9%/%j!<%s$K4X9k%Q%i %a!<%?(%S%e!<%G!<%?) $r<u$1<h$j!"$3li$N%G!< %?$H3F%T%/%;%k$N%9%/%j!<%s:BI8$+$i;k@~%Y%/%H %k$r5a$a!"PCS K*1k%\%/%;%k%5%s%W%j%s%05Z $SSS K*1k%7%'!<%G%#%s%0KI,MWJ%G!<%?(;k @~%G!<%?) $r=PNO$9$k!#RCS K*1k3liN=h M}$rAm>N7F;k@~@8@.=hM}$H8F$V!#

RCS $N4pHD>e$N9=@.$r?^19$K<($9!#

RCS $N9=@.MWAG$O<g$K0J2<$N3 DG$"$k!#

Processing Element (PE) *ReVolver*/C40 $G $OPE H7$F!"TI <R$N TMS320C40 $H$$$& Digital Signal Processor (DSP) $r;HMQ$7$F $$$k!#TMS320C40 $OGLOBAL BUS $*$h$S LOCAL BUS $HL>IU$1il$?2 DN%P%9$r

bD! #RCS GO! "GLOBAL BUS B&$KView Buffer ! "LOCAL BUS B&$KRay FIFO Buffer $,@\B3$5$1$k! #$3$1Kh$j! "%S%e! <%G! <%?$N F I$_=P$7%P%9$H; k@~%G! <%?$NE>Aw%P%9$,J,N% $5$1! "PE 4VGN%P%96%9g$r7Z8 :$9$k! #

View Buffer A4PE $HSCU $G6&M-$5$1$k%a%b%j $G! "SCU $+$i$N%S%e! <%G! <%?$dPE $N%W%m%0%i %`$JIrJ]; }9k! #View Buffer $O64Kwords $NMFNL$rbD SRAM $G9=@.$5$1! "%7%s%0%k %]! <%H9=@.$G$"$k! #

Ray FIFO Buffer PE $N@8@.$7$?; k@~%G! <%?$r <u$1<h$kFirst-In First-Out(FIFO) %a%b%j$G! "8e$NPCS $G%G! <%?$,Fs7OE}Ko$+$1k?$a! "AG-FIFO Buffer $H! "DSP-FIFO Buffer $NFs <oN`$,B8:_9k! #; k@~%G! <%?$r! "; k@~$=Nb NK4X9k>pJs$H! "%T%/%;%kCM$K4X9k>pJs $KJ,3d$7! "$=$1$>$1AG-FIFO JiSKDSP-FIFO $X3JG<$9$k! #$3$1$Khj! "8e=R9kPCS GN%T%/%;%kCM7W; ;$H%"%I%1%97W; ;$NJBNs=h M}$,2DG=$HJk! #

3.3 PCS $N9=@.

PCS $O%\%j%e! <%`%G! <%?$rJ]; }7F$$$k%9%F! < %8G"$j! "RCS $+$i$N; k@~%G! <%?$r<u$1<h$j! "$3 1i$N%G! <%?$K4p$E$$$F$=$N; k@~>eK"$k%\%/%; %kCM$rFI$_=P$9! #%\%/%;%kCM$O?'$HF)L@EY$K4X$9 $k%G! <%?$rI=8=7F$$$k$,! "ReVolver/C40 K*$1 $k%\%/%;%kCM$O 1byte $N%$%s%G%C%/%9CMG"$k! # hCF3$1$rMQ$$$FB0@-%F! <%V%k[3] $r; 2>H$7! "%\ %/%;%k$N?'$dF)L@EY$r5a$a$F%T%/%;%kCM7W; ;$r9T $&! #$=7F$=$N%T%/%;%kCM$rSS XAwk! #

PCS $O%T%/%;%kCM7W; ;%f%K%C%H(PCU) $r1 <! 85$K@\B3$5$;$?9=@.$HJC$F$$$k! #1 Kg$NPCS 4p HD(?^20; 2>H) KO! "8 Bf$NPCU $rEk:\$7! "3N PCS 4pHD$rD>Ns@\B3$9k3HG! "PCS $r9=@.$9 $k! #%W%m%H%?%$%W%7%9%F%`$NPCS $O16 Kg$NPCS 4pHD(128 Bf$NPE) $G9=@.$9$k! #

PCU $N9=@.MWAG$O<g$K0J2<$N5 DG$"$k(?^?? ; 2>H) ! #

Processing Element (PE) %T%/%;%kCM7W; ;$d! "8r: 9H=Dj$r9T$&! #%\%/%;%k%G! <%?%"%/%;%9$r LOCAL BUS $G! "%T%/%;%kCM>pJs$NAw<u?.$r GLOBAL BUS $G9T$&! #

Address Generator (AG) %5%s%W%j%s%0$9$k %\%/%;%k$N%"%I%1%97W; ;! "%\%/%;%kCMNFI_=P$7! "NY@\$9$kAG 4V$NDL?.$r9T$&! #$^$?DL >o$NDRAM Controller H7FN=hM}$d! "PE $NLOCAL BUS $dVoxel Latch $N@)8f$b9T $&! #AG $O! "Xilinx <R$NFPGA(XC4010D) $r MQ$$$F<B8=9k! #

FIFO Buffer <!CJ$NPE $X%T%/%;%kCM>pJs$NAw ?.$r9T$&$?$a$N%P%C%U%!$G$"$k! #

3D Volume Memory %G! <%?$r3JG<$7$F$$$k DRAM G"$k! #ReVolver/C40 $O:GBg$G 512^3voxel $N%\%j%e! <%`6u4V$r0 7$$! "1voxel $, 1byte $J$N$G! "%G! <%?$N3 =E2=[3] $d%W%m%0%i %`$N3JG<JI$b9MN8$7$F! "4Mbyte $NDRAM $rMQ$$$k! #

Voxel Latch AG KhCF%5%s%W%j%s%0$5$1$?%\ %/%;%kCM$rPE KhCFFI$_=P$5$1$k$^$GJ] ; }7F$*$/$?$a$ND-FLIP FLOP G"$k! #

3.4 SS $*$h$SSU $N9=@.

3.4.1 SS $N9=@.

SS $O! "PCS $+$iAwi1F/$k%T%/%;%kCM$r! "; k @~%G! <%?$K4p$E$-E,@Z$J=g=xKJBSBX$(! "1 %U%l! < %`J,$N%G! <%?$,B7$C$?CJ3,$G%7%'! <%G%#%s%0$r9T $$! "$=$N7k2L$rCRT $K=PNO$9$k! #

SS $N4pHD>e$N9=@.$r?^21$*hS?^22$K<($9! # SS $O<BAu$9$kItIJ$,B?NLK"k?$aN>LL<BAu$r 9TC?! #

SS $O! "?^24$Nh&$KSS 4pHD2 Kg$+iJ$k! #1 Kg$NSS 4pHDKO! "PE $r1 8D; }$DSU 4pHD$,8 Kg Ek:\$5$1$F$$$k! #2 Kg$NSS 4pHD$O0lJ}$,Master ! "$b$&0lJ}$,Slave $K@_Dj$5$1$k! #SS $N9=@.MWAG$O <g$K<!$N3 DG$"$k! #

Pixel Transceiver (PT) 3F%T%/%;%k$N%G! <%? $rA0$N%9%F! <%8G"$k PCS $+$i<u1H$j! "$=$N%T%/%;%k$N:BI8rbHK16 J,3d$5$1$? SU N&$A! "INSU $NC4Ev$G$"$k$+$r7W; ; $7! "$=$NSU $N; }$D%a%b%j$K%G! <%?$r=q$-9~

$`!#PT $O!"Xilinx <R$NFPGA (XC4010D) $rMQ$$$F<B8=9k!#

Shading Unit (SU) PT $+$i<u$1<h$C$?%G!<%? rbHK!"depth gradient shading Kh$k%7%'!<%G%#%s%0=hM}$r;\$7!"$=$N%G!<%?$r=q$-9~$`=hM}$r9TCF$$$k!#SU $N9=@.$K$D$$$F$O3.4.2@a$G>\$7$/=R$Y$k!#

Video Signal Generator (VSG) SU $G%7%'!<%G%#%s%0=hM}$r=*$($?RGB %G!<%?$rE,@Z$J=g=x$+$DE,@Z$J%?%$%_%s%0$G<}=8$7!"<u$1<h$C$?RGB %G!<%?(%G%#%8%?%k?.9f) $rD/A Converter rDL7$F%"%J%m%0?.9f$KJQ49$7!"%G%#%9%W%l%$2hLL$K=PNO9k!#VSG $O!"Xilinx <R$NFPGA (XC4010D) $H!"%7%j%"%k%/%m%C%/$r@8@.9k Programmable Array Logic(PAL) $*$h$S D/A Converter $rMQ$$$F<B8=9k!#

3.4.2 **SU** $N9=@.

SU $N4pHD>e$N9=@.$r?^23$K<($9!#SU $N9=@.MWAG$O0J2<$N5 DG$"$k!#

Processing Element (PE) %7%'!<%G%#%s%0$r9T$&!#PT KhCF=q$-9~$^l?%G!<%?NFI_=P7r LOCAL BUS $G9T$$!"%7%'!<%G%#%s%0$r=*$($?%G!<%?$N=q$-9~$_$r GLOBAL BUS $G9T$&!#

Receive Buffer (RB) PT $,PCS $+$i<u$1<h$C$?%T%/%;%k%G!<%?$r=q$-9~$`%P%C%U%!G"$j!" 4Mbit $N SRAM $rMQ$$$F<B8=9k!#PT $H PE $+$i$N%"%/%;%9$,$"$k$?$a!"J*M}E*KO 1 %]!<%HG"k,;~J,3d$G2>A[E*$K 2 %]!<%H K7$F$$$k!#

RB Controller SRAM $N@)8f$H!"PT $H PE $+$i$N%"%/%;%9$ND4Dd$r9T$&!#PT $+$i$N%"%/%;%9$,$"$C$?>l9g$O$=$AirM%@h5;$k!#RB Controller $O!"Xilinx <R$NFPGA(XC4002A) $rMQ$$$F<B8=9k!#

Output Buffer (OB) %7%'!<%G%#%s%0$r=*$($?RGB %G!<%?$r3JG<9k%P%C%U%!G"$j!"CRT $K=PNO$9k?aN%U%l!<%`%P%C%U%!$NLr3d$b$+$M$F$$$k!#VSG $H PE $+$i$N%"%/%;%9$,$"$k$?$a!"2 DN%"%/%;%9%]!<%H$r;}$C$?Video RAM (VRAM) $r;HMQ$7$F$$$k!#

OB Controller VRAM $N@)8f$H!"VSG $H PE $+$i$N%"%/%;%9$ND4Dd$r9T$&!#OB Controller $O!"Xilinx <R$NFPGA(XC4002A) $rMQ$$$F<B8=9k!#

3.5 *ReVolver*/**C40** A4BN$N9=@.

ReVolver/C40 $r9=@.$9k?aK$O!"3F%9%F!<%8$N4pHDO=l>$l I=1 $K<($7$?Kg?t$,I,MWG"$k!#

3liN4pHD$O SCU $N%a%$%s%\!<%I$r=|$$$F Versa Module Europa(VME) $N%H%j%W%k%O%$%H$Nc~BN$KA^F~5l$k(?^??;2>H)!#$3$Nc~BN$NCfKO%P%C%/%W%l!<%s$,<h$jD1ilF*$j!"3F%9%F!<%8$O0lIt$r=|$$$F%P%C%/%W%l!<%sKh$j@\B3$5lk!#B>Kb%P%C%/%W%l!<%s$O!"*ReVolver*/C40 $KEE8;$d%/%m%C%/?.9f!"$*$h$S%j%;%C%H?.9f$r6!5k9kLr3dbO$?$7$F$$$k!#SCU $O%[%9%H%^%7%s$N PCI %9%m%C%H$KA^F~$5$l!"*ReVolver*/C40 $N3F%9%F!<%8$H$NDL?.$K$O%U%i%C%H%1!<%V%k$rMQ$$$k!#

4 *ReVolver*/**C40** $N<BAu

3N>OGO *ReVolver*/C40 $N3FMWAG$N<BAuKD$$$F=RYk!#

4.1 3F%9%F!<%84V$KN.$l$k%G!<%?

$^$:O8aK!"*ReVolver*/C40 $N3F%9%F!<%84V$KN.lk%G!<%?KD$$$F=RYk!#*ReVolver*/C40 KO 2 7OE}$N%G!<%?E>Aw7PO)$,$"$j!"$=$l$>$l PCS GN7PO)$+$i AG bus!"DSP bus $H8F$V3HK9$k!#3F bus rDLk%G!<%?$N%U%)!<%^%C%H$r?^28$K<($9!#$^$?$=l>lN%G!<%?$KBP9k@bL@$rI=19$*hS I=20 $K<($9!#

RGB CM$H INTS $O PCS $G@8@.$5$l!"$=$l0J30$O RCS $G@8@.$5lk!#hC$F RCS $+$i PCS $KE>Aw$5lk%G!<%??t$O 6words!"$=7F PCS $N@hF,$N PCU $G RGB CM$r$"$o$;$F 9words HJ$k!#

4.2 **SCU** $N<BAu

SCU $N<BAu$NFCD'r^HakH0J2<Nh$&$KJk!#

I=1: *ReVolver*/C40 $N9=@.$N$?$aKI,MWJ3F4pHD$NKg?t

4pHDL>	4pHDKg?t	
	:G=*9=@.	%W%m%H%?%$%W
SCU	1 AH	1 AH
RCS	1 Kg(PE8 8D)	1 Kg(PE8 8D)
PCS	64 Kg(PE512 8D)	16 Kg(PE128 8D)
SS	2 Kg(PE16 8D)	2 Kg(PE16 8D)

4.2.1 *ReVolver*/C40 $N3F%9%F!<%8$N@)8f

ReVolver/C40 $N3F%9%F!<%8$N@)8fH7$F!"SCU $O%/%m%C%/?.9f$H%j%;%C%H?.9f$r3F4pHD$K6!5k9kI,MW$,$"$k!#RCS $O%/%m%C%/!"%j%;%C%H$HbK%U%i%C%H%1!<%V%k$+$i6!5k5l!"PCS $HSS $O%j%;%C%H$O%U%i%C%H%1!<%V%k$+$i!"%/%m%C%/$O%P%C%/%W%l!<%s$+$i6!5k$5lk!#$^$?%P%C%/%W%l!<%sKO3F4pHD$K%j%;%C%H?.9f$r6!5k9k$?$a$N%P%$%Q%9$r@_$1$F$$$k!#

9YFN4pHD$NPE $O50MHz $GF0:n$7$F$$$k!#RCS KO50MHz $N%/%m%C%/$,6!5k5l$k!#PCS $HSS KO12.5MHz $N%/%m%C%/$,6!5k5l!"3F4pHD>e$NPLL KhCF%/%m%C%/$r4G\<~$9k3HG50MHz $N%/%m%C%/$r@8@.7F$$$k!#3l$OSCU $+$i3F4pHD$N5wN%$,D9$/$Jk?aK!"<~GH?t$N9b$$%/%m%C%/$r6!5k$9kH?.9f$,8:?j$7F7$^$&$?$aG"$k!#

4.2.2 %W%m%0%i%`$*$h$S3F<o%G!<%?E>Aw

SCU $+$i *ReVolver*/C40 $N3F%9%F!<%8$XE>Aw9k%W%m%0%i%`$*$h$S%G!<%?$O<g$K0J2<$Nh&JbN,$"$k!#

3F%9%F!<%8$N**PE** $N%W%m%0%i%` 3F%9%F!<%8$NPE $O%V!<%H%W%m%0%i%`$KhC$F5/F0$5lk!#3F%9%F!<%8$N%V!<%H$NJ}K!$OB@a$G=RYkDLjG$"$k!#SCU O3$N%V!<%H%W%m%0%i%`$r3F%9%F!<%8$KE>Aw$*hS3JG<9k!#

%S%e!<%G!<%? %S%e!<%G!<%?$O;kE@$H%9%/%j!<%s$K4X$9$k>pJs$G$"$k!#$=$lirRCS Fb$NView Buffer $K3JG<$9$k!#

%\%j%e!<%`%G!<%? *ReVolver*/C40 $G$O%\%/%;%kCM$O!"?'!&F)L@EY$K4X$9$kB0@-%F!<%V%k$X$N%$%s%G%C%/%9$G$"$k!#%\%/%;%kCM$O!"1byte $GI=$o$5$l$F$$$k$?$a%\%j%e!<%`%G!<%?$O!":GBg 512^3byte(=128Mbyte) $N%G!<%?$G$"$k!#SCU $OPCS K3$N%\%j%e!<%`%G!<%?$rE>Aw9k!#

4.3 RCS $N<BAu

RCS $N%=%U%H%&%'%"$r4^a?<BAu$NFCD'$r$^$Hak$H!"0J2<$Nh&KJ$k!#

4.3.1 %9%-%c%s%i%$%sC10L$G$NJBNs=hM}

8D!9$N%T%/%;%k$KBP9k;k@~%G!<%?$N@8@.$K$OK\<AE*$J0MB84X78OJ$$!#9JoA!"JL$N%T%/%;%k$KBP9k;k@~@8@.=hM}HOJBNs$K<B9T2DG=$G$"$k!#$=$3$G!"%9%/%j!<%s$r6QEy$KJ,3d$7!"3F PE $,$=l>$lJ,3d$5l?NN0hFb$N%T%/%;%k$KBP9k;k@~@8@.=hM}$r9T$&3H$G!"=hM}$rJBNs2=$79bB.2=$r?^$k!#

2.3.1@aGO;k@~%Y%/%H%k$\vec{R}$O<0 (1) $N7W;;$Khj5aa?!#7+$7!"F10l%9%-%c%s%i%$%s>e$NNY@\%T%/%;%k$KBP9k=hM}$rO"B3$7$F9T$&>l9gKO!"$\vec{R}$O1 $DA0$N%T%/%;%kKBP7$F5a$a$?$\vec{R}$$KA}J,$\vec{S}_h$$r2C;;9k$@$1$G5a$ak3H,G-$k!#$7$?$,CF!"F10l%9%-%c%s%i%$%s>e$N%T%/%;%kKBP9$k=hM}$r!"9Y$FF10l$NPE $G9T$&$H!";k@~@8@.=hM}$,C1=c2=5l!"9bB.2=$,2DG=$HJk!#$=$3$G!"RCS GNJBNs=hM}$NC10L$O!"%9%-%c%s%i%$%sC10L$H7?!#

4.3.2 %5%$%/%j%C%/J,3d$Khk@EE*Ii2YJ,;6

1 %9%-%c%s%i%$%sJ,$N;k@~@8@.=hM};~4V$O!"$=$N%9%-%c%s%i%$%s>e$N;k@~$,!"%\%/%;%k$rDL2a$9$k3d9g$K1~8FJQ2=9k!#7+7J$,$i!"NY@\$9$k%9%-%c%s%i%$%sFbGOIi2Y$N5^JQ$,>/J/!"$^$?F0E*Ii2YJ,;6$r9T$CFb$=$N%3%9%H$K8+9g$&@-

G=8~>e$,F@$i1J$$!#$=$3$GRCS GO!"%9%-%c%s%i%$%sC10L$N%5%$%/%j%C%/J,3d$Khk@EE*Ii2YJ,;6J}<0$r:NMQ7?!#3NJ}<0GO!"%9%-%c%s%i%$%s$K2hLL$N>e$+$i=g$K0 $+$i511 $^$G$NHV9f$rM?$(!"Bh$n$ HVL\$N%9%-%c%s%i%$%s$KBP7Fn **mod** 8 HV$NPE $,=hM}$r9T$&!#$3$NJ,3d$Khj=hM}$,6QEy$KJ,;6$5$l9bB.2=$,K>$a$k!#

4.3.3 6&M-%a%b%j$N%"%/%;%9@)8f

RCS GO!"SCU $+$iC`<!E*$K%S%e!<%G!<%?$r<u$1<h$j!"PE $K$h$C$FJBNs$K;k@~@8@.=hM}$,9T$o$l!"PCS $KBP$7$FC`<!E*$K;k@~%G!<%?$,E>Aw5l$k!#$hCF!"C`<!"*JBNs"*C`<!N?aN%a%+%K%:%`$,I,MW$KJCF/$k!#$=3G!"SCU $HRCS Fb$N3F PE 4V!"RCS Fb$N3F PE $HPCS 4V$K$=$l$>$l6&M-%a%b%j$r@_CV$9k3HG!"%9%F!<%84VDL?.$r<B8=$9$k!#

1 2hLL$"$?jN%G!<%?NL$O!"%S%e!<%G!<%?$,12words G"kNKBP7$F!";k@~%G!<%?$OLs1.6 × 10^{6}words G"k?$a!"PCS HNDL?.IQEY$,Hs>o$K9b$$!#$=$3$G!"3F PE $HPCS 4V$N6&M-%a%b%jH7FO!"PE $+$i$N=q$-9~$_$HPCS $+$iNFI_=P7,F1;~$K9T$(kh$&$J2 %]!<%H%a%b%jG"$j!"$+$D!"PCS GN=hM}NCYl$KH<$&DL?.CY1d$r;k@~%G!<%?$r%P%C%U%!%j%s%0$9$k3HKh$j5[<}2DG=$J!"FIFO %a%b%j(Ray FIFO Buffer) $r;HMQ$7$F$$$k!#

3FPE $HSCU 4V$N6&M-%a%b%jKBP7FO!"SCU !"PE 6&$K%"%/%;%9IQEY$OHs>o$KDc$$$N$G1 %]!<%H$NSRAM(View Buffer) $r;HMQ$9$k!#$^$?!"RCS GO1 2hLL4H$K3F PE 4V$GF14|A`:n$,I,MW$H$J$k$?$a!"View Buffer Fb$K%P%j%"F14|JQ?t(%U%l!<%`F14|JQ?t) $r@_CV$9k3HG3NA`:n$r<B8=$7$F$$$k!#

6&M-%a%b%j$O3F PE $G6&M-$5lk%P%9$K@\B3$5lk$?$a!"PE $,6&M-%a%b%j$KBP7F%"%/%;%9$9$k:]KO6%9g$,5/$3$k!#$=3G!"%P%9$NGSB>@)8f$N5!9=(D4Dd2sO)) $,I,MW$HJk!#$^$?!"PCS GORay FIFO Buffer $+$iFI$_=P$9;k@~%G!<%?$N=g=x$,7h$^$C$F$$$k$?$a!"RCS GORay FIFO Buffer KBP7$F%G!<%?=q$-9~$_=g=x$NJ]>Z$,$G$-$k5!9=$,I,MW$HJk!#RCS GO!"3liN5!9=$r%O!<%I%&%'%"E*$KE}9g$7!"%=%U%H%&%'%"$N%W%m%H%3%k$r

DjaF<B8=7F$$$k!#

4.3.4 ;k@~%G!<%?E>Aw$N9bB.2=

Ray FIFO Buffer $O!"RCS Fb$NA4PE $N6&M-;q8;$G$"$j!"3F PE $GJBNs$K=hM}5l$?;k@~%G!<%?$r0lC6C`<!2=$7$FPCS $X6!5k$9$kLr3d$rC4$C$F$$$k!#$7$?$,$C$F!"$3$NItJ,$O%7%9%F%`$N@-G=$r;YG[9kMW=j$N1 DHJC$F$$$k!#$"$kPE $,Ray FIFO Buffer $r3MF@$9k?aK$O!"%"%/%;%96%9g$,L5$$>l9gGbE>Aw$N=`Hw$H8e=hM}r"o;$F10 %5%$%/%k!"%k!<%W$KF~$k:]$N4 %5%$%/%k!"$"$o$;$F14 %5%$%/%k[1]I,MW$G$"$k!#;k@~%G!<%?E>Aw$N8zN($r>e2k$?$aKO!"3ND4DdKh$k%*!<%P!<%X%C%I$r8:>/5;k?aK!"1EY$KE>Aw$9$k;k@~%G!<%?$N?t$rA}$d$;$P$h$$!#$=$3$G!"@8@.$7$?;k@~%G!<%?$r0l;~E*$KPE $NFbIt RAM $NNN0h$K3NJ]5l$?Local Ray Buffer $K01Dj?t3JG<$7!"013g7FRay FIFO Buffer $KE>Aw$9k3HK7?!#$^$?!";k@~@8@.=hM}$O1 %9%-%c%s%i%$%s4H$K9T$olkNG!"3N?t$O1 %9%-%c%s%i%$%s>e$NAm%T%/%;%k?t$NLs?tGJ$$$H$$$1$J$$!#$=$3$G!"PCS Fb$G$N;k@~@8@.=hM};~4V!"%G!<%?E>Aw;~4V!"PCS $N=hM}B.EY$N%P%i%s%9$r9MN8$7$?7k2L!"64 %T%/%;%kC10L$G;k@~%G!<%?E>Aw$r9T$&3HK7$?!#

4.4 PCS $N<BAu

PCS $N<BAu$NFCD'r^HakH0J2<Nh$&$KJk!#

4.4.1 %9%1!<%i%S%j%F%#

PCS $O!"PCS 4pHD$rD>Ns@\B3$9$k3H$G9=@.$5lk!#7?$,$C$F!"3FPCU $N3D Volume Memory $K3JG<$9Y-%\%j%e!<%`%G!<%?$,4MByte 0J2<$G$"$k8B$j!"PCS 4pHD$N?t$K1~$8$F!"07$&%\%j%e!<%`%G!<%?$N%5%$%:$rJQ99$9$9$k3H$,$G$-$k!#$^$?!"F101%7%9%F%`$G$b!"1 Bf$NPCU $,C4Ev$9$k%\%j%e!<%`%G!<%?$N%5%$%:$rA}2C$9k3HG!"hjBg$-$J%\%j%e!<%`%G!<%?$r=hM}$9$k$3$H$,2DG=$G$"$k!#B=:_$N@_7W$G$O!"1 Bf$NPCU $G4slice $^$G%\%j%e!<%`%G!<%?$r=hM}$9k3H,G-!"%\%j%e!<%`6u4V$ON)J}BN$N7ArHCF$$$kNG!"1 JU$ND9$5$,PCU

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[1] 25MHz

Bf?t$N4 G\$^GN%\%j%e!<%`6u4V$r=hM}$9$k$3$H$,$G$-$k!#$?$@$7!"$3$N>l9g$O!"%\%j%e!<%`%5%$%:$H=hM};~4V$N%H%l!<%I%*%U$,@8$8$k!#

4.4.2 %\%/%;%kCM$N%W%j%m!<%I

%\%j%e!<%`%G!<%?$OKDBg$J%G!<%?NL$G$"$k$?$a!"%\%j%e!<%`%a%b%j(3D Volume Memory) $O DRAM $G<B8=$5lF$$$k!#7+$7!"FI$_=P$9%\%/%;%kCM$,3JG<5l$F$$$k%"%I%l%9$r7W;;$7!" DRAM $X%"%/%;%9$9kH$$$&;~4V$OHf3SE*Bg$-$/!"%T%/%;%kCM7W;;=hM}$N;~4V$HHf3S$7FbL5;kG-$J$$[IG$"$k!#$3$3$G!"FI$_=P$9%\%/%;%kCM$N%"%I%l%9$O;k@~%G!<%?$N$_$+$i5a$ailk3HKCeL\$7!"%5%s%W%j%s%0$9$k%\%/%;%kCM$N%"%I%l%97W;;$HFI$_=P$7$r9T$&@lMQ%O!<%I%&%'%"(AG) $r@_$1k3HG!"%\%/%;%kCMNFI_=P$7;~4V$r1#JCG-kH9M$($?!#AG GO%\%/%;%kCM$N%W%j%m!<%I$r9T$$Voxel Latch $K3JG<$9$k!#PE XN%\%/%;%kCM$N6!5k$OVoxel Latch $,9T$&!#3lKh$j!"%a%b%j%"%/%;%9$H%T%/%;%kCM7W;;$NJBNs<B9T$,2DG=HJ$j!"%\%/%;%kCM$NFI$_=P$7;~4V$N1#JC$r?^CF$$$k!#%\%/%;%kCM$N%W%j%m!<%I$NMM;R$r?^30$K<($9!#

Voxel Latch $+$iNFI_=P7O!"PE $+$i9k$H30It%m!<%+%k%a%b%j$N$"$k%"%I%l%9$+$iNFI_=P7H$$$&7A$G9T$&3H$,$G$-$k!#Voxel Latch $K%G!<%?$,F~CF$$$J$$>l9g!"PE $O=hM}$r$=$3$G%9%H!<%W$7!"Voxel Latch $K%G!<%?$,3JG<5lkNrBTD!#5U$KVoxel Latch $K%G!<%?$,F~CF$$$k4V$O!"AG $O<!$N;k@~%G!<%?KBP9$k%\%/%;%kCM$NFI$_=P$7$r9T$o$:!"Voxel Latch $+$i%G!<%?$,FI$_=P5lkNrBTD!#3Nh&K7$FPE $H AG $N4V$GF14|rH$j!"?^30 $N%Q%$%W%i%$%s$,MplJ$$$3HrJ]>Z7F$$$k!#

4.4.3 DRAM XN%"%/%;%9

DRAM XN%"%/%;%9$O!"4.4.2$G=RY?%\%/%;%kCM$N%W%j%m!<%I$NB>$K<!$Nh&JbN,$"$2il$k!#

- SCU $+$i<u$1<h$C$?%\%j%e!<%`%G!<%?$r DRAM $N@5$7$$0LCV$K=q$-9~$`!#
- DRAM $N%j%U%l%C%7%e$r9T$&!#

SCU $+$i<u$1<h$C$?%\%j%e!<%`%G!<%?$rDRAM $K=q$/$?$a$K!"PE $O%\%/%;%kCM$N%W%j%m!<%IKh$k%"%/%;%9$K2C$($FDL>o$NDRAM %"%/%;%9$b2DG=GJ1lPJiJ$$!#AG GO!"PE $NDRAM %"%/%;%9$N@)8f$d%j%U%l%C%7%e$N@)8f$b9T$&DRAM Controller H7FNLr3d$b<u$1;}CF$$$k!#

4.4.4 PE 4VDL?.

AG $G9T$&%\%/%;%kCM$N%"%I%l%97W;;$K$O!";k@~%G!<%?$N$_$,I,MW$G%T%/%;%kCM$OI,MW$,$J$$!#$^$?%T%/%;%kCM7W;;r*3J$&PE $O!"A0CJ$NPE $N%T%/%;%kCM7W;;$NESCf7k2L$H%\%/%;%kCM$@1,I,MWG"$j!"5U$K;k@~%G!<%?OI,MW,$J$$!#

$=$3$G!"4.1@a$G=RY?h&$K2 7OE}$N%G!<%?E>Aw7PO)$r@_$1!"%"%I%l%97W;;MQ$N;k@~%G!<%?$OAG Bus!"%T%/%;%kCM7W;;MQ$NRGB CM$dF)L@EY$N7W;;ESCf7k2L$ODSP Bus $KN.$9!#

AG $OAG 4V$rN.1k%G!<%?$NDL?.$r9T$&$,!"%\%/%;%kCM$,PE KhCFFI$_=P$5lk%?%$%_%s%0$O3FAG $G0[$JkN$G!"NY@\AG 4V$G@)8f?.9f$rMQ$$$?%O%s%I%7%'!<%/Kh$jDL?.$r9TCF$$$k!#

$=$lKBP7$F!"PE 4V$G9Tol$kDL?.$O$"$kPCU $G=hM}CY1d$,$*$3$j!"$=l,860x$GDL?.BT$A$,5/$3C?>l9g!"$=$NCY1d$,2<N.$KEAHB$7=hM}B.EYDc2<$N860xHJ$k!#$hCFG-k+$.$jBTA,5/3i$J$$h$&$JDL?.$,5a$ail$k!#$=3G!"PE 4V$NDL?.$K$O4V$K2 DN%"%/%;%9%]!<%H$r;}$DFIFO %a%b%j$rG[CV$7!"DL?.$rFIFO %a%b%j$X$N=q$-9~$_!"FI$_=P7G<B8=9k!#3lKhCF!"2<N.$KCY1d$,EAHB9k3HrKI0!#

PE $N30It%a%b%j%"%/%;%9MQ$N%P%9KO2 DN@)8f7O$,$"kN$G!"1 7OE}$rA0CJ$NFIFO %a%b%j$+iN<u?.$K;HMQ$7!"b&1 7OE}$r<!CJ$NFIFO %a%b%jXNAw?.$KMQ$$$k!#

4.4.5 PE Kh$k AG $N@)8f

AG $O FPGA rb$A$$$F<B8=5l$F$$$k!#FPGA $O%W%m%0%i%`$r=q$-49$($k$3$H$K$h$C$FFbIt$N@_7W$rJQ99$G$-$k!#$=$N%W%m%0%i%`$O SPROM(Serial PROM) $+$i%S%C%H%7%j%"%k$K%3%s%U%#%.%e%l!<%7%g%s$5lk!#PCS GO9YFN AG $,1 DN%W%m%0%i%`$G%3%s%U%#%.%e%l!<%7%g%s$5lk$?$a!"$"$kFCDj$NAG $@$10c$&F0:n$r$5

$;$k$H$$$C$?$3HO30It$+$i@)8f$r9T$o$J$$8B$j IT2DG=$G$"$k!#

AG 4V$NDL?.$O@h$[$I4.4.4@a$G=R$Y$?$h$&$K!"NY@\AG 4V$G@)8f?.9f$rMQ$$$?%O%s%I%7%'!<%/Kh$jDL?.$r9TCF$$$k!#7+$7!"RCS $HDL?.$r9T$&AG $OFIFO HNDL?.$r9T$&I,MW$,$"$k!#3N FIFO HNDL?.$ONY@\AG 4V$NDL?.HO<c430 [JkbNG"kN$G!"RCS $HDL?.$r9T$&AG $@$1$OB>$NAG HO0c$&DL?.%W%m%H%3%k$r;}DI,MW,$"$k!#

4.4.3@a$G=R$Y$?$h$&$K!"AG $OPE $NDL>o$N DRAM %"%/%;%9@)8f$b9T$C$F$$$k!#$=$3$G!"PE $,DRAM $K%"%/%;%9$9$k;~$K;HMQ9k%"%I%l%9@~$rMxMQ$7!"DRAM %"%/%;%9$K;HMQ$7$J$$30It%a%b%j%"%/%;%9MQ$N%P%9$N@)8f7O$rMQ$$$F%"%I%l%9$N?tbit $rAG $N@)8f%3%^%s%I$H7F;HMQ9k3H$G!"FPGA FbIt$N>uBV$r@)8f$9k3HK7?!#3N@)8f%3%^%s%I$rMxMQ$9k3HG!"RCS $HDL?.$r9T$&AG $@$1rJLNDL?.%W%m%H%3%k$r;}$Dh&K7$?$j!"4.4.1@a$G=R$Y$?$h$&$K!"1Bf$NPCU $,=hM}$9$kslice ?t$r<+M3KJQ($?$j9k3H$,$G$-$k!#

4.5 SS $*$h$SSU $N<BAu

SS $*$h$SSU $N%=%U%H%&%'%"$r4^a?<BAu$NFC D'$r$^$Hak$H0J2<$Nh&KJ$k!#

4.5.1 %7%'!<%G%#%s%0=hM}$NJBNs2=

ReVolver/C40 GOdepth gradient shading $rMQ$$$F%7%'!<%G%#%s%0$r9T$&!#3NJ}K!GO!"5aak%T%/%;%k<+?H$r4^$`>e2<:81&9go;$F13 %T%/%;%k$NNN0hKBP9$k%G!<%?$+$iK!@~%Y%/%H%k$r5aaF51EY$r7W;;$9$k(?^??;2>H)!#$3$N:]!"3F%T%/%;%k$N7W;;$OA4j8_$K0MB8$,L5$$$?$a!"%T%/%;%kC10L$N%G!<%?JBNs=hM}$,2DG=$G$"$k!#0lJ}!"K!@~7W;;K*1k%G!<%?$N%"%/%;%9%Q%?!<%s$K$O!"x J}8~!"y J}8~$NN>J}8~$K4X$7$F!";2>H$N6I=j@-$,B8:_$9$k!#$7$?$,CF!"8zN(E*$JJBNs=hM}$r9T$&$?aK$O!"1<!85!"$"$k$$$O2<!85$N%V%m%C%/J,3d$,E,7F$$$k!#$=$3$G!"*ReVolver*/C40 GO2hLL$r?^31 Nh$&$K2<!85%V%m%C%/J,3d(4 × 4 $N16J,3d)!"$b7/$Oy J}8~$K1<!85$KJ,3d$7!"$=$1$>$l$r1 DNSU $K3d$jEvFk3H$G!"JBNs=hM}$r9T$&!#

4.5.2 %9%1!<%i%S%j%F%#

4.5.1@aGb=RY?h&$K!"SS GO2hLL$r2<!85%V%m%C%/J,3d$b7/$O1<!85$KJ,3d$7!"$=1>lr1 DNSU $K3d$jEvFk3H$G!"%7%'!<%G%#%s%0=hM}$rJBNs2=7F$$$k!#1<!85$K2hLL$rJ,3d9kJ}K!GO2hLL$rSU $NBf?t$GJ,3d9k3HKh$j!"SU16 Bf$hjb>/$J$$9=@.$G%7%'!<%G%#%s%0$r9T$&$3H,G-$k!#%7%'!<%G%#%s%0$r9T$&$K$ONY@\$9$kSU 4V$GDL?.$r9T$&I,MW$,$"k,!"PE 4VDL?.$rMxMQ$7IAiN2hLLJ,3dGb9T$($kh&$K<BAu$7$?!#

4.5.3 C`<!=hM}$HJBNs=hM}$N:.:_Kh$k:90[$N5[<}

SS $OPCS $+$iAwilF/$k%G!<%?$rMQ$$$F%7%'!<%G%#%s%0$r9T$$!"2hA|$rCRT $K=PNO$9$k!#PCS $O;~4VE*$JJBNs=hM}$r9T$C$F$$$k$?$a!"SS $+$i$_$k$H!"%G!<%?$OC`<!E*KAwilF$/$k!#SS GOPCS $N%Q%$%W%i%$%s$rMp$9$3HJ$/16 8D$NSU $K%G!<%?$rJ,G[9k3H$,MW5a$5lk!#

$^$?16 8D$NSU $KJ,G[$5l?%G!<%?$O!"$=l>lNSU $GJBNs$K=hM}5l!":G=*E*$KRGB CM$,@8@.5l$k!#$3NCMOCRT $K=PNO$9k?aKD/A Converter KhCF%"%J%m%0$NRGB %G!<%?$KJQ49$5$l$k!#$3$3$G16 8D$NSU $G@8@.$5l?%G!<%?$rC`<!E*$K<h$j=P$9$H$$$&=hM}$r9T$o$J$$$H$$$1$J$$!#$=$N$?$a$K!"SS $G$OA0<T$rPT!"8e<T$rVSG $,9T$&$3$H$K$h$j!"C`<!=hM}$HJBNs=hM}$N4V$KB8:_9k:90[$r5[<}$7$F$$$k!#

SU GO?^32 Nh$&$KRB KBP9$kPT $+$i$N=q$-9~$_$HPE $+$iNFI_=P$7!"OB KBP9$kPE $+$i$N=q$-9~$_$HVSG XNE>Aw$H$$$&=hM}$rJBNs$K9T$&$?$a!"RB $HOB O=l>$l2 %P%s%/9=@.K7!"%U%l!<%`C10L$N%7%'!<%G%#%s%0=hM}$,=*$ok?SKPT $,%P%s%/$r@Z$j49$($k!#RB $O?^33$K<(9h$&$K!"PT $HPE $N2%v=j$+$i%"%/%;%9$5lk!#RB $N%"%/%;%9$NFCD'H7FO!"<!Nh$&$JbN$,$"$k!#

- PT $HPE $N%"%/%;%9$O!"A4$/0[$J$kNNN0h$KBP7F9Tol$k!#

- PT B&$bPE B&$b; 6H/%"%/%;%9G"$k! #

?^33$K< ($9h&$K! "PT $,RB $K%"%/%;%9$9$k; ~4V$OC;$/! "$^$?PE $O16 8D$"kN$GPT $,1 8D$N PE $NRB $r@jM-$9$k; ~4V$Oo:$+$G$"$k! #hC$F RB $OSRAM $r2 8D@\B3$7! "U*M}E*KO1 %]!<%H $G<B8=$5$l! "; ~J,3d$G2>A[E*$K2 %]!<%H$K7F$$ $k! #$=7FPT $+$i$N%"%/%;%9$,$"$C$?>l9g$K$= Ai$rM%@h5;$kh&K7$F$$$k! #

$^$?! "OB $b?^33$K< (9h$&$K! "PE $HVSG $N 2%v=j$+$i%"%/%;%9$5lk! #OB $N%"%/%;%9$NFCD' H7FO! "< !Nh$&$JE@$,$"2ilk! #

- PE $HVSG $N%"%/%;%9$O! "A4$/0[$J$kNNN0h$K BP7F9Tol$k! #

- PE B&$O; 6H/%"%/%;%9! "VSG B&$OC1H/$NO"B3 %"%/%;%9$G$"$k! #

?^33$K< ($9h&$K! "VSG $,OB $K%"%/%;%9$9$k; ~4V$OD9$/! "$=$N4VOB $r@jM-$7F7$^$&$HPE $, D9$$4VOB $K=q$-9~$`$3H,G-J/Jk! #hC $FOB GORAM %]!<%H$HSAM %]!<%H$H$$$&2 DN%"%/%;%9%]!<%H$r; }$C$?VRAM $r; HMQ$7$F $$$k! #$3$3GO! "PE $+$i$N=q$-9~$_$K$O9bB.@- $CMW5a$5lF$$$J$$$N$G! "DRAM $HF1$8J}K!$G %"%/%;%9$G$-$kRAM %]!<%H$r; HMQ$7! "VSG XN %G!<%?E>Aw$O! "9bB.$J$7!<%1%s%7%c%k%"%/%;%9$, 2DG=$JSAM %]!<%H$r; HMQ9k! #3NVRAM $r MQ$$$k3HKhCF! "OB $OVSG $+$iNFI_=P $7MW5a$H! "PE $+$i$N=q$-9~$_MW5a$,VD$+$k$3 HO$J$$$! #$?$@! "CRT $K2hA|$r@5$7$/=PNO9k$? aK$O! "1 %9%-%c%s%i%$%s4HK"$k%?%$%_%s%0 $GRAM %]!<%H$K$"$k%G!<%?$rSAM %]!<%H$KE> Aw9kI,MW$,$"$k! #$3NH$-$@1O! "VSG $bPE $bOB $K%"%/%;%9$9k3HOG-J/Jk! #3N RAM-SAM E>AwKI,MWJ; ~4V$O160ns G"kN $G! "VSG $,SAM %]!<%H$K%"%/%;%9$7$J$$%V%i%s %-%s%0=hM}r7$F$$$k4V$KE>Aw$r$*$3J&3H$K hC$F! "VSG $NF0:n$rK8$2$k3H$,$J$$$h$&$K$7 $F$$$k! #

4.5.4 2hA|=PNON?aN@)8f

SU $G%7%'!<%G%#%s%0=hM}$r=*$($? RGB %G!< %?$O! "SU >e$NVRAM(OB) $K3JG<$5lk! #3N RGB %G!<%?$OD/A Converter $r2p$7$F%"%J%m%0 ?.9f$KJQ49$5$l! "CRT $K=PNO$5lk! #VSG GO 16 8D$NSU NCf+i=$N; ~!%G1 8D$NSU $rA*$s $G! "VRAM NCfNRAM %]!<%H$+$iSAM %]!<%H XN%G!<%?E>Aw$N@)8f$*hS! "D/A Converter $X $N%G!<%?E>Aw@)8f$H! "$=$N:]$NVideo Data Bus $NA*Br$N@)8f$r9T$&! #$^$?! "CRT $G2hA|=PNO$r9T $&$?aNF14|?.9fG"$k! "?eJ?F14|?.9f$H?bD>F1 4|?.9f$rJ#9g$7$?%3%s%]%8%C%HF14|?.9f$N@8@.$d! " <B:]$N2hA|?.9f$NB8:_$7$J$$>l=jrCNi$;$k?.9f G"$k%V%i%s%/?.9f$N@8@.$r9T$C$F$$$kNbVSG G"$k! #$3li$N@)8f$O%+%&%s%?! <$HHf3S4o$KhC $F9T$olF$$$k! #3N2hA|@8@.!"=PNON?aN; ~4V$OA4Av:I}?t$HA4Av:@~?t$K0MB8$9$k! #

4.6 *Re Volver*/C40 $N%V!<%H

$3$3GO! "*Re Volver*/C40 $KEE8;$,F~CF$+$i<B :]$K%\%j%e!<%`%l%s%@%j%s%0$r9T$$$! "2hA|$r=PNO $9$k$^$G$N%G!<%?$H%W%m%0%i%`$NN.lr?^34$rMx MQ$7J,$i@bL@$9$k! #

(1) %/%m%C%/?.9f$H%j%;%C%H?.9f EE8;$,F~kH! " 3F4pHDKOSCU $+$i%/%m%C%/?.9f$H%j%;%C %H?.9f$,6!5k5l$k! #

(2) 3F%9%F!<%8$N**PE** $N%V!<%H B@a$G=RY?3F%9 %F!<%8$NPE $N%V!<%HJ}K!$rMQ$$$F! "%V!<%H $r9T$&! #3N; ~E@$GPCS $HSS $N%j%;%C%H$r 2r=|9k! #

(3) %\%j%e!<%`%G!<%?$NE>Aw SS $N%V!<%H%W%m%0 %i%`rAwj=*$($?PCS $NPE $O! "B3$$$FSCU $+$i$N%\%j%e!<%`%G!<%?$NE>Aw$r$^$C$F$$$k! # SCU $OPE $NDL?.%]!<%H$r; H$C$F%\%j%e!<%` %G!<%?$rE>Aw9k! #PCS $N3FPE O=NCf+ iI,MWJI tJ,$rA*S@$7! "3D Volume Memory $K3JG<$9$k! #

(4) %S%e!<%G!<%?$N3JG< SCU $O RCS $N View Buffer $N%S%e!<%G!<%?3JG<NNN0h$K%S%e!<%G!< %?$r%i%$%H9k! #RCS $NPE $O%V!<%H$,=*$o kHD j4|E*K3$NNN0h$r; 2>H9k! #

(5)RCS $N%j%;%C%H2r=| :G8e$KRCS $N%j%;%C%H $r2r=|$9kH*Re Volver*/C40 $O%\%j%e!<%`%l %s%@%j%s%0=hM}rO8a$k! #

5 *ReVolver*/C40 $N@-G=I>2A

0J2<GO<g$K*ReVolver*/C40 $N2hLL@8@.B.EY$K$D$$$F$N@-G=I>2A$r9T$&!#

4.2.1@a$G=R$Y$?$h$&$K!"9YFN PE KO50MHz $N%/%m%C%/$,6!5k5l$F$$$k!#$^$?<~JU2sO)KOPE $GJ,<~$5l?25MHz $N%/%m%C%/(01It$OPLL $G@8@.)$,6!5k5l$k!#0J9_2<oN`$N%/%m%C%/$r6hJL$9$k$?$a!"50MHz %/%m%C%/$rDSP %/%m%C%/!"25MHz %/%m%C%/$r%7%9%F%`%/%m%C%/$H8FV3HK9k!#

5.1 *ReVolver*/C40 $N%W%m%H%?%$%W$N%5%V%;%C%H$N<BB,;~4V

$^$:*ReVolver*/C40 $N%W%m%H%?%$%W$N%5%V%;%C%H$rMQ$$$F$N2hLL@8@.;~4V$rB,Dj9k!#3N%5%V%;%C%H$O3F4pHD$NPE $,RCS3Bf!"PCS8Bf!"SS8Bf$H$$$&9=@.HJCF$$$k!#hC$F=hM}2DG=$J:GBg%\%j%e!<%`6u4V$OPCS $NPCU $,4J?LL=hM}$7$?>l9g$N32^3voxel [2] G"$k!#

ReVolver/C40 $N%5%V%;%C%H$rMQ$$$?2hLL@8@.B.EY$rI=2$K<($9!#

<!$K%5%V%;%C%H$N3F%9%F!<%8$N<BB,$r<($9!#I=3 $KRCS $N<BB,!"I=4$K2hLL%5%$%:$128^2$pixel GNPCS $N<BB,$+$i5a$a$?1 %T%/%;%k$N=hM}KMW9$k;~4V!"I=5 $KSS $N<BB,$r<($9!#

5.2 %f!<%6%$%s%?%U%'!<%9$NI>2A

ReVolver/C40 $N%f!<%6$KHCFO!"2hLL@8@.B.EY$b=EMW$G$"$k$,!"<B:]$K;HMQ9kH-$N;H$$$d$9$5$b=EMW$G$"$k!#*ReVolver*/C40 $G%f!<%6%$%s%?%U%'!<%9$rC4$C$F$$$kNOSCU G"$k!#$3$3$G$O%f!<%6$+iN*ReVolver*/C40 KBP9$kMW5a$K3?$($k$?$aKIN/$i$$$N;~4V$,I,MW$+$r<BB,$Khj5aak!#

0J2<$K3F%G!<%?E>Aw;~4V$K$D$$$F$NI>2A$r9T$&!#

%S%e!<%G!<%? *ReVolver*/C40 GO;kE@$NJQ99$r%j%"%k%?%$%`$G9T$&$?aK!"%S%e!<%G!<%?$rE>Aw$9$k!#%S%e!<%G!<%?$ORCS Fb$NView Buffer $K3JG<$9$k!#$3$N%P%C%U%!$ORCS $N3FPE $H6&M-$7$F$$$k$?$a!"3FPE $,F0:n$7$F$$$k;~KO%"%/%;%9@)8f$,I,MW$G$"$k$,!"SCU $O%"%/%;%9$NM%@hEY$,3FPE hj9b$$$?$a!"%S%e!<%G!<%?$NJQ99$,M%@h$5lk!#%S%e!<%G!<%?$NE>Aw;~4V$r<BB,7?H3$m!"1word KD$-360ns G"k3H,o+C?!#%S%e!<%G!<%?$O12word $"$k$?$a!"4.32μs $G1 2s$N%S%e!<%G!<%?$NE>Aw$r=*$($k!#7+$7!"%[%9%H%^%7%s$O%S%e!<%G!<%?$NE>Aw$K@lG0$7$F$$$ko1GO$J$$$N$G!"<B:]$KO3$N;~4V$N1.2 $+$i1.3 G\$N;~4V$,$+$+$kN,IaDLG"$k!#%S%e!<%G!<%?$NJQ99$O1 %U%l!<%`C10L$G9T$o$l$k$,!"1 %U%l!<%`J,$N=hM};~4VKBP7$F==J,C;$$$?$a*ReVolver*/C40 $N2hLL@8@.B.EY$K1F6A$rM?$(k3HO$J$$!#9JoA!"%f!<%6$+$i$N;kE@JQ99;X<($K%j%"%k%?%$%`$GDI=>G-k3H,o+C?!#

%\%j%e!<%`%G!<%? *ReVolver*/C40 $G$O:G=i$K%\%j%e!<%`%G!<%?$r%a%b%j$K3JG<9kI,MW$,$"$k!#$^$?!"ESCf$G%\%j%e!<%`%G!<%?$rJQ99$7$?$$$H$$$&MW5a$b$G$F$/$k$G$"$m$&!#$=$N>l9g!"$$$C$?$s*ReVolver*/C40 $NF0:n$rCfCG$5$;$F%\%j%e!<%`%G!<%?rAwk!#%\%j%e!<%`%G!<%?$NE>Aw;~4V$r<BB,$7$?$H$3$m!"$32^3$voxel J,$N%G!<%?(96KByte) $NE>Aw$KLs82ms $+$+$k$3$H$,$o$+$C$?!#$3$l$h$j!"$512^3$voxel $N>l9g$G$bLs7 J,$GE>Aw$,=*N;$9$k$3$H$,$o$+$k!#B?$/$N>l9g%f!<%6$O0lEY%\%j%e!<%`%G!<%?rAwk$H!"$7Pi$/$O$=$N%G!<%?$G;kE@$rJQ99$7$J$,$i4Q;!$r9T$&NG!"IQHK$K%\%j%e!<%`%G!<%?$rJQ99$9$k$3$H$O$J$$$H;W$o$l$k!#$=$NE@$G$O==J,%f!<%6$NMW5a$K$3$?$($i$l$k!#$b$7$5$i$K$O$d$/%\%j%e!<%`%G!<%?$rAwj?$$$H$$$&MW5a$,$"C?H-KO!"%\%j%e!<%`%G!<%?$r;0=E2=$;$:$KAw$j!"<u$1<jG"$kPCS $G;0=E2=$9k3H,9M$($ilk!#

5.3 **RCS** $NI>2A

RCS $N2hLL@8@.B.EY$r7hDj9kMW0xH7FO!";k@~%G!<%?E>Aw$H;k@~@8@.=hM}$,9M$($ilk!#$=$l$>$lKD$$$FFHN)$K2hLL@8@.B.EY$rI>2A7?8e!"N>J}$N=hM}$r4XO"5;$?RCS $N2hLL@8@.B.EY$NI>2A$r9T$&!#

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[2] %\%j%e!<%`6u4V%5%$%:=(PCU Bf?t×C4EvJ?LL?t)^3

I=2: *ReVolver*/C40 $N2hLI@8@.B.EY(<BB,)

1PCU $N C4Evslice ?t	2hLL %5%$%:	2hLI@8@. ;~4V	2hLI@8@. B.EY
1slice	128^2pixel	79.94ms	12.51frames/s
2slice	128^2pixel	93.58ms	10.68frames/s
4slice	128^2pixel	135.82ms	7.36frames/s

I=3: RCS $N2hLI@8@.B.EY(3 Bf$G$N<BB,)

2hLI%5%$%:	1 2hLL=hM};~4V	2hLI@8@.B.EY
128^2pixel	75.9ms	13.18frames/s
256^2pixel	308.6ms	3.24frames/s
512^2pixel	1206.2ms	0.83frames/s

5.3.1 ;k@~%G!<%?E>Aw

$3$3GO!";k@~%G!<%?E>AwG=NO$+$i$_$?2hLI@8@.B.EY$NI>2A$r9T$&!#

Ray FIFO Buffer $K=q$-9~$`1 %T%/%;%kEv$?$j$N;k@~%G!<%??t$O!"4.1@a$h$j6words $G$"$k!#$^$?4.3.4@a$h$j!"0l2s$ND4Dd$KMW$9$k%5%$%/%k?t$,%7%9%F%`%/%m%C%/14 %5%$%/%kG"$k!#$^$?4.3.4@a$G!"0lEY$K64 %T%/%;%kJ,$N;k@~%G!<%?r^Ha$FE>Aw$9k3HK7?!#$=$7$F%O!<%I%&%'%"$*hS%=%U%H%&%'%"$r<BAu$7$?7k2L!"Ray FIFO Buffer $K1word E>Aw$9k?aK%7%9%F%`%/%m%C%/6 %5%$%/%kI,MW$G$"$k3H$,$o$+$C$?!#$=3G$^$:!"3N%G!<%?$rMQ$$$?;k@~%G!<%?E>AwB.EYM=B,$rI=6$NM=B,NMsK<($9!#

<B:]$K64 %T%/%;%kJ,$N;k@~%G!<%?$NE>Aw$K$+$+$k;~4V$rB,Dj7F$_$k$H!"E>Aw0l2sEv$?j92.2μsG"C?!#3N;~4V$r4p$K7W;;7?1 %U%l!<%`J,$N;k@~%G!<%?E>AwB.EY$rI=6$N<BB,$NMs$K<($9!#

3N7k2L;k@~%G!<%?E>Aw;~4V$OM=B,$H$[$\F1$8CM$KJk3H$,<($5l?!#

5.3.2 ;k@~@8@.=hM}

;k@~@8@.=hM}$O2.3.1@a$G$b=R$Y$?$h$&$K!"<!Nh$&$J=hM}r^Ha$?$bNG$"$k!#

- ;k@~%Y%/%H%k$N@8@.
- <g<45Z$S<g<4J}8~$NH=Dj
- 4pK\%Y%/%H%k$N7W;;
- ;k@~$H%\%j%e!<%`6u4V$N8r:9H=Dj
- =i4 |:BI8!"=i4 |5wN%$N7W;;
- %5%s%W%j%s%03+;OO1LCV$N7W;;

3liN=hM}$OPE $G9T$olk!#%W%m%0%i%`$N<BAu$7$FF@$il?PE3 BfGN<BB,CM(I=3$r;2>H) $+$i5aa?PE8 BfGNRCS $N;k@~@8@.B.EYM=B,$rI=7$K<($9!#

3lhj!";k@~@8@.=hM}B.EYO[$\2hLI%5%$%:$KHfNc$9k3H,o+C?!#

5.3.3 RCS $N2hLI@8@.B.EY

RCS $N2hLI@8@.B.EY$O!";k@~@8@.=hM}$H;k@~%G!<%?E>Aw$NIAi+$KN'B.$5lk!#;k@~@8@.=hM}$O3F PE $GJBNs$K<B9T5lk,!"@8@.5l$?;k@~%G!<%?$rPCS XAwk:]$N%G!<%?E>Aw$O6&M-%P%9>e$GC`<!2=$5lk!#$=$NMM;R$r?^35$K<($9!#

RCS $O8 Bf$NPE $GJBNs=hM}$r9TCF$$$kNG!"?^35$+$ibo$+$kh&$K!"7 8D$NPE $+$i$N%G!<%?E>Aw;~4V($T_{trans}$) NOB,;k@~@8@.=hM};~4V (T_{calc}) hjD9$1$l$P($T_{calc} \leq 7T_{trans}$)!"3F PE $N;k@~@8@.=hM};~4V$O;k@~%G!<%?E>Aw;~4V$K40A4$K1#JC5l$k!#$=$l0J30$N>l9g$O2hLI@8@.B.EY$O;k@~@8@.B.EY$KHfNc$9$k!#$3$3$G!"I=6hj$T_{trans}$$r5a$a!"$T_{calc}$$HHb$KI=8$K<($9!#

I=4: 1 %T%/%;%k$N=hM}$KMW9k;~4V(2hLL%5%$%:$128^2$ $G8 Bf$G$N<BB,)

1PCU C4Ev slice ?t	PCS =hM} ;~4V	1 %T%/%;%k =hM};~4V
1slice	79.94ms	4.88μs
2slice	93.58ms	5.71μs
4slice	135.82ms	8.29μs

I=5: SS $N2hLL@8@.B.EY(8 Bf$G$N<BB,)

2hLL%5%$%:	1 2hLL=hM};~4V	2hLL@8@.B.EY
128 × 64pixel	20.41ms	41.00frames/s
256 × 128pixel	80.93ms	12.36frames/s
512 × 256pixel	323.26ms	3.09frames/s

3N7k2L9YFN2hLL%5%$%:$G $T_{calc} > 7T_{trans}$ HJ$j!";k@~@8@.=hM};~4V$,RCS $N2hLL@8@.B.EY $r7hD j$9k3H,o+C?!#

5.4 PCS $NI>2A

PCS $N2hLL@8@.B.EY$r7hD j9kMW0xH7FO!"%T%/%;%kCM7W;;$H%\%/%;%kCM$N%W%j%m!<%I$,9M$(il$k!#0J2<$=l>lK$D$$$FFHN)$K2hLL@8@.B.EY$rI>2A7?8e!'N>J}$N=hM}$r4XO"5;$?PCS $N2hLL@8@.B.EY$NI>2A$r9T$&!#

5.4.1 %T%/%;%kCM7W;;

PCS $G9T$olk%T%/%;%kCM7W;;$O!"=hM}$r%Q%$%W%i%$%s2=9k3HKh$j9bB.2=$r?^CF$$$k!#3N%Q%$%W%i%$%s$NC10lMWAG$,PCU G"$j!"PCS $N%T%/%;%kCM7W;;;~4V$O3NPCU GN7W;;;~4V$K1F6A$5lk!#PCU GORCS $+$i$N;k@~%G!<%?$r4pK7$F!";kE@$K6a$$=gK=$N;k@~>e$K$"$k%\%/%;%kCM(*Re Volver*/C40 GO1byte $N%$%s%G%C%/%9) $r%\%j%e!<%`%a%b%j$+$iF I$_=P$7!"$=$N%\%/%;%kCM$rMQ$$$F%\%/%;%k$N?'!'F)L@EY$rF I$_=P$9!#$=$7F=liNCMHA0CJ$NPCU $+$i<u?.7?%T%/%;%kCM$N7W;;ESCf7k2L$r4p$K!"8=CJ3,$N%T%/%;%kCM$r7W;;$7!"<!$NPCU K=$NESCf7k2Lr*$/kH$$$&=hM}$r9T$C$F$$$k!#

1 %T%/%;%kJ,$N%T%/%;%kCM7W;;(H>F)L@%\%j%e!<%`) KMW9$k;~4V$r!"PCS N_$rF0:n$5$;$F7WB,7?7k2L$rI=9$K<($9!#

5.4.2 %\%/%;%kCM$N%W%j%m!<%I

5.4.1@aGb=RY?h&$K!"%T%/%;%kCM7W;;$OPCU $r1<!85$K@\B3$7$?%Q%$%W%i%$%s=hM}KhCF9Tol$k!#%T%/%;%kCM7W;;$GI,MW$J%\%/%;%kCM$O4.4.2@a$G=R$Y$?$h$&$K!"AG KhCF%W%j%m!<%I5l$k!#$3$N%\%/%;%kCM$N%W%j%m!<%IKMW9$k;~4V[3]$rI=10$N<BB,$NMs$K<($9!#

$3$3$G!'8=:_%W%j%m!<%I$K$*$$$F;k@~%G!<%?$N<u?.$H;k@~%G!<%?$NAw?.$O1word $:$D%O%s%I%7%'!<%/$r9T$C$FDL?.$7$F$$$k$,!"$3lOK\Mh$J$i1 %/%m%C%/4H$NO"B3E>Aw$,2DG=G"$k!#$=$N>l9gI,MW$J>r7oH7FORCS $NFIFO $K%G!<%?$,1 %T%/%;%kJ,B7CF$$$k3H$,J]>Z$5lF$$$k3HG"$k!#

5i$K%\%/%;%kCM$N%W%j%m!<%IKMW9$k;~4V$O!"3N=hM}NCfN;k@~%G!<%?$N<u?.!"%\%/%;%kCM$N%"%I%l%97W;;!";k@~%G!<%?$NAw?.$H$$$&3 DN=hM}$r%Q%$%W%i%$%s2=$9k3HKhC$F9bB.2=$G$-$k3H$,$o$+$C$F$$$k!#3N%Q%$%W%i%$%s$O%\%/%;%kCM$N%"%I%l%97W;;$KN'B.$5lk!#7+$7!"%Q%$%W%i%$%s9=@.$rHk$HFPGA $NC10L9=@.MWAG$G$"$k%3%s%U%#%.%c%V%k!&%m%8%C%/!&%V%m%C%/(CLB) $N@)8B;HMQNL$r1[$($F7^$&$?$a!"8=:_;HMQ$7$F$$$kFPGA GO<BAu$,$G$-$J$$!#[4]

%\%/%;%kCM$N%W%j%m!<%I$r%Q%$%W%i%$%s2=7?>l9g$N:GB.M=B,(01It<BB,$r4^$`) $rI=10$N:GB.

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[3] $3$3GN%W%j%m!<%I;~4V$O%\!<%IFb$G$N;~4V$G$"$k!#

[4] <B:]$O<BAu$G$-$kN@$,!"F0:nIT0BDj$KJk!#

I=6: ;k@~%G!<%?E>AwB.EY

		1 2hLL=hM};~4V	2hLI@8@.B.EY
2hLI%5%$%: 128^2pixel	M=B,	23.74ms	42.12frames/s
	<BB,	23.75ms	42.11frames/s
2hLI%5%$%: 256^2pixel	M=B,	94.95ms	10.53frames/s
	<BB,	94.99ms	10.53frames/s
2hLI%5%$%: 512^2pixel	M=B,	379.78ms	2.63frames/s
	<BB,	379.94ms	2.63frames/s

I=7: ;k@~@8@.=hM}B.EY(8BfGNM=B,)

2hLI%5%$%:	1 2hLL=hM};~4V	2hLI@8@.B.EY
128^2pixel	28.46ms	35.14frames/s
256^2pixel	115.73ms	8.64frames/s
512^2pixel	452.33ms	2.21frames/s

M=B,NMsK<($9!#

5.4.3 PCS $N2hLI@8@.B.EY

5.4.1@a$*$h$S5.4.2@a$G=RY?h&$K!"PCS $N2hLI@8@.B.EY$O%T%/%;%kCM7W;;$H%\%/%;%kCM$N%W%j%m!<%INIAi$+$KN'B.5l$k!#$3li$NB.EY$O1Bf$NPE $,2?Kg$Nslice $rC4Ev$9k+!"9JoA%\%j%e!<%`6u4V$NBg$-$5$H!"%U%l!<%`NBg-5K1F6A5l$k!#

1pixel $"$?jN%T%/%;%kCM7W;;~4V$*$h$S%\%/%;%kCM$N%W%j%m!<%I;~4V$O!"1PCU $,C4Ev$9$kslice ?t$N$_$K0MB8$7!"%U%l!<%`$NBg$-$5$K$O0MB8$7$J$$!#$^$?%\%j%e!<%`6u4V$NBg$-$5$O6u4V$,N)J}BNJN$G!"PCU Bf?t$H1PCU $,C4Ev$9$kslice ?t$G7h$^$k!#hCF3li$N2hLI@8@.B.EY$rbHakKO!"PCU $rDL2a$9$k;k@~?t$r3]$19g$o$;$lPh$$!#

?^36$K%T%/%;%kCM7W;;$H%W%j%m!<%I$N%Q%$%W%i%$%s$NMM;R$r<($9!#

?^36$r4p$KI=9$HI=10$r$/$iY?>l9g!"%T%/%;%kCM7W;;$,PCS $N2hLI@8@.B.EY$,N'B.$7!"%\%/%;%kCM$N%W%j%m!<%I$N;~4V$r1#JC9k$HM=B,$5lk!#I=11K3$NM=B,$K4p$E$$$?PCS $N2hLI@8@.B.EY$r<($9!#

7+$7I=4$HI=11$NF1>r7o$N>l9gNCMr$/$iYF8+kH!"M=B,hj2hLI@8@.B.EY$,Mn$A$F$$$k3H$,$o$+$k!#B.EYDc2<$N3d9g$O1PCU $,C4Ev$9$kslice ?t$,>/$J$$$[IBg-$$!#3N860x$rD4$Y$?7k2L!"4pHD4V(RCS-PCS 4V!"PCS 4pHD4V!"PCS-SS 4V) $NDL?.!"FC$K$=$NCfGbAG bus $NDL?.$GAw<u?.$N;~4V$,D9$/$J$k8=>]$,4QB,5l$?!#D4::$N7k2L!"?^36GNA0CJ$NPCU $NVaccess $,=*N;$;$:!"$=$N<!$NPCU $NVreceive $NA0$KBTA,@8$8!"CY1d$,8eCJ$KEAHB$7$F$$$k3H$,$o$+$C$?!#$3lO4pHDFb$NDL?.5wN%$K$/$iYF!"4pHD4V$NDL?.5wN%$,D9$/DL?.;~4V$,Bg$-$$$3HK5/0x9k!#3l$KBP=h$9$kJ}K!$H7F!"%W%j%m!<%I$r%Q%$%W%i%$%s2=$7DL?.=hM};~4V$r1#JC$9k3H,9M$($ilk!#7+$7!"5.4.2@a$G=RY?h&$K!"8=:_$NFPGA GO%W%j%m!<%I$N%Q%$%W%i%$%s2=$,G-$J$$!#

<!$K!"$3$N%\%/%;%kCM$N%W%j%m!<%I$NI,MW@-$K$D$$$F=RYk3HK9$k!#8=:_$O>e=R7?h&$K!"AG 4V$N4pHD4VDL?.$GCY1d$,H/@8$7$F$$$k$,!"$b$7AG $r<BAu$7J+C?>l9g!"%T%/%;%kCM7W;;~4VOBg-$/$JkH9M$($ilk!#$3$3GO!"AG $r;HMQ$;$:$K%T%/%;%kCM7W;;$r9T$C$?$H$-$N;~4V$HHf3S$7!"%\%/%;%kCM$N%W%j%m!<%I$KhC$F!"$I$NDxEY$N9bB.2=$,F@$ilkN+$r8!F$$9$k!#

AG $r;HMQ$7$J$$>l9g!"3FPE $G;k@~%G!<%?$r<u$1<h$j!"$=$l$r4p$K%\%j%e!<%`%a%b%j$K%"%/%;%9$9$k%"%I%l%9$r7W;;$7!"%\%/%;%kCM$rFI$_=P$5

I=8: %G!<%?E>Aw;~4V$H;k@~@8@.=hM};~4V$NHf3S

2hLL%5%$%:	;k@~@8@.=hM}	;k@~%G!<%?E>Aw	
	T_{calc}	T_{trans}	$T_{\text{calc}}/T_{\text{trans}}$
128^2pixel	28.46ms	2.97ms	9.58
256^2pixel	115.73ms	11.87ms	9.75
512^2pixel	452.33ms	47.49ms	9.52

I=9: 1 %T%/%;%k$N%T%/%;%kCM7W;;=hM}$KMW9k;~4V(<BB,)

1PE $,C4Ev$9$kslice ?t	%T%/%;%kCM7W;;;~4V
1slice	3.28μs
2slice	4.80μs
4slice	7.24μs

$J$$$H$$$1$J$$!#

I=12$KHf3S$N7k2L$r<($9!#

3N7k2L!"AG $r@_$1k3HKhC$F1PE $,C4Ev$9$kslice ?t$,1 Kg$N>19g2.53 G\!"2 Kg$N>19g2.49 G\!"4 Kg$N>19g2.63 G\$N7W;;;~4V$N8~>e$,F@ilk3H,o+C?!#

5.5 SS $NI>2A

SS GO!"?^37$K<($9h&$J%Q%$%W%i%$%s$,AH$^$l$F$$$k!#3N3H$+$ibo$+$kh&$K!"SS $N2hLL@8@.B.$r7hDj9kMW0x$O!"PT GN%G!<%?<u?.$*hSJ,G[$N;~4V$H!"3FSU K*1k%7%'!<%G%#%s%0=hM}$N;~4V!"$=7FVSG GN%G!<%?<u?.$HCRT XN=PNO;~4V$,9M$(il$k!#0J2<$=l>lK$D$$$FFHN)$K2hLL@8@.B.EY$rI>2A7?8e!"9YFN=hM}$r4XO"$5$;$?SS $N2hLL@8@.B.EY$NI>2A$r9T$&!#

5.5.1 %T%/%;%kCM$NJ,G[

PCS $O%Q%$%W%i%$%s!"$D$^$j;~4VE*$JJBNs=hM}$G%T%/%;%kCM$r@8@.$7$F$$$k!#hC$FSS KO1 %T%/%;%kJ,$:$D%G!<%?$,AwilF/$k(?^28;2>H)!#3N%G!<%?$r<u$1<hCF$$$kN,PT G"$k!#PT GO2 DN%P%9$+$iAwilF/$k%G!<%?$r?^38Nh$&$K1 DN%P%9$rA*Br7F<u$1<h$k!#PCS $+$i<u$1<h$C$?%G!<%?$O16 8D$NSU $KG[J,$5lk!#PT GO!"%T%/%;%k$N:BI8CM$K=>CFSU $rA*Br$7!"3FRB $K%G!<%?$r=q$-9~$`$?$a$N%"%I%l%97W;;$r9T$&!#$^$?!"PCS $+$i$*$/ilF/$kRGB CM$O!"$=$l$>$l32 %S%C%H$NIbF0>.?tE@?t$GAwilF/k,!"<B:]$K2hA|I=<($9$k:]$KD/A Converter KAwilkNO!"RGB $=$l$>$l8 %S%C%H$N@0?t$G$"$kNG!"3NJQ49$b9T$&!#

1 %T%/%;%kJ,$N%T%/%;%kCM$r<u$1<h$j!"A*Br7?SU $K%T%/%;%k%G!<%?$r=q$-9~$`$?$aKMW9$k;~4V$O!"<BB,$G2440$ns$ G"k3H,o+C?!#3NCf$G<gMW$J=hM};~4V$N<BB,CM$rI=13$N<BB,$NMs$K<($9!#

I=13$N<BB,$N;~4Vr9YFB-9H!"PT $N1 %T%/%;%k$N<BB,$N=hM};~4V$rBg$-$/1[$($k$,!"$3lO3liN=hM}$r%*!<%P!<%i%C%W$7$F9T$C$F$$$k$?$aG"$k!#

8=:_$O*Re Volver*/C40 $,F0:n$9k3HrA0DsK7$FAG bus $+$i$N%G!<%?$r1word $:$D%O%s%I%7%'!<%/7F<u$1<h$C$F$$$k$,!":GB.$G1word KD$-40ns!"$D$^$j%/%m%C%/$KF14|$7$F5word O"B3$G<u?.9k3H$,$G$-$k!#$^$?DSP bus $+$i$N%G!<%?$b!"%G!<%?$,$DMK<u$1<h$lk3H,J]>Z5l$F$$$l$P!"4 %/%m%C%/$G1word <u?.$7float-intJQ49$9k3H,2DG=KJ$k!#F1$8h&$K!"RB XN=q$-9~$_$b1word $:$D%O%s%I%7%'!<%/7F$$$k$,!"0lEYRB $K=q$-9~$_MW5a$r9T$&$H4word O"B3E>Aw$,2DG=$G$"$k!#I=13$N:GB.M=B,$NMsK3lir9YF9MN8$7$?>19g$N:GB.;~4V$r<($9!#

3N>19g$N PT $N 1 %T%/%;%k$N=hM};~4V$O

I=10: 1 %T%/%;%k$N%\%/%;%kCM$N%W%j%m!<%IKMW9$k;~4V

1PCU $,C4Ev$9$kslice ?t	%\%/%;%kCM%W%j%m!<%I;~4V	
	<BB,	:GB.M=B,
1slice	2.52μs	0.52μs(<BB,$KF1$8)
2slice	2.80μs	0.80μs
4slice	3.36μs	1.36μs

I=11: PCS $N2hLI@8@.B.EY(<BB,$rMQ$$$?M=B,)

PCU $NBf?t	%\%j%e!<%`6u4V NBg-$5	%U%l!<%` NBg-$5	2hLL=hM};~4V	2hLI@8@.B.EY
128 Bf	128^3voxel	128^2pixel	53.74ms	18.61frames/s
	256^3voxel	128^2pixel	78.64ms	12.72frames/s
		256^2pixel	314.57ms	3.18frames/s
	512^3voxel	128^2pixel	118.62ms	8.43frames/s
		256^2pixel	474.48ms	2.11frames/s
		512^2pixel	1897.92ms	0.53frames/s
256 Bf	256^3voxel	128^2pixel	53.74ms	18.61frames/s
		256^2pixel	214.96ms	4.65frames/s
	512^3voxel	128^2pixel	78.64ms	12.72frames/s
		256^2pixel	314.57ms	3.18frames/s
		512^2pixel	1258.29ms	0.79frames/s
512 Bf	512^3voxel	128^2pixel	53.74ms	18.61frames/s
		256^2pixel	214.96ms	4.65frames/s
		512^2pixel	859.83ms	1.16frames/s

$1240ns$ G"$k!#$3lKhC$FLs2 G\$N@-G=8~>e$,4|BT$5lk!#

RB XNPT $N%"%/%;%9$OPE hj$bM%@h$5lkNG!"b7PCS $N=hM}$,==J,B.$$$H2>Dj9l$P!"PT $N1 %T%/%;%kJ,$N=hM};~4V$K=hM}%T%/%;%k?t$r3]$19g$o$;$?bN$,1 %U%l!<%`$N=hM};~4VHJ$k!#I=14$KPT $N<BB,$H:GB.M=B,$N>l9g$N2hLI@8@.B.EY$r<($9!#

3N7k2L!"PT $N=hM};~4V$O2hLL%5%$%:$KHfNc9k3H$,$o$+$C$?!#

5.5.2 %7%'!<%G%#%s%0

2.3.3@a$G=R$Y$?$h$&$K!"depth gradient shading GO!"<+?H$r4^$`>e2<:81&9go;$F13 %T%/%;%k$NNN0hKBP9$k%G!<%?$+$iK!@~%Y%/%H%k$r5aaF51EY$r7W;;$9$k!#$=$N:]SU $,C4Ev$9$kNN0h$N$&$A!">e2<:81&3 %T%/%;%k(2hLLJ,3d$NJ}K!$KhCFO>e2<3 %T%/%;%k) KD$$$F$O!"<+J,$NNN0hKJ$$%T%/%;%k$N>pJs$rMQ$$$FK!@~%Y%/%H%k$r7W;;$9kI,MW,$"$k!#3NLdBj$r2r7h$9k?aNJ}K!H7$F!"

1. PT KhCF3FPE >e$K>e2<:81&3 %T%/%;%kJ,$N<~JUNN0h$Ndepth >pJs$r0lIt=EJ#7F3djEvF$k!#
2. PE 4VDL?.KhCF!"%T%/%;%kCM$r;}$DNY@\PE $+$idepth >pJs$r<hF@$9$k!#

$,$"$k!#

1 $NJ}K!$G$O!"%7%'!<%G%#%s%0=hM}$N;~4V$O2 $NJ}K!$HHfYk$HC;$/F9$`!#$7$+$7!"PT $G6&M-$5$l$F$$$k%T%/%;%k$N%"%I%l%97W;;$r9T$&I,MW$,$"$j!"2C$($F$=$N%"%I%l%9$X%G!<%?$r=q$-9~$`2s?t$,:GBg3 G\$KJkNG!"2 $NJ}K!$HHfYk$HPT $N=hM}$,$HJ#;(2=$9$k!#

2 $NJ}K!$G$O!"%7%'!<%G%#%s%0$,INDxEY$N4|4V$G=*ok$+$,LdBjKJCF$/$k!#

$=$3$G!"N><T$NHf3S$r9T$&!#

$^$:1 $NJ}K!$rMQ$$$?>l9g$N1 %U%l!<%`$N%7%'!<%G%#%s%0=hM}KI,MWJ;~4V$rI=15$K<($9!#

I=12: %T%/%;%kCM7W;;=hM};~4V$NHf3S

1PE C4Evslice ?t	%T%/%;%kCM7W;;;~4V	
	AG $"$j	AG J7
1slice	3.28μs	8.31μs
2slice	4.80μs	11.96μs
4slice	7.24μs	19.11μs

I=13: PT $N<gMW$J=hM}$N;~4V

=hM}FbMF	<BB,	:GB.M=B,
AG bus $+$i1word <u?.	$160ns$	$40ns$
DSP bus $+$i1word <u?.	$160ns$	$80ns$
PT $NRB XN=q$-9~$_(4word)	$1280ns$	$560ns$
%"%I%1%97W;;	$120ns$	$120ns$
float-int JQ49	$80ns$	$80ns$

<!$K2 $NJ}K!$rMQ$$$?1 %U%1!<% '$N%7%'!<%G%#%s%0=hM}$KI,MW$J;~4V$rI=16$K<($9!#

$3$3$GSU $,%7%'!<%G%#%s%0$K$+$1i1$k:GBg;~4V$r5aak!#$3$3GOPCS $N%Q%$%W%i%$%s$r5M$^$i$;$J$$$3Hr>r7oK9$k!#PCS $,1 %T%/%;%k$r=hM}9k$?$a$K:G9b$3.28\mu$s G"$k(I=9;2>H)!#$hCFSS GO1 %U%1!<% '$r16 Bf$NPE $GJBNs=hM}$r9T$&$N$G!"$3.28 \times 16 = 524.80\mu$s $G1 %T%/%;%k$N%7%'!<%G%#%s%0$r=*$(1P$h$$!#D^j512^2$pixel $N>19g$rNcKHkH859.8ms 0J2<!"F1MMK7$F!"$256^2$pixel $N>19g215.0ms 0J2<!"$128^2$pixel $N>19g53.7ms 0J2<$G1 %U%1!<% '$N%7%'!<%G%#%s%0$r=*$($1Ph$$!#$3$1$O1 $H2 NIAi$NJ}K!!"$=7FIN2hLL%5%$%:Gb==J,K~$?7F$$$k!#hC$F2 $NJ}K!$G$bPCS $N%Q%$%W%i%$%s$r5M$^$i$;$J$$$?aN==J,$JB.EY$,F@i1kH9M$($i1kNG!"SS GOPT $NIiC4$r7Z8:9k$?$a2 $NJ}K!$r:NMQ9k3HK7$?!#

5.5.3 2hA|=PNO

4.5.4@a$G=R$Y$?$h$&$K!"2hA|@8@.!"=PNON?aN;~4V$OA4Av::I}?t$HA4Av::@~?t$K0MB8$9$k!#1 IC 4V$K60 Kg(%U%1!<% '<~GH?t$60 frame/s$) $N2hA|$rI=<(9k>19g!"$1 frame$ $K3d$jEvFi1k;~4VOLs16.7ms$ G"$k!#$3$3$G!"A4Av::I}?trX$!"A4Av::@~?t$rY H9kH!"%I%C%H%/%m%C%/$,25MHz JN$G!"X HY$ $N4X78$O<011$GM?$(i1$k!#

$$X \times Y \times 60 = 25 \times 10^6 \qquad (11)$$

hCFX \times Y \doteqdot 4.17 \times 10^5$ G"$k!#

$^$?!"?eJ?F14|?.9frHkNKLs10.9\mu s$!"?bD>F14|?.9f$rHkNK$20 Line$ I,MWJN$G!"$512^2$pixel $N%U%1!<% '$rI=<(9k>19g!"$X = 780, Y = 535$ $[$I$NAv::LL$,I,MWG"$k!#$3$3$G$780 \times 535 \doteqdot 4.17 \times 10^5$ G"$k!#$hCF512^2pixel $N%U%1!<% '$rI=<(9kKO==J,$J%9%T!<%I$,F@i1k3H,o+C?!#

5.5.4 SS $N2hLL@8@.B.EY

5.5.3@a$+$ibo$+$kh&$K!"2hA|=PNO$KO512^2$ $N2hLL$rI=<(9k==J,$J%9%T!<%I$,F@i1k3H,o+CF$$$k!#hC$FSS $N2hA|@8@.B.EY$r7hDj9$kMW0x$O!"PT Kh$k%T%/%;%kCM$NJ,G[$+!"$b7/$O%7%'!<%G%#%s%0$G$"$k!#$3$3$GCm0U$7J1$1$PJi$J$$$N$O!"4.5@a$G$b=R$Y$?$h$&$K!"SU $NRB $OPT $HPE NIAi$+ib%"%/%;%9$,$"$k;v!"$=7FSU $NOB $bVSG $HPE NIAi$+ib%"%/%;%9$,$"$k;vG"$k!#RB $O;~J,3d$G2 %]!<%HK7$F$$$k$,!"<B:]$K$O1 %]!<%H$G$"$kNG!"PT $+$i$N=q$-9~$_MW5a$HPE $+$iNFI_=P$7MW5a$,VD$+$k>19g$,$"$k!#$3$N>19gPT $+$i$N%"%/%;%9$,M%@h$5$1kNG"k,!"DSP O=$N4V%"%/%;%9$9k3H,G-$J$$!#

I=14: PT $N2hLI@8@.B.EY

		1 2hLL=hM}; ~4V	2hLI@8@.B.EY
2hLI%5%$%: 128^2pixel	<BB,	39.98ms	25.01frames/s
	:GB.M=B,	20.32ms	49.21frames/s
2hLI%5%$%: 256^2pixel	<BB,	159.9ms	6.254frames/s
	:GB.M=B,	81.26ms	12.31frames/s
2hLI%5%$%: 512^2pixel	<BB,	639.6ms	1.563frames/s
	:GB.M=B,	325.1ms	3.076frames/s

I=15: 1 %U%1!<% '$N%7%'!<%G%#%s%0=hM}$KMW9k; ~4V(1)

2hLI%5%$%:	%7%'!<%G%#%s%0; ~4V	2hLI@8@.B.EY
128^2pixel	18.38ms	54.41frames/s
256^2pixel	70.76ms	14.13frames/s
512^2pixel	296.12ms	3.38frames/s

$3$1KBP7$F!'OB $ORAM %]!<%H$HSAM %]!<%H$H$$$&2 DN%"%/%;%9%]!<%H$r; }$C$?VRAM $r;HMQ$7$F$$$k!#3NVRAM rb$A$$$k3HKhCF!"OB $OVSG $+$iNFI_=P$7MW5a$H!"PE $+$i$N=q$-9~$_MW5a$,VD$+$k3HOJ$$!#$?$@!"RAM %]!<%HK"$k%G!<%?$rSAM %]!<%H$KE>Aw$9kH$-$@1O!"VSG $bPE $bOB $K%"%/%;%9$9k3HOG-J/Jk!#

hC$F!"C1=c$KI=14$HI=16!"$=7F%U%1!<% '<~GH?trHfYkNGOJ/!"PT!"PE!"VSG 9YFrF0:n5;$?>e$GSS $N2hLI@8@.B.EY$r7WB,9kI,MW$,$"$k!#I=17$KPE8 BfGNSS $N<BB,(I=5 ;2>H) hj5aa?PE16 BfGNSS $N2hLI@8@.B.EYM=B,$r<($9!#

3N7k2L!"8=:_$OPT $N2hLI@8@.B.EY$,SS $N@-G=$r7hD}9kBg$-$JMW0xG"kH$$$($k!#<BB,$NJ}$,I=14$NPT $N1%T%/%;%kJ,$N<BB,=hM}; ~4V$K=hM}%T%/%;%k?t$r3]$19g$o$;$?CMhj>/$7Bg$-$/$JkN$O!"PT $HRB Controller $N4V$K%/%m%C%/0IAj:9$,B8:_$9k?aK!"RB $K%G!<%?$r=q$/:]$NPT $HRB Controller $N%O%s%I%7%'!<%/$N; ~4V$,IaCJ$h$j1%/%m%C%/D9$/$+$+kH$-$,$"$k$?$aG"$k!#

PT $O5.5.1@a$G=RY?h&$K!"DL?.J}<0$rJQ$($k3HKhCF9bB.2=$,9T$($k!#$3$1$K$OPCS $N2~NI$bI,MWG"k,!"3N3HKhCFSS $N2hLI@8@.B.EY$O8~>e5;k3H,G-$k!#

5.6 I>2A7k2L$+$i$N9M; !

$3$3GO!"5.3@a!"5.4@a$*$h$S5.5@a$G=RY?3F%9%F!<%8$NI>2A$r4p$K!"*Re Volver*/C40 $N2hLI@8@.B.EY$NI>2A$r9T$&!#

Re Volver/C40 $O2.3.4@a$G=RY?h&$K!"3F%9%F!<%8$G9T$&=hM}$r%U%1!<% '4H$K%Q%$%W%i%$%s=hM}$9k3HG9bB.2=$r?^$C$F$$$k(?^??;2>H)!#5i$K!"RCS $HPCS Fb5Z$SSS $N0lIt$G$O%T%/%;%kC10L$N%Q%$%W%i%$%s=hM}$,9T$o1F$$$k!#hC$F!"*Re Volver*/C40 $N2hLI@8@.B.EY$O1%U%1!<% 'K+$+$k=hM}; ~4V$,0lHVBg$-$JItJ,$KN'B.$5$1$k!#

0J>e$N7k2L!"$$$:1N>19g$b PCS $,*Re Volver*/C40 $N2hLI@8@.B.EY$rN'B.9k3H$,$o$+$C$?!#

<!$K@_7WEv=i$N@-G=M=B,$,$INh$&$JbNG"C?$+$r4JC1$K=R$Y$k!#*Re Volver*/C40 @_7WEv=i$O!"*Re Volver*/C40 $N@-G=$OPCS $N=hM}$N%Q%$%W%i%$%s%T%C%A$,N'$9kH9M$($i1F$$$?!#$=$N%Q%$%W%i%$%s%T%C%A$OPCS $NPE $N=hM}; ~4V$,7hD}9k$HM=B,$7$F$$$k!#$=$3$G!"%\%j%e!<% '6u4V$NBg$-$5r512^3$voxel!"%U%1!<% '$NBg$-$5r512^2$pixel!"PE $NBf?t$r512 BfH7$?$H$-$NPE $N=hM}; ~4V$rM=B,7?7k2L!"H>F)L@%\%j%e!<% '$N>19g$N2hLI@8@.; ~4V$O188.8ms!"ITF)L@%\%j%e!<% '$N>19g$N$=$1

I=16: 1 %U%l!<%`$N%7%'!<%G%#%s%0=hM}$KMW9k;~4V(2)

2hLL%5%$%:	%7%'!<%G%#%s%0;~4V	2hLL@8@.B.EY
128^2pixel	20.68ms	48.36frames/s
256^2pixel	75.36ms	13.27frames/s
512^2pixel	304.78ms	3.28frames/s

I=17: SS $N2hLL@8@.B.EY(PE16 Bf$G$NM=B,)

%U%l!<%`NBg-$5	SS =hM};~4V	2hLL@8@.B.EY
128^2pixel	40.82ms	24.50frames/s
256^2pixel	161.85ms	6.18frames/s
512^2pixel	646.51ms	1.55frames/s

$O136.2ms HJC?!#3l$O2hA|@8@.B.EYG_kH!"$=l>$l15.30frames/s!"7.34frames/s HJ$k!#RCS $dSS $NPE ?t$O!"PCS $NITF)L@%\%j%e!<%`$rI=<(9k:]$N@-G=$K9go;F=l>$l8=:_$N8Bf!"16 Bf$H$$$&?tKJCF$$$k!#

8=:_$N*ReVolver*/C40 $N@-G=$OPCS $N=hM}$N%Q%$%W%i%$%s%T%C%A$G7hDj$7F*$j!"N'B.$9$k=hM}$NM=B,$O4V0c$C$F$$$J$+$C$?!#$7$+$7<BB,$N2hLL@8@.B.EY$OEv=i$N@-G=M=B,$hjCY/JC$F$$$k!#$3$3$G*ReVolver*/C40 $N@_7WEv=i$KM=B,$7@Z$lJ+C?!"*ReVolver*/C40 $NB.EY$rCY$/$9$kMW0x$r9M;!9k!#$^$:PCS $N%T%/%;%kCM7W;;=hM}$,2hLL@8@.=hM}$r7hDj$7$F$$$kNG!"3lKD$$$Fb&>/$7>\$7$/I>2A$r9T$&$3HK9k!#

%T%/%;%kCM7W;;=hM}$O:Y$+$/$o1k$H!"A0CJ$NPE $+$i$N%G!<%?<u?.!"%\%/%;%kCM$rMQ$$?%T%/%;%kCM$N7W;;(DL?.$r=|$/)!"8eCJ$NPE XN%G!<%?Aw?.$H$$$&3 DN=hM}Ko1ilk!#$3$3$G%G!<%?Aw<u?.$N;~4V$r7WB,$7$?7k2L!"A0CJ$NPE $+$i$N%G!<%?<u?.$K$O1.20μs!"8eCJ$NPE XN%G!<%?Aw?.KO1.00μs G"k3H,o+C?!#D^$j%T%/%;%kCM7W;;$NJ+$G!"2.20μs $ODL?.$KMxMQ5l$F$$$k$H$$$&3HKJ$k!#$3l,%T%/%;%kCM7W;;=hM}NCfGINDxEY$N3d9g$r@jak$+$rI=18K7a9!#

3N7k2L!"%G!<%?Aw<u?.$N;~4V$,%T%/%;%kCM7W;;;~4VNCfG$+$JjN3d9g$r@j$a$F$$$k3H$,$o$+$j!"FC$K1PE $G=hM}$9$kslice ?t$,>/J/JlPJk[I=$N3d9g$,Bg$-$/Jk3H$,$o$+$C$?!#$D$^$j3NItJ,$r2~NI$9lP*ReVolver*/C40 $N2hLL@8@.B.EY$O8~>e9k3HKJ$k!#8=:_PE 4VDL?.$K$OFIFO %a%b%j$r;HMQ$7!"%0%s%I%7%'!<%/$r9T$&$3HG%a%b%jXNAw<u?.$r9T$C$F$$$k!#3l$OFIFO $K<!$K<u?.9Y$-%G!<%?$,B8:_7J$$>l9g$KBP=h$9k?aG$"$k!#7+$7!"<u?.$9kY$-1 %T%/%;%kJ,$N%G!<%?$,B8:_$9k3H,J]>ZG-kJ$i%G!<%?$rO"B3$7$F<u$1<h$CFb9=oJ$$!#3N$?$aKO1 %T%/%;%kJ,$N%G!<%?$,B7C?H-$K8eCJ$NPE $K=`Hw40N;?.9f$r$@$9h&K9lP$h$$!#3l$ORCS-PCS 4V!"PCS-SS 4V$K$b$$$(k3HG$"$k$,!"$3li$N>l9g$O8=:_$N;EMM$Gb3$N2~NI$r9T$&$3H,G-$k!#$3$N2~NI$KhC$F!"PE 4VAw<u?.$O:GC;$G0.80μs $G9T$(kh$&$KJk!#3N>l9gPCS $N2hLL@8@.;~4V$O@h$[$I$HF1$8>r7o$G492.83ms HJ$j!"$3lO2hLL@8@.B.EY$G2.03frames/s HJ$k!#$3lOLs1.75 G\$NB.EY8~>eHJ$k!#

3NB>$N*ReVolver*/C40 $NB.EY$rCY$/$9$kMW0x$H7F$O!"3F%9%F!<%8$G$NDSP %W%m%0%i%`$NA}Bg$,9M$(il$k!#$3lK$D$$$F$O=hM}<+BN$NA}Bgb"k,!"DSP $NFCD'$N0lDG$"$kJBNsL?Na$rMxMQ$7$F$$$J$$$3Hb$"$j!"2~A1$NM>CO$O$"$k$H;W$olk!#

6 *ReVolver*/**C40** $K4X$9$k9M;!

6.1 %7%9%F%`MWAG$K4X$9$k9M;!

ReVolver/C40 $OMM!9$JEE;RItIJ$rMQ$$$F<BAu$5

I=18: %T%/%;%kCM7W; ;=hM}; ~4VNCfNDL? .; ~4V$N3d9g

1PE $NC4Evslice ?t	%T%/%;%kCM7W; ;; ~4V	DL? .; ~4V$N3d9g
1slice	3.28μs	67.1%
2slice	4.80μs	45.8%
4slice	7.24μs	30.4%

$ l$ F$ $$ k! #$ =$ NI tI J$ NC f$ N< g$ J$ b$ N$ K$ D$ $$ F *ReVolver*/C40 $ G; HMQ$ 7$?$ 3$ H$ KB P$ 9$ kBEE v@ -! "$ *$ h $ S? 7$ 7$ /% 7% 9% F% `$ r9 =C [$ 9$ k> l9 g$ K; HMQ$ G$ -$ k$ H 9M$ ($ i$ l$ kI tI J$ K$ D$ $$ F9M; !$ 9$ k! #

6.1.1 *ReVolver*/**C40** $ G; HMQ$ 7$?I tI J$ K4 X$ 9$ k 9M; !

ReVolver/C40 $ G$ O=hM}$ N9 bB .2 =$ d! "@_7W$ N=@ Fp@ -$ r9 b$ a$ k$?$ a$ K! "MM! 9$ JI tI J$ rMQ$ $$ F<BAu$ 5 $ l$ F$ $$ k! #<B:]$ K: NMQ$ 5$ l$?$ =$ l$ i$ NI tI J$ NC f$ G! " <gMW$ JI tI J$ KB P$ 9$ k9M; !$ r$ N$ Y$ k! #

DSP $N: NMQ(A4% 9% F! <% 8)

ReVolver/C40 $ G$ O DSP(TMS320C40) $,3F %9% F! <% 8$ G< gMW$ J=hM}$ r9 T$ &C f? 4$ H$ J$ C$ F$ $ $ k! #*ReVolver*/C40 $ G$ 3$ NDSP $,: NMQ$ 5$ l$ F $ $$ kM}M3$ H$ 7$ F$ O! "< !$ N$ h$ &$ J$ b$ N$,$ "$ k! #

1. IbF O> .? tE @$ N> h; ;$ d2 C8 :; ;$,1 %5% $% /%k $ G9 T$ ($ k! #
2. $ "$ kAH9 g$ o$;$ NL ?Na$,1 %5% $% /%k$ GJBN s $ K<B9 T$ G$ -$ k! #
3. 100*MB/sec* $NE>AwB .EY$ N% P% 9$ r2 K\; } $ D! #
4. 20*MB/sec* $NE>AwB .EY$ r; }$ D Communication Port $ r6 K\; }$ D! #

8=: _*ReVolver*/C40 $ G$ O1 $ H3 $ K$ D$ $$ F$ O3F %9% F! <% 8$ G! "4 $ K$ D$ $$ F$ O< g$ KPCS $ HSS $ G MxMQ$ 5$ l$ F$ *$ j! "DSP $NF CD '$ r==J ,$ K@ 8$ +$ 7 $ F$ $$ k$ H9M$ ($ i$ l$ k! #$ 7$ +$ 7! "2 $ K$ D$ $$ F$ O C $ G=q$ $$?% W% m% 0% i% `$ r% 3% s% Q% $% k$ 9$ k$ @$ 1 $ G$ OMxMQ$ 9$ k$ 3$ H$,$ G$ -$ J$ $! #$ h$ C$ F8 =: _$ O JBN sL ?Na$ O$ 4$ /0 lI t$ G$ 7$ +; HMQ$ 5$ l$ F$ $$ J$ $! # $ 3$ NJBN sL ?Na$ r; HMQ$ 9$ k$ 3$ H$ G$ h$ j DSP $ N @ -G=$ r$ h$ j0 z$ -=P$ 7! "2 hLI@ 8@ .B .EY$ r8 ~> e$ 5 $;$ k$ 3$ H$,$ G$ -$ k$ H9M$ ($ i$ l$ k! #

FIFO %a%b% j$N: NMQ(RCS,PCS)

RCS $ H PCS $ N4 V$ N6 &M-%a%b% j$ H PCS $ N3F PCU $ N4 V$ NDSP 4VDL? .MQ$ K$ O FIFO %a%b% j (SN74ABT3611) $,: NMQ$ 5$ l$ F$ $$ k! #$ 3$ l$ O PCS $ G$ N=hM}$ NC Y$ l$ d! "3F PCU 4V$ N=hM}B . EY$ N: 90 [$ r5 [< }$ 9$ k$?$ a$ K: NMQ$ 5$ l$?$ b$ N$ G $ "$ k! #

8=: _! "RCS $ HPCS $ N4 V$ G$ O PCS $ N=hM}$,CY $ /! "$ ^$?3F PCU 4V$ G$ b! "Nc$ ($ P% \% j% e! <% `6u 4V$ rDL2 a$ 9$ k% T% /%;%k$ HDL2 a$ 7$ J$ $% T% /%;%k $ N4 V$ GB g$ -$ J=hM}B .EY$ N: 90 [$,H /@ 8$ 9$ k! #$ 3 $ l$ i$ N$ 3$ H$ +$ i FIFO %a%b% j$ N: NMQ$ OI ,MW$ G $ "$ C$?$ H9M$ ($ i$ l$ k! #

FPGA $N: NMQ(PCS,SS)

PCS $ G$ NAG ! "SS $ G$ NPT $ HVSG $ K$ O! "%3 %s% U% #% .%e% l! <% 7% g% s$ r7 +$ jJV$ 9$ 3$ H$ K$ h$ C $ FFbI t% m% 8% C% /$ N: F% W% m% 0% i% `$ ,2 ?EY$ G$ b2 D G=$ J FPGA(XC4010D) $ r: NMQ$ 7$ F$ $$ k! #$ 3 $ N; v$ K$ h$ j! "=@F p$ J@_7W$ ,2 DG=$ K$ J$ j! "$ ^$ ? *ReVolver*/C40 $ N% G% P% C% 0$ N2 aD x$ K$ *$ $$ F$ O% P %0$ NH /8 +$ KB g$ -$ /9W8 %$ 7$ ?! #RCS $ G$ b6 &M-%a %b% j$ ND 4D d$ K! "FPGA $ HF l$ 8$ h$ &$ K: F% W% m% 0 %i% `2 DG=$ J PAL(Programable Logic Array) $ rMxMQ$ 7$ F$ $$ k$,! "FPGA $ rMxMQ$ 9$ l$ P! "J# ?t$ N PAL $ K$ ^$?$,$ C$?@_7W$ r$ 9$ kI ,MW$,$ J $ /$ J$ j! "$ h$ j4 JC l$ J@_7W$,2 DG=$ K$ J$ C$?$ H; W $ o$ l$ k! #

$ 7$ +$ 7! "5.4.2@ a$ G$ b=R$ Y$?$ h$ &$ K! "PCS $ N AG $ N<B8 =$ N:]$ K$ O! ": #2 s: NMQ$ 7$?FPGA $ G $ O *ReVolver*/C40 $ GI ,MW$ J=hM}B .EY$ rF @$ k$ 3 $ H$,$ G$ -$ J$ +$ C$?! #$ ^$?8 =: _$ NAG $ G$ O$ *$ 3 $ J$ o$ l$ F$ $$ J$ $ MASK =hM}$ J$ I$ r$ *$ 3$ J$ & $ H$ 9$ l$ P! "$ h$ j CLB %j% =! <% 9$ NB ?$ $ FPGA $ rA *B r$ 9$ Y$ -$ G$ "$ C$?$ H9M$ ($ i$ l$ k! #

DRAM $N: NMQ(PCS)

PCS GO%\%/%;%kCM$r3JG<$9$k Volume Memory $K!"4MB $NDRAM $r:NMQ$7$F$$ $k!#$3$1$OPCS $,128 Bf9=@.$G!"512^3voxel $N6u4V$r07$&$3Hr9MN8$K$$$1$?5-21MFNL$G $"$k!#8=:_$N*Re Volver*/C40 GO==J,$J5-21 MFNL$H$$$($k!#

6.1.2 %7%9%F%`$N>.7?2=$K4X9k9M;!

Re Volver/C40 $G;HMQ$7$F$$$kDSP!"Memory!" FPGA Ey$NMWAG%G%P%$%9$O!"6aG/$GOh$j9b@-G= 2=$+$D>.7?2=$,?^i1$F$$$k!#$3$1$i:G6a$NMWAG %G%P%$%9$rMQ$$$?*Re Volver*/C40 $N@-G=$r0];}$7 DD>.7?2=9kJ}K!$r9M;!9k!#

%W%m%;%C%5 8=:_$OTMS320C40 H/iY$F10 G\ 0J>e$N@-G=$r;}C?%W%m%;%C%5$,EP>l7F$* $j!"$3$1$i$r:NMQ$9$1$P!"PCS GN%T%/%;%k CM7W;;;~4V$r==J,>.$5$/$9k3H,G-$k!# 7+7J$,$i!"1PE $"$?jN%a%b%j%P%s%II} (%i%s%@%`%"%/%;%9;~) $NI|B-$N$?$a!"9bB.$J HFMQ%W%m%;%C%5$rMQ$$$?>.7?2=$O:$FqG"$k!# $?$@$7!";k3Q$r@)8B9kEyKh$j%a%b%j%"%/ %;%9$N6I=j@-$r>e$2!"BgMFNL%-%c%C%7%e$rJ; MQ$9k3HG9bB.2=/>.7?2=$,?^$1$k2DG=@- $,;D$C$F$$$k!#

DRAM 8=:_GOMFNIE*KO!"512^3voxel J,$N%\ %/%;%k%G!<%?$r3JG<G-$kVolume Memory $,DIMM1 Kg$G9=@.2DG=G"k,!"A0=R$N%W %m%;%C%5$HF1MM$K%i%s%@%`%"%/%;%9$K4X7F $O!"*Re Volver*/C40 $N3+H/Ce<jEv;~$H$/$iYF $b?tG\DxEY$NB.EY8~>eG"$j!"*Re Volver*/C40 H7FI,MWH$5$1$k%a%b%j%"%/%;%9%P%s%II} $r1Kg$NDIMM $G<B8=$9k3HOI|T2DG=G" $j!"=>MhDL$j$N%P%s%/9=@.$,I,MWG"$k!#$? $@$7!"%a%b%j%"%/%;%9$N%Q%$%W%i%$%s2=$,2D G=G"kN$G!"%\%/%;%kCM$N%W%j%m!<%IKI, MWJ%"%I%l%97W;;$r4^$a$?%Q%$%W%i%$%s2=$K hkB.EY8~>e$O4|BT$G$-$k!#

FPGA :G?7$NFPGA $O!":GBg%2!<%H?t500000 %2!<%H!":GBg%f!<%6;HMQ2DG=%T%s?t448 K\!" :GB.%/%m%C%/<~GH?t200MHz $N@-G=$r;}CF $*$j!"FC$K%2!<%H?t$K4X7F$OHtLvE*$J8~>e G"$k!#

Re Volver/C40 $G;HMQ$7$F$$$k FPGA(XC4010D) $O!"$=$N%2!<%H?t$H%f!< %6;HMQ2DG=%T%s?t$K@)8B$5$1$k$?$a!"8=:_$O %\%/%;%kCM$N%W%j%m!<%I$K@1G0$7$F$$$k!#$7 $+$7PCS GN%T%/%;%kCM7W;;$O!"4pK\E*$K $O2C;;4o$H>h;;4o$,$"1P<B8=2DG=G"kN $G!"FPGA $G<BAu$G$-$k!#hC$FFPGA $,%T %/%;%kCM7W;;$H%\%/%;%kCM$N%W%j%m!<%I$NN> J}$N=hM}$N%Q%$%W%i%$%s2=KI,MWJ%2!<%H?t $r;}$C$F$$$1$P!"PE $HAG $N=hM}$rFPGA C1FH$G<BAu$9k3H,2DG=$H;W$o1k!#2C$(F3$N>19g%2!<%H?t$KM>M5$,$"1P!"A0=R$N %a%b%j%"%/%;%9$N%Q%$%W%i%$%s2=$rFPGA $G 9T$&3H$,$G$-$k!#hC$FFPGA $rMQ$$$k$3 HKhj!"%\%/%;%kCM$N%W%j%m!<%I$r4^a? %T%/%;%kCM7W;;$N%Q%$%W%i%$%s2=$KhkB.EY 8~>e$,2DG=G"kH9M$(i1$k!#

6.2 JBNs=hM}$K4X$9$k9M;!

Re Volver/C40 GO!"A4BNH7FN%^%/%m%Q%$ %W%i%$%s$+$i3F%9%F!<%8$G$NJBNs=hM}$^$G!"MM!9 $JJBNs=hM}<jK!$r;HMQ7J$,$i9bB.2=$r?^$C$F$$ $k!#$3NCfG!"%\%j%e!<%`%1%s%@%j%s%0=hM}$NCf ?4$HJC$F$$$k%T%/%;%kCM7W;;=hM}$NJBNs2=$K$D $$$F9M;!9k!#

$^$:!"%T%/%;%kCM7W;;$NJBNs=hM}J}<0$rJ,N`$9 k3HK9k!#

%T%/%;%kJBNs=hM} %9%/%j!<%s$rJ,3d$7!"%5%V%9%/ %j!<%sKh$K%W%m%;%C%5$r3djEvF$kJ}<0!#3F %W%m%;%C%5$G$O8eJ}Ej1F%"%k%4%j%:%`$Khj %T%/%;%kCM$N7W;;$rJBNs2=9k!#

%\%/%;%kJBNs=hM} 3F;k@~KBP9$k%\%/%;%kKh$K=h M}$rJ,3d$7!"%W%m%;%C%5$r3d$jEvFkJ}<0!#$3 $NJ}K!$b8eJ}Ej1F%"%k%4%j%:%`Kh$k!#

**%\%j%e!<%`JBNs=hM}** %\%j%e!<%`6u4V$rJ,3d$7!"3F %5%V%\%j%e!<%`$N=hM}$K%W%m%;%C%5$r3d$jEv $F$kJ}<0!#3F%W%m%;%C%5$O%5%V%\%j%e!<%`$r %9%/%j!<%s$KEj1F$7!"$=$N3F2hA|$rAH$_9g$o $;$k3HKh$j:G=*E*$J2hA|$rF@$k!#3NJ} K!$OA0J}Ej1F%"%k%4%j%:%`$Khk!#

0J>e$NJ}<0$r?^??$K<($9!#

%\%j%e!<%`%l%s%@%j%s%0$OH>F)L@I=<($r9T$&$?$a!";kE@$K6a$$=g$+$i$N%\%/%;%k$NJB$S$N=g=x$rJ]>Z$9$kI,MW$,$"$k!#%\%j%e!<%`JBNs=hM}GO!"3N=g=x$rJ]>Z$9kN$,:$FqG"$k!#$hCF%T%/%;%kCM7W;;$NJBNs2=$K$O!"%\%/%;%k$NJBSN=g=x$,J]>Z$G$-$k%T%/%;%kJBNs=hM}$+%\%/%;%kJBNs=hM}$NIAi+$,9M$(il$k!#

%T%/%;%kJBNs=hM}$N>l9g!"J?9TEj1F$JiP!"$"$i$+$8$a%T%/%;%kCM$r7W;;9k%\%j%e!<%`%G!<%?$r%-%c%C%7%e$J$I$KMQ0U$9$k$3$H$,$G$-!"$=$N>l9g9bB.$K%T%/%;%kCM$r7W;;$9$k$3$H$,$G$-$k!#$7$+$7!"1s6aK!$K$h$kEj1F$r9T$*$&$H$9$k$H;k@~J}8~$,0lDj$G$O$J$/!"$"$i$+$8$a%\%j%e!<%`%G!<%?$rMQ0U$9k3HO:FqG$"$k!#

hC$F%T%/%;%kJBNs$GPCS $HF1$8$3$H$r9T$&3H$r9M$(kH!"1 DNJ}K!H7FO6u4VA4BN$N%\%j%e!<%`%G!<%?$r3JG<$7$?%a%b%j$rA4PE $G6&M-$9$kI,MW$,$"$k!#$3$N>l9g%a%b%j%"%/%;%9$N6%9g$,Bg$-$JLdBj$H$J$k!#$b$&1 $D9M$($i$l$k$N$O!"3FPE $KA4%\%j%e!<%`%G!<%?$r;}$?$;$kJ}K!$G$"$k!#8=:_DRAM OFCK5-21MFNL$K4X$7$F@.D9$,Cx7/!"*ReVolver*/C40 GN512^3voxel 6u4V$NA4%\%/%;%kCM$N3JG<KI,MWJ32MByte $r1[$(F5iKBg$-$J5-21MFNLrbC?DRAM $b=P8=$7$F$$$k!#3N32MByte $NDRAM $r%\%j%e!<%`%a%b%j$H7FMxMQ7?>l9g$N%T%/%;%kCM7W;;;~4V$NM=B,$r0J2<$K9T$&!#

5.6@a$G!"%T%/%;%kCM7W;;$KI,MW$J%G!<%?$rAw<u?.9k$?$a$K2.20μs $,I,MW$G$"$k3H$,$o$+$C$?!#$3lO0.80μs $^$G2~A1$+2DG=$G$"$k3Hbo$+$C$F$$$k!#%T%/%;%kJBNs=hM}GO3FPE $G%T%/%;%kCM$r7W;;9k$?$a!"3NAw<u?.$O1 2s$G$h$$!#%\%/%;%k$N%W%j%m!<%I$r%Q%$%W%i%$%s2=$7!";k@~$NDL2a9k9YFN%\%/%;%kGN%\%j%e!<%`%G!<%?$N%"%/%;%9$,%T%/%;%kCM7W;;=hM}$K1#JC$5$l$k$H2>Dj$9$k$H!"%\%j%e!<%`6u4V$,$512^3$voxel!"PE512Bf$N>l9g!"{512 × (DL?.$r=|$$$?%T%/%;%kCM7W;;~4V) + 0.80}μs $G%T%/%;%kCM7W;;~4V$,5a$^$k!#$3$3$GDL?.$r=|$$$?%T%/%;%kCM7W;;~4V$O!"5.6@a$h$j1.08μs G"kN$G!"%T%/%;%kJBNs$Khk1pixel $N%T%/%;%kCM7W;;~4V$O553.76μs $HM=A[$5lk!#1PE $NC4Ev%T%/%;%k?t$O512pixel JN$G!"M}A[E*$J>l9gGO1 %U%l!<%`$N=hM}$,283.53ms $G=*$ok3HKJk!#D^j3lO*ReVolver*/C40 H/iYkHLs1.6 G\[5]$N@-G=$r;}D3HKJk!#

7+$7!"$3$NJ}K!$G*ReVolver*/C40 Nh$&$K3%9%F!<%89=@.K9kN$ONI$$J}K!GO$J$$!#hC$F;k@~@8@.$b%7%'!<%G%#%s%0$bF1$8PE $G9T$&3H$,I,MW$G$"$k!#$^$?!"2hA|=PNON?aK3FPE $+$i%G!<%?$r=8$aJ1lPJi$J$$$N$G!"512 8D $NPE $r;HMQ$9k3Hb8=<BE*GO$J$$!#3N%7%9%F%`$r8=<BE*$JbNK9k?aK$O!"PE64 Bf 0i$$$,E,EvG"$k!#$D$^$j8=:_;HMQ7F$$$kPE hj8 G\0J>e$N@-G=$r;}$D%W%m%;%C%5$rMxMQ9lPh$$$3HKJk!#7+7=$N>l9g6.1.2@a$G$b=R$Y$?$h$&$K!"%a%b%j%P%s%II}$,ITB-$9kH9M$($ilk!#hC$F!"*ReVolver*/C40 $G9T$C$F$$$k=hM}$r%T%/%;%kJBNs=hM}$G9T$&$3HO8=<BE*GO$J$$!#hC$F%\%/%;%kJBNs=hM}$rMQ$$$? *ReVolver*/C40 $N%"!<%-%F%/%A%c$NBEEv@-$,<($5l?!#

7 $*$ojK

K\9FK*$$$F!"%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5!*ReVolver*/C40 K*1k2hLL@8@.B.EY$NI>2A$K$D$$$F=RY?!#

ReVolver/C40 $O2J3X5;=Q7W;;$N2D;k2=$d!"0eNEJ,Ln$K$*$1$k?MBN%G!<%?$N2D;k2=JIKI,MWJ!"H>F)L@%\%j%e!<%`$NI=<(!"1s6aK!$K$h$k2hA|@8@.!"9bB.IA2h$H$$$&3 $D$NMW7o$rK~B-$9$k$?$a$K!"%l%$%-%c%9%F%#%s%0K!$N:NMQ!"%5%s%W%j%s%0J}K!$NC1=c2=!"%P%s%/%3%s%U%j%/%H$N$J$$%a%b%j9=@.$H$$$&%"%W%m!<%A$r9M$($?!#$5$i$K*ReVolver*/C40 $G$O%\%j%e!<%`%l%s%@%j%s%0=hM}$r;k@~@8@.!"%T%/%;%kCM7W;;!"$*$h$S%7%'!<%G%#%s%0$H$$$&3 DN=hM}Ko$1!"$3li$N=hM}$KBP7FHEMQ$NDSP $rMQ$$$k3HKhCF=@Fp$J=hM}$r9T$&$3Hr2DG=K7$F$$$k!#

$^$?!"*ReVolver*/C40 $OJBNs7W;;5!$G$"$k!#*ReVolver*/C40 $O!"A4BN$H7F;k@~@8@.%9%F!<%8(RCS)!"%T%/%;%kCM7W;;%9%F!<%8(PCS)!"%7%'!<%G%#%s%0%9%F!<%8(SS) $H$$$&3 DN%9%F!<%8Kh$j%\%j%e!<%`%l%s%@%j%s%0=hM}$r9T$&!#$3$N3 $D$K$o$1$i$l$?%9%F!<%8$G$O!"=hM}$r%U%l!<%`$4HK%Q%$%W%i%$%s=hM}9k3H$G9bB.2=$r?^CF$$$k!#$^$?3F%9%F!<%8GbMM!9$JJBNs=hM}$,

---

[5] PE DL?.;~4V$,:GC;$N>l9gH/iY$F$$$k!#

9Tol$F$$$k!#

:#2s!"3liN3DN=hM}$r9T$&$?$a$N3F%9%F!<%8$N4pHD$r@_7W$*hS<BAu$7!"$=l>lK$D$$$F$N2hLI@8@.B.EY$NI>2A$r9T$C$?!#$^$?$=li$N%9%F!<%8$r@\B3$7!"Re Volver/C40 $N%5%V%;%C%H$H7FF0:n5;!"$=$l$r4p$K7?!"Re Volver/C40 K*1k2hLI@8@.B.EY$NI>2A$r$*$3JC$?!#$=$N7k2L!"2hLI%5%$%:: 128^2 pixel!"%\%j%e!<%`6u4V%5%$%:: $128^3$!"%T%/%;%kCM7W;;%9%F!<%8$G$NDSP Bf?t128Bf$G!";k@~@8@.%9%F!<%8$G$O35.14frame/s!"%T%/%;%kCM7W;;%9%F!<%8$G$O18.61frame/s!"%7%'!<%G%#%s%0%9%F!<%8$G$O24.50frame/s $N@-G=$,$"$k$3$H$,$o$+$C$?!#$^$?Re Volver/C40 $N2hLI@8@.B.EY$O!"Re Volver/C40 $G=hM}2DG=$J$9$Y$F$N2hLI%5%$%:$H%\%j%e!<%`6u4V%5%$%:$G%T%/%;%kCM7W;;%9%F!<%8$,N'B.$9k3H,o+C?!#$^$?3NB.EY$O!"3FMWAG4V$NDL?.$G@)8B$5lF$*$j!"3NDL?.B.EY$r2~A1$9k3HKhj!"Re Volver/C40 $N2hLL@8@.B.EY$r8~>e5;k3H,G-$k!#

8=:_GO3F%G%P%$%9$NH/E8$,Cx$7$/!"ReVolver/C40 $,@_7W$5l?;~K/iYkH$+$J$j@-G=$,8~>e7F$$$k!#$=$Nh&$J%G%P%$%9NCfG$bFPGA $rPE H7$F;HMQ$9k3HKhC$F!"8=:_$N Re Volver/C40 hj$b5,LO$r>.5/%3%9%H$r2<$2J,ibF1MM$N@-G=$,$@$;kbN,3+H/G-kH;Wol$k!#

<UK-

K\8&5f$N5!2q$rM?$($F$/$@5C$?!"IYED bC<#65<x$K?<$/46<U$N0U$rI=$7$^$9!#

?t!9$NM-MQ$J8f;XF3!"8f0U8+$rD:$$$?!"?9bC0lO:=u65<x!"8^Eg@5M5=u<j$K?4$+$i46<UCW$7$^$9!#

K\8&5f$N6&F18&5f<T$G$"$k=EED Bg=u;arO8a!"%3%s%T%e!<%?9)3X9V:B7W;;5!%"!<%-%F%/%A%cJ,Ln$N=t;a$K46<UCW7^$9!#

;29MJ88%

[1] Arie Kaufmann(Lu!F#Be01@.)!%\%j%e!<%`%S%8%e%"%i%$%<!<%7%g%s35O@, PIXEL,No.116

[2] UtGOM:<!!%\%j%e!<%`%1%s%@%j%s%0@lMQJBNs7W;;5!Re Volver/C40 $N%"!<%-%F%/%A%c, JBNs=hM}%7%s%]%8%&%`JSPP '94 H/I=O@J8(1994)

[3] UtGOM:<!!%\%j%e!<%`%1%s%@%j%s%0@lMQJBNs7W;;5!Re Volver/C40, JBNs=hM}%7%s%]%8%&%`JSPP '95 H/I=O@J8(1995)

[4] 6b4nET!;k3P@)8B%T%/%;%kJBNs=hM}Kh$k%\%j%e!<%`!&%1%s%@%j%s%08~$-$ND69bB.@lMQJBNs7W;;5!$N%"!<%-%F%/%A%c, JBNs=hM}%7%s%]%8%&%`JSPP '96 H/I=O@J8(1996)

[5] 5HC+ D><y!"Re Volver/C40 $N@_7W5Z$S<BAu, JBNs/J,;6/6(D4=hM}$K4X$9$k!XP$N9q!Y%5%^!<!&o!<%/%7%g%C%W SWoPP 0$AI '97 H/I=O@J8(1997)

[6] F#862m9(!3,AX3J;R%\%j%e!<%`%G!<%?$N<B;~4V2D;k2=, !VO%$%Q%U%)!<%^%s%9!&3%s%T%e!<%F%#%s%0$H%"!<%-%F%/%A%c$NI>2A!W$K4X$9$kKL3$F;%o!<%/%7%g%C%W(HOKKE-98) H/I=O@J8 (1998)

[7] %H%i%s%8%9%?5;=QSPECIAL No.31 FC=8 4p AC$+$i$N%S%G%*?.9f=hM}5;=Q

[8] :mEg7IG7, @>_7Dg<!, @u86=EIW 6&Cx!JBNs ?^7A=hM}

[9] CfEh@5G7, @n9g7E 6&Cx!%0%i%U%#%/%9$H%^%s%^%7%s%7%9%F%`

[10] :Y1)<B: 0eMQ2hA|7WB,(1996)

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graphics Workshop on Graphics Hardware, August 1995, pp. 123-130

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A FbIt;qNA

Re Volver/C40 $K4X$9$kFbIt;qNA$N%j%9%Hr3$3$K<($9!#

- UtGOM:<!!%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5!-*Re Volver*/C40- , =$;NO@J8, 5~ETBg3X (1995)
- K\ED =SG7 !%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5! *Re Volver*/C40 $N%l%$%-%c%9%F%#%s%0%9%F!<%8$N@_7W, 5~ETBg3XFCJL8&5fJs9p=q (1996)
- LZCf 0lGn !'*Re Volver*/C40 $N%l%$%-%c%9%F%#%s%0%9%F!<%8$N<BAu$HI>2A, 5~ETBg3XFCJL8&5fJs9p=q(1997)
- Cf;3 L@B' !%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5! *Re Volver*/C40 $N%T%/%;%kCM7W;;%9%F!<%8$N@_7W, =$;NO@J8, 5~ETBg3X(1996)
- 2.LnM'N4!%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5! *Re Volver*/C40 %7%'!<%G%#%s%0%9%F!<%8;EMM=q, 5~ETBg3X(1995)
- 2.Ln M'N4 !%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5! *Re Volver*/C40 $N%7%'!<%G%#%s%0%9%F!<%8, 5~ETBg3XFCJL8&5fJs9p=q(1995)
- LZLJK'9T!%\%j%e!<%`%l%s%@%j%s%0@lMQJBNs7W;;5! *Re Volver*/C40 $N%7%'!<%G%#%s%0%9%F!<%8$N@_7W, 5~ETBg3XFCJL8&5fJs9p=q(1996)
- 5HC+D><y !'*Re Volver*/C40 $N%7%'!<%G%#%s%0%9%F!<%8$N@_7W$H<BAu, 5~ETBg3XFCJL8&5fJs9p=q(1997)
- =EEDBg=u!*Re Volver*/C40 $N%7%9%F%`%3%s%H%m!<%k%f%K%C%H, 5~ETBg3XFCJL8&5fJs9p=q(1998)

B 3F%9%F!<%8$NPE $N%V!<%H

0J2<GO3F%9%F!<%8$NPE $N%V!<%HJ}<0$K$D$$$F=RYk!#

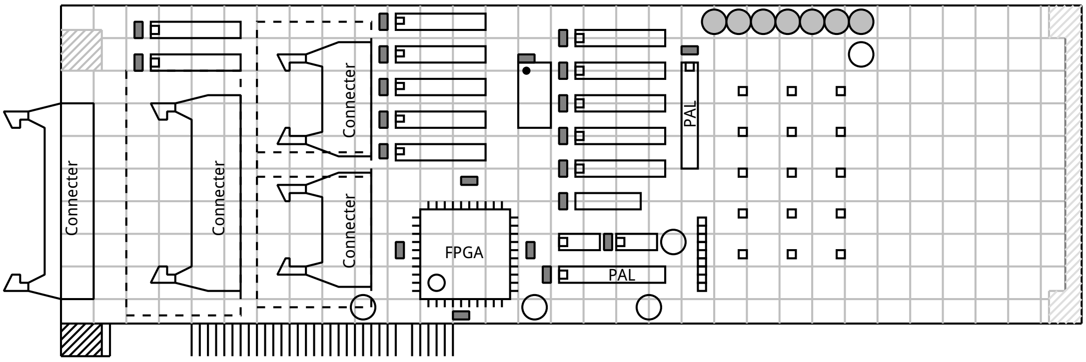
RCS : 6&M-%a%b%j%V!<%HJ}<0 SCU $,RCS HN6&M-%a%b%jG"$kView Buffer $KRCS $N%V!<%H%W%m%0%i%`$r%i%$%H$9$k!#RCS $N3FPE $OView Buffer $+$i%V!<%H%W%m%0%i%`$r%j!<%I9k!#PE $N%V!<%H<+BN$ORCS $N%j%;%C%H$,2r=|5l$?$H$-$K9Tol$k!#$3$NJ}K!$GRCS Fb$NA4$F$NPE $N%V!<%H$r9T$&$3H,G-$k!#

PCS : C`<!E*<+8JJ#@=%V!<%HJ}<0 PCS $OPE $NDL?.%]!<%H$rMQ$$$F%V!<%H$r9T$&!#$^$:SCU $OPCS $N%V!<%H%W%m%0%i%`$rPCS $N@hF,$NPE $KE>Aw$9$k!#%V!<%H$r=*$($?@hF,$NPE O=$N%V!<%H%W%m%0%i%`$N%3%T!<$r<!$NPE $KE>Aw$9$k!#$3lr;DjNPE $,=g$K7+jJV9$3$HKhCFPCS FbN9YF$NPE $N%V!<%H$,40N;9k!#

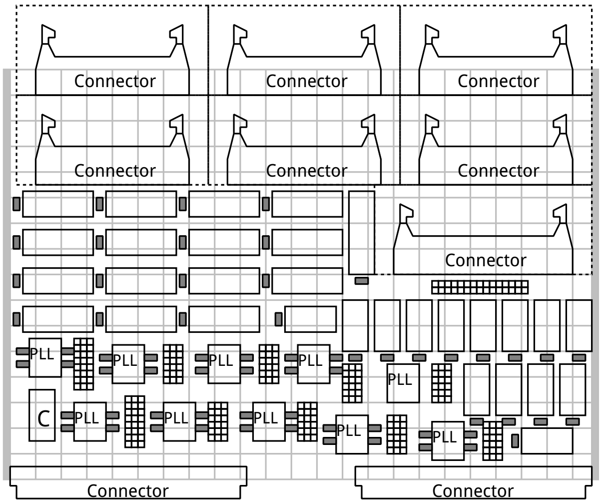
SS : **PCS** %P%$%Q%9+C`<!E*<+8JJ#@=%V!<%HJ}<0 SS Fb$NPE $N%V!<%H$O!"PCS Fb$NA4PE $N%V!<%H40N;$N8e$K9T$o$l$k!#SCU $OSS $N%V!<%H%W%m%0%i%`$rPCS $N@hF,$NPE $KE>Aw$9$k!#%V!<%H$N=*oC$?PCS $N3FPE $O!"SS $N%V!<%H%W%m%0%i%`$r$=$N$^$^<!$NPE $KE>Aw$9$k!#PCS $N:G8e$NPE $O$=$N%W%m%0%i%`$rSS $N@hF,$KE>Aw9k!#$"$H$OPCS $N>l9g$HF1MMG"$k!#

C 3F4pHD$N%l%$%"%&%H

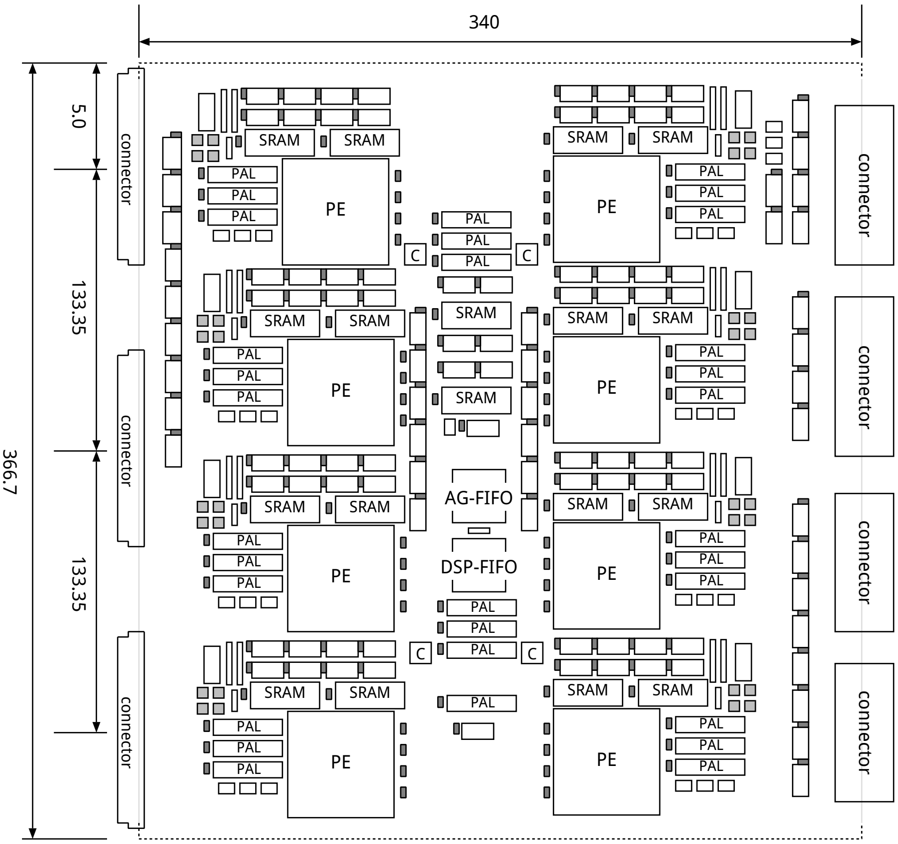
3F4pHD$N%l%$%"%&%H$r0J2<$K<($9!#



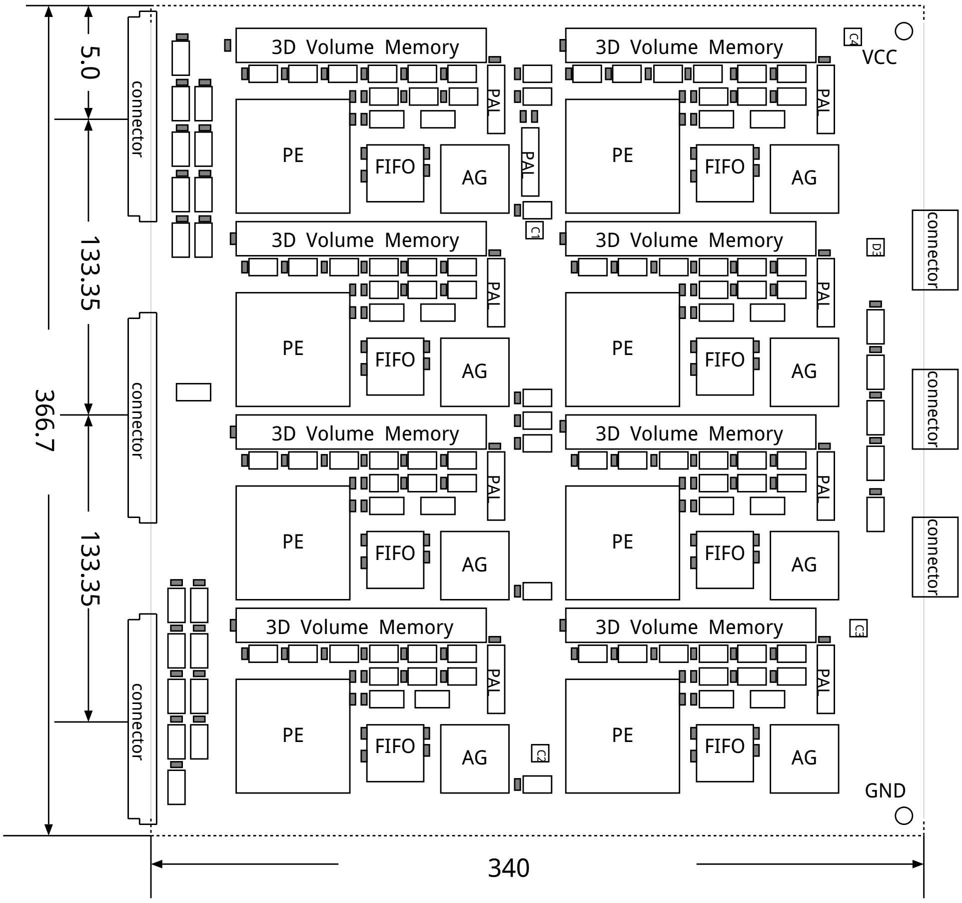
?^17: SCU %a%$%s%\!<%I$N9=@.



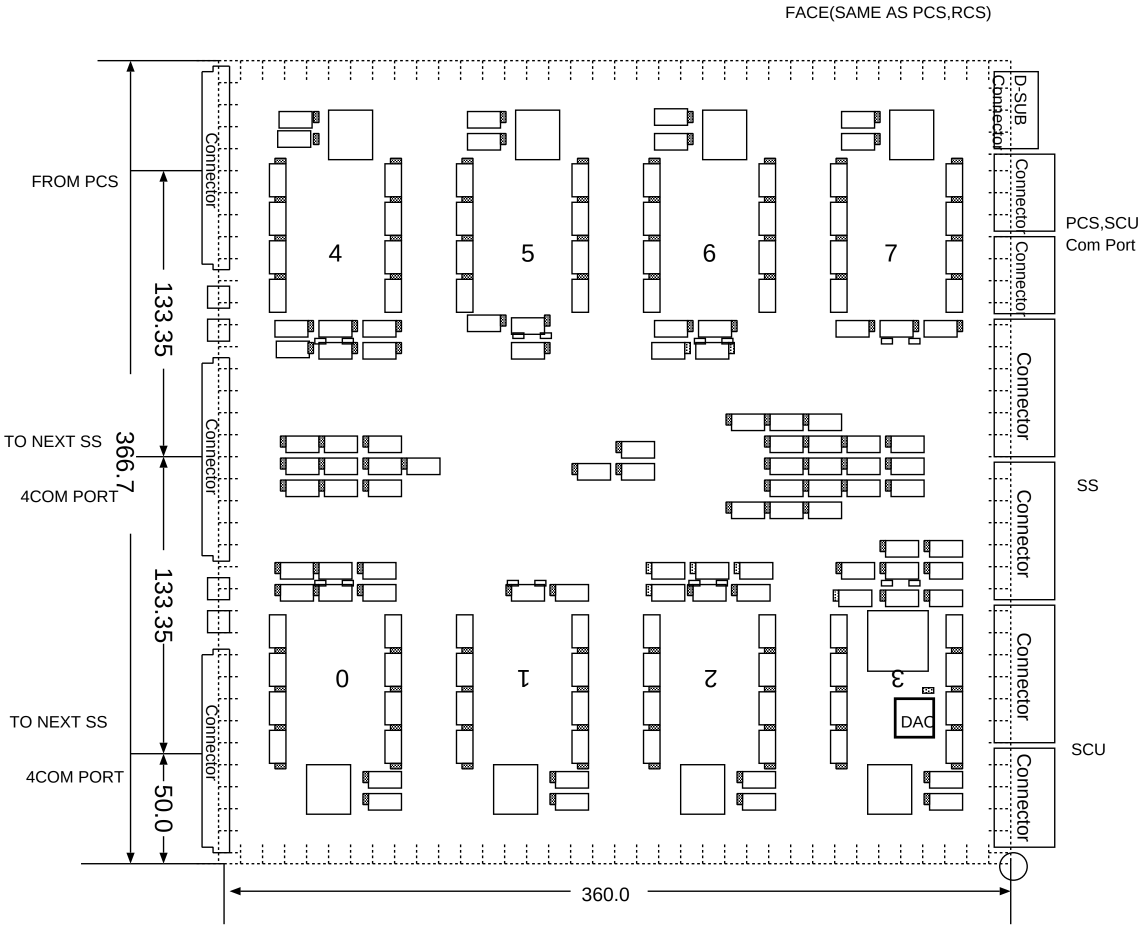
?^18: SCU %5%V%\!<%I$N9=@.



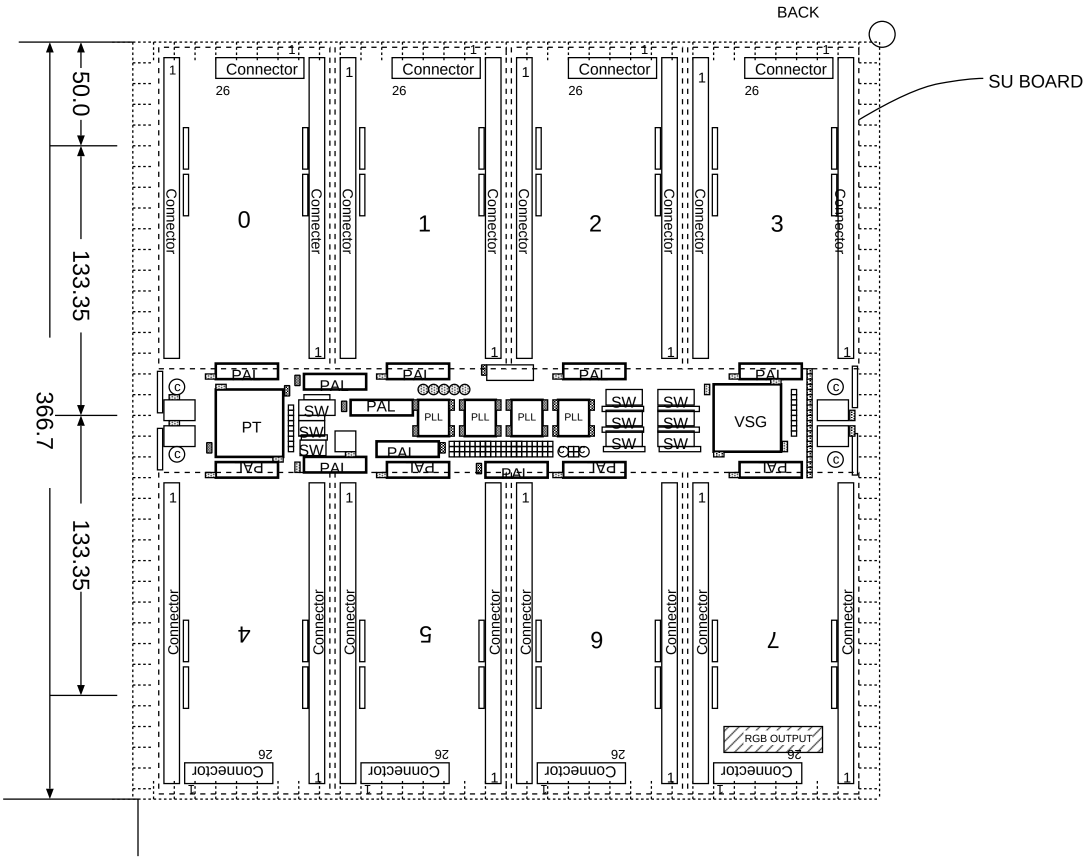
?^ 19: RCS 4pHD$N%1%$%"%&%H



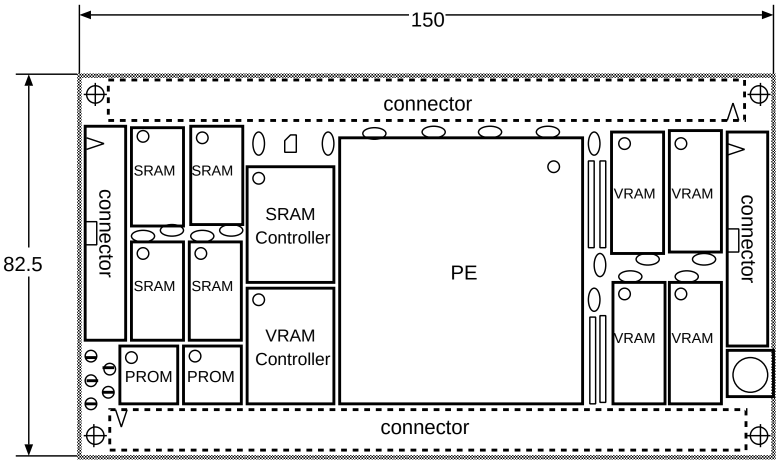
?^20: PCS 4pHD$N%1%$%"%&%H



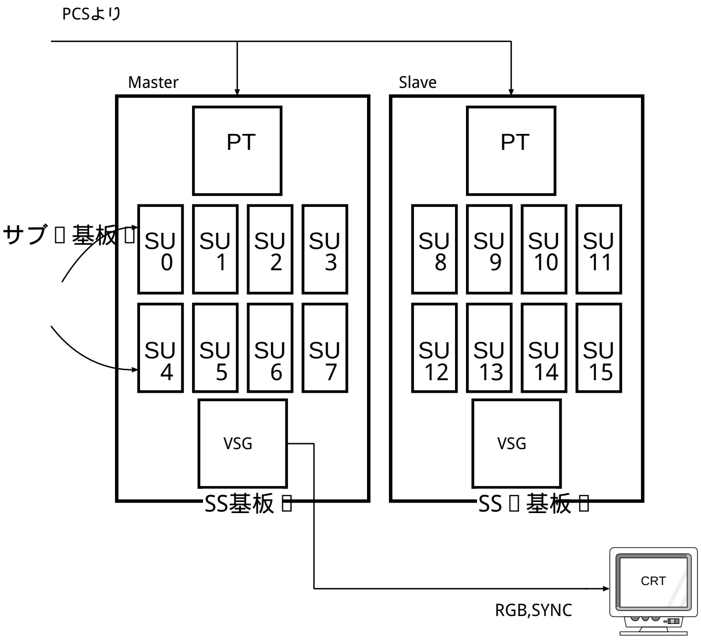
?^ 21: SS 4pHD$N%1%$%"%&%H(I=)



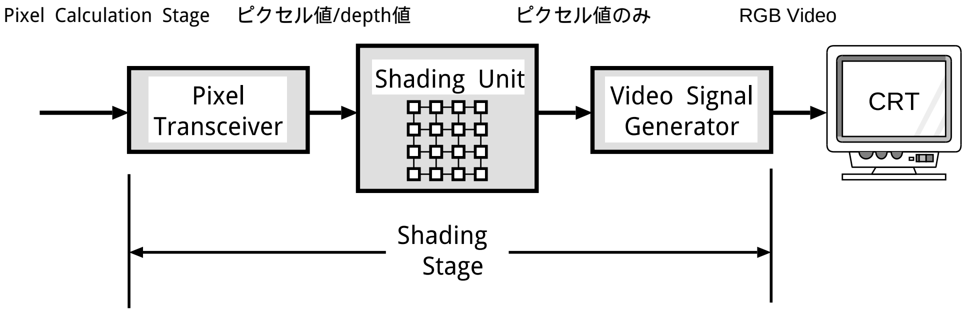
?^ 22: SS 4pHD$N%1%$%"%&%H(N")



?^ 23: SU 4pHD$N%1%$%"%&%H



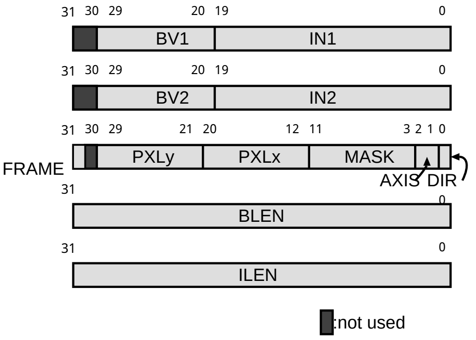
?^24: SS 4pHD@_7W

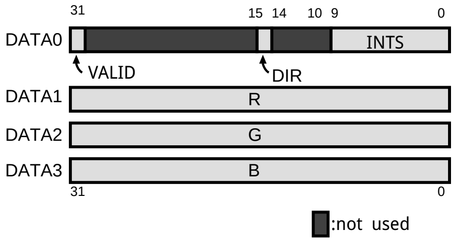


?^25: Shading Stage $NA4BN9=@.

I=19: AG bus $rN.$l$k%G!<%?

=gHV	%G!<%?L>	2r@b
1	IN1,BV1	%\%/%;%k$NF~<ME@$N y :BI8$H4pK\%Y%/%H%k
2	IN2,BV2	%\%/%;%k$NF~<ME@$N z :BI8$H4pK\%Y%/%H%k
3	FRAME,MASK	%U%l!<%`%S%C%H, %5%s%W%j%s%03+;O0LCV
	AXIS,DIR	<g<4L>, <g<4J}8~
	PXL.x,PXL.y	%9%/%j!<%s:BI8r"io$9
4	BLEN	4pK\5wN%(;k@~%Y%/%H%k$N4pK\5wN%) $rI=$o$9
5	ILEN	=i4 |5wN%(;kE@$+$i!";k@~%Y%/%H%k$,%\%j%e!<%`6u4V$KF~<M7?E@$^$G$N5wN%) $rI=$o$9





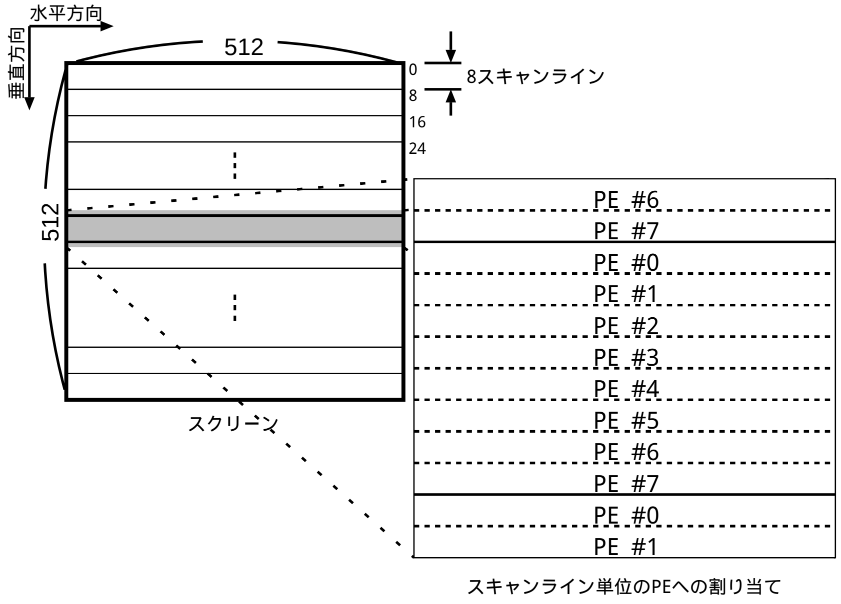
?^ 27: DFIFO_BUS $+$i<u$1<h$k%G!<%?$N%U%)!<%^%C%H

?^ 26: DAG_BUS $+$i<u$1<h$k%G!<%?$N%U%)!<%^%C%H

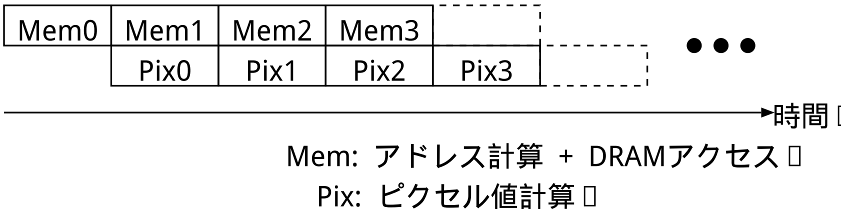
?^ 28: %9%F!<%84V$KN.$1$k%G!<%?$N%U%)!<%^%C%H

I=20: DSP bus $rN.$1$k%G!<%?

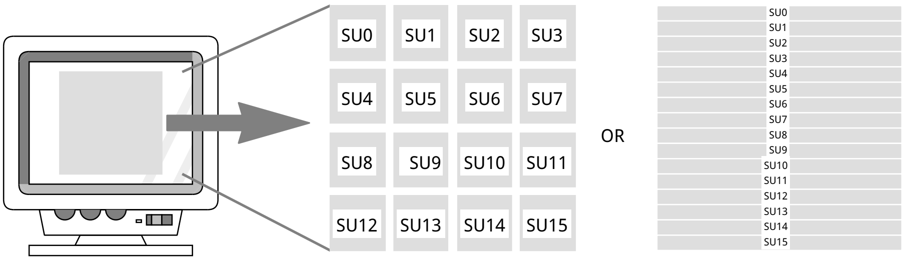
=gHV	%G!<%?L>	2r@b
1	VALID,DIR INTS	M-8z%S%C%H, <g<4J}8~ 8rE@:BI8(;k@~$+$i0lHV6a$$L5?'F)L@GJ$$ %\%/%;%k$rI=$o$9)
2	R	%T%/%;%kCM$N@V@.J,(float)
3	G	%T%/%;%kCM$NNP@.J,(float)
4	B	%T%/%;%kCM$N@D@.J,(float)



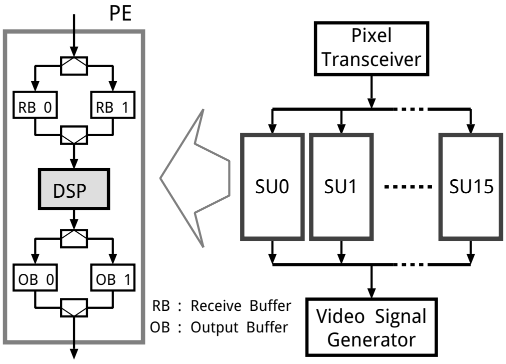
?^ 29: %9%/%j!<%sJ,3d



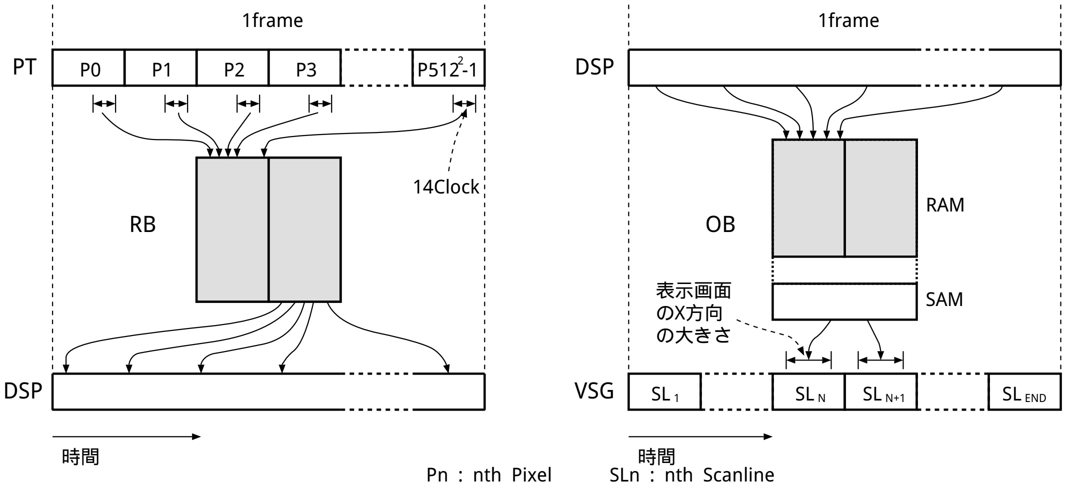
?^ 30: %\%/%;%kCM$N%W%j%m!<%I$NMM;R



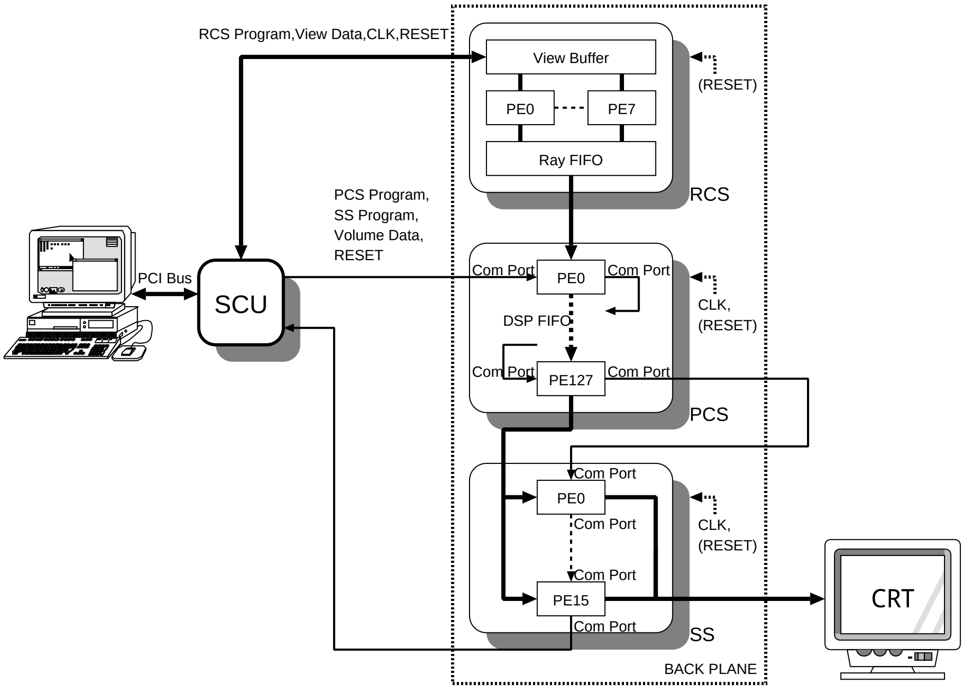
?^ 31: 2hLL$NJ,3d



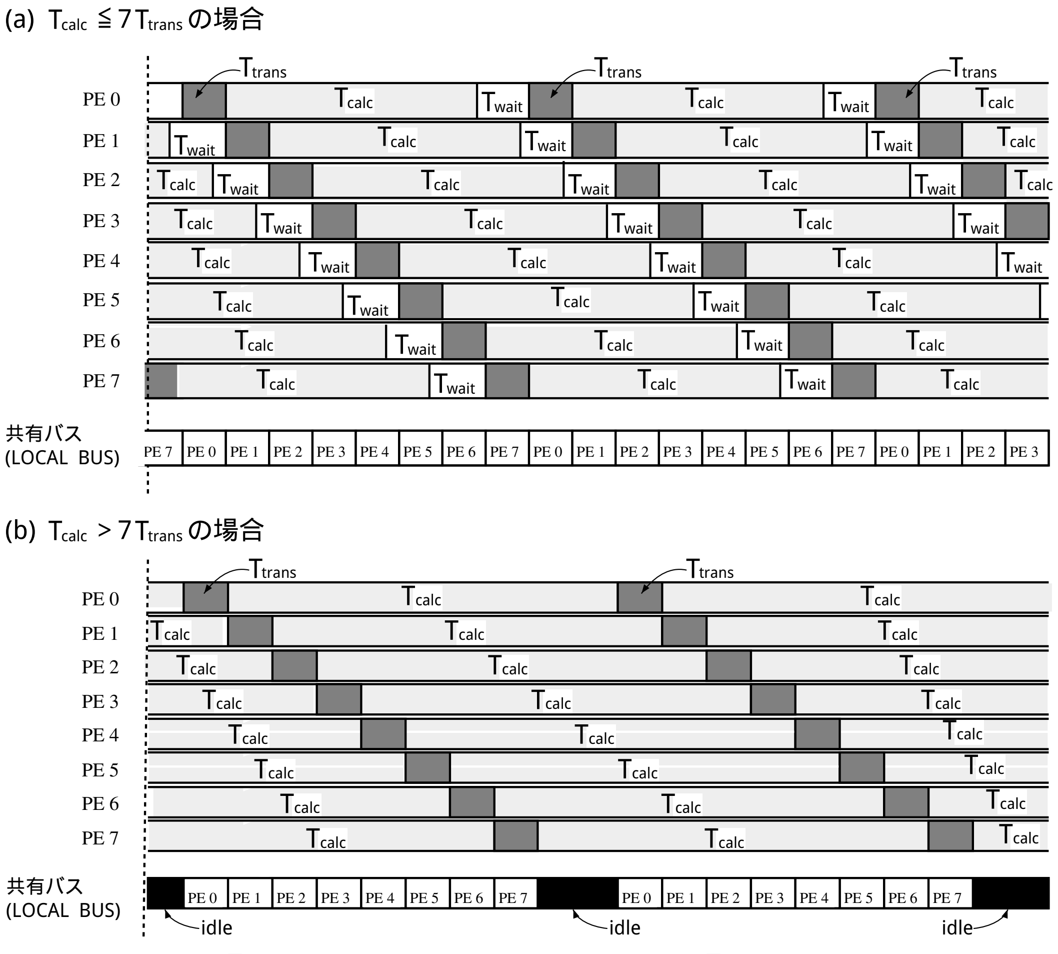
?^ 32: Shading Unit(SU) $N9=@.



?^33: RB $HOB $N%"%/%;%9J}K!$N0c$$

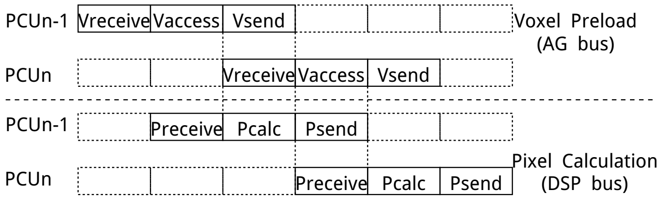


?^34: *ReVolver*/C40 Fb$N%G!<%?$H%W%m%0%i%`$NN.$l



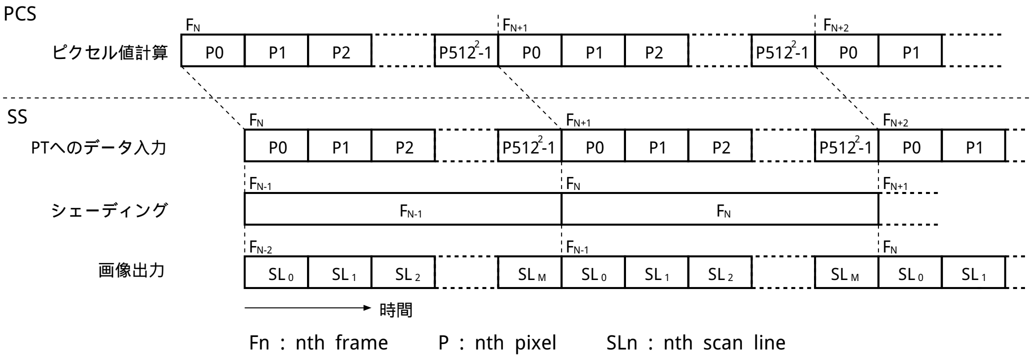
(注) T_{calc} 視線データ生成 T_{trans} 視線データの転送 T_{wait} Ray FIFO Buffer のアクセス待ち

?^35: ;k@~@8@.=hM}$H;k@~%G!<%?$NE>Aw

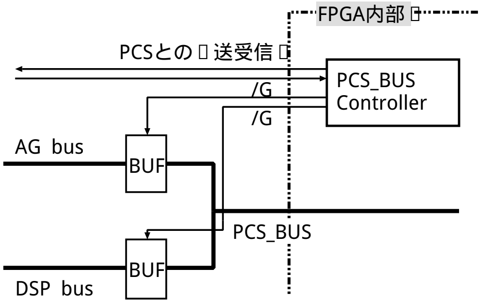


Vreceive : AG busを介した前のPCUからのデータの受信
Vaccess : DRAM へのボクセル値のアクセス
Vsend : AG busを介した次のPCUへのデータ送信
Preceive : DSP busを介した前のPCUからのデータ受信
Pcalc : ピクセル値計算(通信を含まない)
Psend : DSP busを介した次のPCUへのデータ送信

?^36: %T%/%;%kCM7W;;$H%W%j%m!<%I$N%Q%$%W%i%$%s$NMM;R



?^ 37: SS $N%Q%$%W%i%$%s=hM}



?^ 38: PCS $HPT $rN.$l$k2 K\$N%P%9$N@)8f