D6JBNs7W;;5!JUMP-1 K*1k
J,;66&M-%a%b%j4IM}$N<BAu$H$=$NI>2A
Evaluation for Implementation of Distributed Shared Memory Management of the Massively Parallel Processor JUMP-1

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J?@.11G/27n12F|

Abstract

CC-NUMA 7?JBNs7W;;5!$N<B8=$K$*$$$F$O!"J,;66&M-%a%b%j (DSM: Distributed Shared Memory) 4IM}$r9T$&5!9=$N<BAuJ}<0$,=EMW$J0LCV$r@jak!#

2f!9$,8=:_3+H/$7$F$$$k CC-NUMA 7?D6JBNs7W;;5!JUMP-1 GO!"%/%i%9%?9=@.$r:NMQ$7F*$j!"%3%R!<%l%s%9@)8f$r!"%/%i%9%?Fb%-%c%C%7%e%a%b%j4V!"%/%i%9%?$KJ,;6G[CV$5l?<g5-21(%/%i%9%?%a%b%j) 4V$N2CJ3,$K3,AX2=7F$$$k!#

%/%i%9%?4V%3%R!<%l%s%9@)8fGO!"=hM}$NJ#;($5$d;EMM$NJQ99$9$KBP9k=@Fp@-$,I,MW$G$"$k!#$=$N$?$a JUMP-1 GO DSM 4IM}@lMQ%W%m%;%C%5 MBP-light $r3+H/$7!"%W%m%0%i%`%Y!<%9$G%/%i%9%?4V%3%R!<%l%s%9@)8f$r9T$&$3$H$G!"@)8f$N=@Fp@-$H9bB.@-$NN>N)$r?^$C$F$$$k!#MBP-light $O%a%b%j%"%/%;%9$,%/%i%9%?Fb$KJD$8$F$$$J$$$H$-$K5/F0$5$l!"DSM 4IM}%W%m%0%i%`$,<B9T$5lk!#

MBP-light $O%Q%1%C%H$r9bB.$K=hM}$9kI,MW,$"$k$?$a!"%Q%1%C%H3JG<@lMQ$N%P%C%U%!PBR (Packet Buffer Register) $,MQ0U$5lF$*$j!"PBR A`:nN?aN@lMQ$NL?Na$,Hw$($ilF$$$k!#3lKh$j%Q%1%C%H$NJ,@O!":n@.JI$N=hM}$r=@Fp$K9T$&3H$,$G$-$k!#

K\8&5fGOMBP-light >e$G<B9T$5$;$kDSM 4IM}%W%m%0%i%`$N%W%m%H%?%$%W$N3+H/$r9T$C$?!#$^$?!"$=$N%W%m%0%i%`3+H/$K;HMQ$9$k!"MBP-light $rBP>]$H7?C %3%s%Q%$%i$N<BAu$r9T$C$?!#C 8@8l$G%W%m%0%i%`3+H/$r9T$$!"%3%s%Q%$%i$K:GE,2=$5$;$k$3$H$G!"%W%m%0%i%`3+H/$N@8;:@-$N8~>e$H DSM 4IM}$N9bB.2=$r?^$k$?$aG"$k!#

C %3%s%Q%$%i$N<BAuK*$$$F$OGNU C Compiler $r0\?"$9$kJ}K!$r:NC?!#MBP-light $O!"$=$NLr3d$+$iFC<l$JL?Na$,B?$/Hw$($ilF$$$k!#$=$liNL?Na$OC 8@8l$GD>$KI=8=$9kN$O:$FqG"$j!":#2s$O4X?t8FSGI=8=9kJ}K!$r:N$C$?!#C %3%s%Q%$%i$N<BAu;~$K$O!"L?Na$r4X?t8FSGI=8=9k3HKh$j<A$N0-$$L?NaNs$r=PNO$7$J$$$h$&$KCm0U9kI,MW$,$"C?!#

$^$?DSM 4IM}%W%m%0%i%`$K$*$$$F$O!"MBP-light $,=hM};~4V$NBg$-$/0[$J$k$h$&$J%Q%1%C%H$r07$&I,MW$,$"$k$3$H$+$i!"%Q%1%C%H=hM}$rM%@hEYIU$-$N%W%m%;%9$H$7$F4IM}$9$kJ}K!$r:N$C$?!#$=$N$?$aDSM 4IM}%W%m%0%i%`$O%W%m%;%94IM}AX$H!"%Q%1%C%H=hM}%W%m%;%9$N2 3,AX$G<B8=7?!#

:#2s<BAu7?DSM 4IM}%W%m%0%i%`$NI>2A$r9T$&$?aK!"VHDL $GO@M}9g@.2DG=$Jh&$K5-=R$5l?@_7W%G!<%?$rMQ$$!"Mentor Graphics <R$N VHDL %7%_%e%l!<%?!<qhsim v8.5_4.6c $rMQ$$$FL5Ii2Y>uBVGN%7%_%e%l!<%7%g%s$r9T$C$?!#$3$N7k2L!"F I$_=P$7MW5a$G$O922 %5%$%/%k!"99?7MW5aK*$$$F$O!"1 DN%/%i%9%?$G440 %5%$%/%k$N;~4V$,$+$+$k7k2LHJC?!#$3lO%"%;%s%V%i$G5-=R$5l?%W%m%0%i%`hj$bB?>/;~4VN+$+$k7k2LG"$k!#

$^$?%7%_%e%l!<%7%g%s7k2L$+$i!":#2s<BAu7?DSM 4IM}%W%m%0%i%`$r;HMQ$7$?>l9g$N%W%m%;%C%5$+$i$N%G!<%?$NJ?6QFI$_=P$7;~4V$r5a$ak3H,G-$?!#$=$N7k2L!"%-%c%C%7%e%R%C%HN($ND c2<$KH<

$$!"$+$JjN3d9g$GJ?6QFI$_=P$7;~4V$,A}2C9k 3H$,L@$i$+$HJC$?!#

:#2s<BAu7?%3%s%Q%$%i$K5/0x9k%5%$%/%k?t $NA}Bg$K$*$$$F$O!"$=$NItJ,$,%W%m%0%i%`Cf$GL@ 3N$G$"$C$?$?aK!"%3%s%Q%$%i$,2~A1$5$l$?>l9g $NM=A[=hM};~4V$r5aak3H$,$G$-$?!#$=$N7k2L!" %3%s%Q%$%i$N2~A1Kh$j:GBg10 ?t%$N9bB.2=$,$J 5l!"%"%;%s%V%i$G5-=R$5l?bNhj$b=hM};~ 4V$,B.$/$Jk3H,4|BT5l$k!#

It is important to decide the way to implement distributed shared memory (DSM) contoller on CC-NUMA type multiprocessor.

A massively parallel processor JUMP-1 takes a cluster structure. So JUMP-1 has two layers for coherence control. One is for conherence control between caches in a cluster, and the other is for the inter-cluster coherence control.

On the inter-cluster coherence control, the flexibility to the complication of the processing and the change of the specification is required. Therefore, we developed MBP-light, which is the processor exclusive to the DSM management. And the inter-cluster coherence control is composed of software which runs on MBP-light. This approach achieves both flexibility and performance. The inter-cluster memory access starts MBP-light and the DSM management program is run.

MBP-light is required to deal with packets at high speed. So MBP-light has special buffers called PBR (Packet Buffer Register). Packets are set in PBR. And MBP-light has some instructions for PBR. This structure makes it possible to analyze and make, for example, packets flexibly.

In this research, the DSM management program is implemented. And for this implement, the C compiler for MBP-light is developed. This reason is that the programs are developed in C languages in order to improvement the productivity, and optimizing the programs by the compiler helps the programs to be processed at high speed.

On the implement of the C compiler, we make a point of porting GNU C Compiler. MBP-light has special operations for its role. These operations are hard to be expressed directly by C language, so we make a point of expressing these operations by calling subroutines. This way may incur redundant sequence of operations. Therefore, on the implement of the C compiler, it is necessary to make the compiler not to output redundant sequence of operations

There are two types of packets that MBP-light must deal with. One is taken much time to manage, the other is not taken so much. So, in the DSM management program, the packet management is process with priority. This program is divided into process management and packet management process.

In order to evaluate the implemented DSM management program, the program is simulated with no load condition on qhsim v8.5_4.6c Mentor Graphics corporation with the data described VHDL which can be logic composition. As a result, it takes 922 cycles to manage read request packet. And it takes 440 cycles to manage update request packet in one cluster. This time is a little more than the time of the program developed in assembly language.

With the result of this simulation, we can formula the average read time from the processor. This result means that this average time increases at the big rate as cache hit rate decreases.

In the program, we can identify the place which is taken much time to executed caused by the compiler. So, we can formula the expected management time in case of improvement of the compiler. This result shows that we can expect that the management time will be 10 and some percent faster and this time will be faster than the time of program developed in assembly language when the compiler is improved.

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1 O8aK

CC-NUMA 7?JBNs7W;;5!$N<B8=$K$*$$$F$O!"J,;66&M-%a%b%j(**DSM**: Distributed Shared Memory) 4IM}$r9T$&5!9=$N<BAuJ}<0$,=EMW$J0LCV$r@jak!#3l$r40A4$K%O!<%I%&%'%"$G9=@.$9lP9bB.<B9T$,2DG=$G$"$k$,!"@_7W%3%9%H$,Hs>oKBg-$/$JC?$j!"DSM 4IM}J}<0$N=@Fp@-$rB;$&2DG=@-$,$"$k!#

2f!$O8=:_CC-NUMA 7?D6JBNs7W;;5!**JUMP-1** $r3+H/$7$F$$$k!#JUMP-1 GO!"%/%i%9%?9=@.$,:NMQ$5lF$*$j!"%3%R!<%l%s%9@)8f$r%/%i%9%?Fb$N4 DN%-%c%C%7%e%a%b%j4V!"%/%i%9%?%a%b%j4V$N2 CJ3,$K3,AX2=7F$$$k!#

%/%i%9%?Fb$N%3%R!<%l%s%9@)8f$O!"IQHK$K@)8fMW5a$,5/3k3H$+$i!"%9%L!<%WJ}<0$K4p$E$-%O!<%I%&%'%"$Khj9bB.$K9T$olk!#$=$lKBP7$F%/%i%9%?4V$G$O DSM 4IM}@)8fJ}<0$N=@Fp@-$d=hM}$NJ#;(5KBP1~9kI,MW$,$"k?$a!"%3%R!<%l%s%9@)8f$O%W%m%0%i%`%Y!<%9$G9T$olk!#3l$rC1$KHFMQ$N%W%m%;%C%5$rMQ$$$F<B8=7F$b!"I,MW$J=hM}G=NO$rF@$k3H$OF q$7$$!#$=$3$GJUMP-1 GO DSM 4IM}@lMQ%W%m%;%C%5**MBP-light** $r3+H/$7!"=@Fp@-$H9bB.@-$NN>N)$r?^$C$F$$$k!#

DSM 4IM}%W%m%0%i%`$O!"%7%9%F%`A4BN$N@-G=$N$?$a$K9bB.$K=hM}5lkI,MW,$"$k!#$=$N$?$a%W%m%0%i%`%3!<%I$O2DG=$J8B$j:GE,2=$5$l$F$$$k$3$H$,I,MW$G$"$k!#=>Mh!"$3$N%W%m%0%i%`$O%"%;%s%V%j8@8l$rMQ$$$F3+H/5lF-$?$?$a!"=J,$J:GE,2=$r9T$J$&$3HO:FqG$"$j!"3+H/$N@8;:@-$rK8$2$F$$$?!#

K\8&5fGO!"MBP-light >e$G<B9T$5$;$k DSM 4IM}%W%m%0%i%`$N%W%m%H%?%$%W$r3+H/$7$?!#$^$?!"$=$N%W%m%0%i%`3+H/$K;HMQ$9$k!"MBP-light $rBP>]$H7?C %3%s%Q%$%i$N<BAu$r9T$C$?!#K\9F$G$O!"$=$N<B9TB.EY$K4p$E$$$F<BAu7?DSM 4IM}$NI>2A$r9T$&!#

2>OGOBP>]HJ$k7W;;5!$G$"$k JUMP-1 $N35MW$H7F!"$=$N%/%i%9%?9=@.$H%3%R!<%l%s%9%W%m%H%3%k!"5Z$S MBP-light $N35MW$K$D$$$F=RYk!#3>OGO%W%m%0%i%`3+H/$K;HMQ$7$?C %3%s%Q%$%i$N<BAu$K$D$$$F=R$Y$k!#4>O$G$O:n@.$7$?%W%m%0%i%`KD$$$F=R$Y!":G8e$K5>OGO%W%m%0%i%`$N%7%_%e%l!<%7%g%s7k2L$+$i@-G=$NI>2A$H9M;!$r9T$&!#

2 JUMP-1 $N35MW

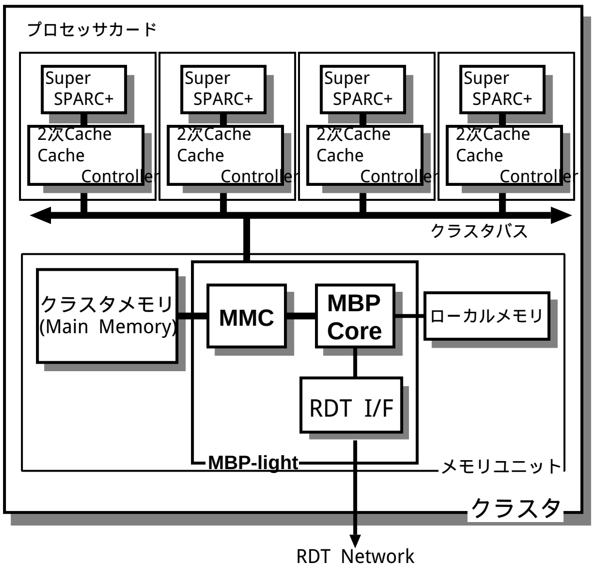
K\>OGO!"DSM 4IM}$NBP>]$HJk7W;;5!JUMP-1 $N9=@.$H!"$=$NDSM 4IM}J}<0KD$$$F=RYk!#

$=$N8e!"JUMP-1 K*$$$F!"DSM 4IM}%W%m%0%i%`$r<B9T$9$k@lMQ%W%m%;%C%5MBP-light KD$$$F=RYk!#

2.1 JUMP-1 $N9=@.

JUMP-1 $O%/%i%9%?$r1C10LH7!"$=$N4V$r RDT (Recursive Diagonal Torus)[1] $H8F$Plk%M%C%H%o!<%/Kh$jAj8_$K7k9g7?J,;66&M-%a%b%j7?D6JBNs7W;;5!G"$k!#

%/%i%9%?$N9=@.$r?^1$K<($9!#%/%i%9%?GO4DN%W%m%;%C%5%+!<%I$H!"%a%b%j%f%K%C%H$,%/%i%9%?%P%9$G7k9g$5lF$$$k!#



?^1: JUMP-1 $N%/%i%9%?9=@.

3FItJ,$N9=@.$O0J2<Nh$&$KJC$F$$$k!#

%W%m%;%C%5%+!<%I JUMP-1 $NMWAG%W%m%;%C%5$G$"$kSuperSPARC+ (1<!%-%c%C%7%e$r4^$`)!"30It2<!%-%c%C%7%e5Z$SCache Contoroller(0J2<!"CC H9$k) $+$i@.$k!#

CC $O%P%9%Y!<%9$N%9%L!<%WJ}<0$G%/%i%9%?Fb2<!%-%c%C%7%e4V$N%3%R!<%l%s%9@)8f$r9T$&!#IQHK$K@)8fMW5a$,$*3k$?$a!"CC $O%O!<%I%&%'%"$G9=@.5l9bB.<B9T5l$k!#

%a%b%j%f%K%C%H %/%i%9%?%a%b%j$H!"%/%i%9%?%a%b%j4V$N%3%R!<%l%s%9@)8f$r9T$&@lMQ%W%m%;%C%5MBP-light $+$i@.$k!#

%/%i%9%?%a%b%j$O!"%/%i%9%?$4HKJ,;66G[CV5l$?!"%7%9%F%`A4BN$N<g5-21$G$"$k!#$^$?!"B>%/%i%9%?%a%b%j$N%G!<%?$r;HMQ$9$k>l9g$N!"3<!%-%c%C%7%e$H$7$F$bMxMQ$5$l$k!#%/%i%9%?%a%b%j$NCf$K$O!"%7%9%F%`$NJ,;66&M-%a%b%j$N0lIt$H!"B>%/%i%9%?%a%b%j$N%-%c%C%7%e%3%T!<$NN>J}$,B8:_$7F*$j!"IU?o$9$k%?%0$KhC$F!"$=$N%G!<%?$N6&M->uBV$,<($5lF$$$k!#3<!%-%c%C%7%e$N@)8f$N>\:Y$O<!@a$G=RYk!#

$^$?!"MBP-light KD$$$F$O!"2.3@a$G>\:Y$J@bL@$9$k!#

2.2 JUMP-1 GN DSM 4IM}J}<0

%/%i%9%?FbGN%3%R!<%l%s%9@)8f$O CC KhCF!"%P%9%Y!<%9$N%9%L!<%WJ}<0$G9Tol$k!#$3lOMBP-light $G9T$olkDSM 4IM}$+$i$OIT2D;k$G$"$kNG3lKD$$$F$N@bL@$O9ToJ$$!#

0J2<!"%/%i%9%?4V%-%c%C%7%e%3%R!<%l%s%9%W%m%H%3%kKD$$$F=RYk!#

2.2.1 JUMP-1 K*1k%3%R!<%l%s%9%W%m%H%3%k

JUMP-1 GO!"$"$k%"%I%l%9KD$$$F!"%/%i%9%?Fb$KM-8z$J%G!<%?$r;}$D%/%i%9%?$O3<oN`$KJ,1ilk!#3l$r0J2<$K@bL@9k!#

Home %/%i%9%? Home %/%i%9%?$O!"$=$N%"%I%l%9$K$D$$$F6&M->uBV$r<($9%G%#%l%/%H%j$rJ];}$9$k%/%i%9%?$G$"$k!#Home %/%i%9%?$N%/%i%9%?%a%b%j$O!"$=$N%"%I%l%9$K4X$7$F!"B>%/%i%9%?$N3<!%-%c%C%7%eKBP9$k<g5-21$NLr3d$r2L$?$9!#B>%/%i%9%?$G3<!%-%c%C%7%e%_%9%R%C%H$,5/$3C?>l9g!"Home %/%i%9%?$KMW5a$,Aw?.5l$k!#$3NH$-%-%c%C%7%s%0$O%V%m%C%/(32Byte) C10L$G9T$olk!#DL?.$N=8Cf$rKI0?aKHome %/%i%9%?$O%"%I%l%9$4HKJ,;6$7$FG[CV5l$k!#

Renter %/%i%9%? Renter %/%i%9%?$O!"$=$N%"%I%l%9$K4X7FHome %/%i%9%?0J30$GM-8z$J%G!<%?$r;}$D%/%i%9%?G"$k!#

Owner %/%i%9%? JUMP-1 GO%*!<%J!<%7%C%W%W%m%H%3%k$,:NMQ$5lF$*$j!"G?7$N%G!<%?$r=jM-9k%/%i%9%?$,%*!<%J!<%7%C%W$r;}DH9k!#%*!<%J!<%7%C%W$r;}$D%/%i%9%?$rOwner

%/%i%9%?$H8F$V!#Owner %/%i%9%?$,$=$N%"%I%l%9$K4X9kFI$_=P$7MW5a$K1~Ez$9$k5AL3$r;}$D!#

Home %/%i%9%?$,:G?7%G!<%?$r=jM-9k>l9g$OHome %/%i%9%?$,Owner %/%i%9%?$r7s$M!"$=$l0J30$N>l9g$K$O:G?7%G!<%?$r;}$DRenter %/%i%9%?$,Owner %/%i%9%?HJ$k!#

JUMP-1 K*$$$F$O!"%G!<%?$r%/%i%9%?4V$G6&M-$9$k>l9g$K$O!"Home %/%i%9%?$N%/%i%9%?%a%b%jKOI,$:M-8z$J%G!<%?$,B8:_$9$k;EMM$HJC$F$$$k!#

%/%i%9%?4V$NDL?.$O%Q%1%C%H$r8r49$9k3HG9Tol$k!#%Q%1%C%H$O%X%C%@It1%U%j%C%H!"%G!<%?It4%U%j%C%H$+$i9=@.5l$k!#1%U%j%C%H$O64bit$G$"$j!"$^$?%?%02bit$,IU?o7F$$$k!#%G!<%?It$O1%V%m%C%/$KAjEv9k!#%?%0O=$N%U%j%C%H$N%G!<%?$NM-8z@-$r<(7F$$$k!#99?7MW5a%Q%1%C%HK*$$$F$O!"%?%0$Khj%V%m%C%/NCfG4Byte C10LGN99?7$,2DG=$G$"$k!#

%Q%1%C%HKh$kMW5a$ODL>o%V%m%C%/C10L$G9T$olk$,!"%Z!<%8C10L$N=hM}$b2DG=$G$"$k!#

<B:]$N%3%R!<%l%s%9@)8f$K$*$1$k%Q%1%C%H$NN.lO<!9`$G=R$Y$k!#

2.2.2 %3%R!<%l%s%9@)8f$NN.$l

%/%i%9%?4V$G6&M-$5l?%G!<%?KBP9$k%a%b%j%"%/%;%9$KH<$&!"0lO"$N>uBVA+0\5Z$S%G!<%?E>Aw$r%H%i%s%6%/%7%g%s$H8F$V!#%H%i%s%6%/%7%g%s$r3+;O$7$?!"$9Jo$A6&M-%G!<%?$KBP9k%a%b%j%"%/%;%9$r9T$C$?%/%i%9%?$r**Initiator** %/%i%9%?$H8F$V!#

0J2<!"E57?E*$J%H%i%s%6%/%7%g%s$G$"$kFI$_=P$7MW5a!"99?7MW5aK*1k%Q%1%C%H$NN.$lNNcr?^2!"3$K<($9!#

FI$_=P$7MW5a Ev3:%/%i%9%?$KM-8z$J%G!<%?$r=jM-$7$J$$%"%I%l%9XNFI$_=P$7MW5a$,5/$3C?>l9g(?^2;2>H)!#3NNc$OHome %/%i%9%?$,Owner %/%i%9%?$r7s$M$F$$$J$$>l9gG"$k!#

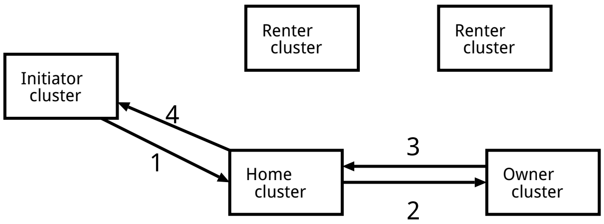
1. FI$_=P$7MW5a$r5/$3$7$?Initiator %/%i%9%?$O!"$=$N%"%I%l%9$NHome %/%i%9%?$KMW5a%Q%1%C%H$rAw?.9k!#

2. Home %/%i%9%?O=$NMW5a$KBP7F!"%G%#%l%/%H%j$r;2>H$7$FOwner %/%i%9%?$rC5$7,FI$_=P$7MW5a%Q%1%C%H$rAw?.9k!#

3. Owner %/%i%9%?O=$NMW5a$KBP7F!"%G!<%?rFI_=P$7!"Home %/%i%9%?$K1~Ez%Q%1%C%H$rAw?.$9$k!#

4. Home %/%i%9%?O=$N1~Ez%Q%1%C%H$rInitiator %/%i%9%?$KAw?.$9$k!#$3$N:]!"Home %/%i%9%?$N%/%i%9%?%a%b%jKb=q$-9~$_$,9T$olk!#

Home %/%i%9%?$,Owner %/%i%9%?$r7sMF$$$k>l9g$O!"Home %/%i%9%?$,%G!<%?rFI_=P$7!"Initiator %/%i%9%?$K1~Ez%Q%1%C%H$rAw?.$9$k!#



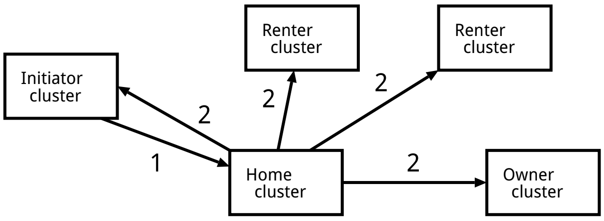
?^2: FI$_=P$7MW5aK*1k%/%i%9%?4VGN%Q%1%C%H$NN.$l

99?7MW5a Ev3:%/%i%9%?$K=q$-9~$_$,5/3jB>%/%i%9%?$b99?7$9$kMW5a$,5/3C$?>l9g(?^3;2>H)!#

1. 99?7MW5a$r5/$3$7$?Initiator %/%i%9%?$O!"$=$N%"%I%l%9$NHome %/%i%9%?$KMW5a%Q%1%C%H$rAw?.9k!#

2. Home %/%i%9%?O=$NMW5a$KBP7F!"%G%#%l%/%H%j$r;2>H$7$FRenter %/%i%9%?$rC5$799?7MW5a%Q%1%C%H$rAw?.9k!#$=$l$>$l$N%/%i%9%?$G%G!<%?$,99?7$5lk!#

3Nh&K9YF$N%H%i%s%6%/%7%g%s$,Home %/%i%9%?7PM3$G?J9T$9$k!#%a%b%j%G!<%?$OHome %/%i%9%?$KMW5a$,E~Ce7?=g$KH?1G$5lk!#



?^ 3: 99?7MW5aK*1k%/%i%9%?4VGN%Q%1%C%H$NN.$1

2.3 MBP-light $N35MW

DSM 4IM}$O40A4$K%O!<%I%&%'%"$G9=@.$9$1$O9bB.@-$,<B8=$G$-$k$,!"@)8fJ}<0$N=@Fp@-$rB;$J$&62$1$,$"k?$a!"%W%m%;%C%5$rCV$-%W%m%0%i%`%Y!<%9$G@)8f$r9T$&!#$3$N%W%m%;%C%5$G$O%Q%1%C%HA`:n$JINFC<l$JL?Na$rI,MWH7!"C1$KHFMQ%W%m%;%C$rMQ$$$?NG$O==J,$J@-G=$,F@$ilJ$$!#$=$3$GJUMP-1 GODSM 4IM}$r9T$&$?aN@lMQ%W%m%;%C%5 **MBP-light** $r3+H/$7$?!#

K\@aGO!"%/%i%9%?4V$N%3%R!<%l%s%9@)8f$r9T$&MBP-light $N%O!<%I%&%'%"9=@.$H!"%W%m%;%C%5%3%"K*1k%Q%1%C%H$NO7$$$K$D$$$F=RYk!#$^$?MBP-light $N;}$DL?Na%;%C%HKD$$$F$N@bL@$r9T$&!#

2.3.1 MBP-light $N%O!<%I%&%'%"9=@.

?^1$K<($7$?$h$&$K!"MBP-light $O%W%m%;%C%5%3%"$G$"$k **MBP-Core**, %/%i%9%?%a%b%j$N%3%s%H%m!<%i(MMC: Main Memory Contoroller) 5Z$S30It%/%i%9%?$H$N%$%s%?!<%U%'%$%9(RDT I/F)$+$i9=@.$5lF$$$k!#

3l$i!"MBP-light $N9=@.MWAG$r@bL@9k!#

MBP-Core %W%m%;%C%5%3%"G"$jDSM 4IM}%W%m%0%i%`$r<B9T$9$k!#$=$N>\:Y$O<!9`$G@bL@9k!#

MMC %/%i%9%?%P%9$dMBP-Core $+$i$N%/%i%9%?%a%b%j"%/%;%9MW5a%Q%1%C%H$N=hM}$r9T$&!#

%/%i%9%?%P%9$+$i$NMW5a$N>l9g$O!"MMC $OEv3:%"%I%l%9$N%/%i%9%?%a%b%j$N%?%0$r;2>H7F!"6&M->uBV$,%/%i%9%?Fb$GJD8F$$$J1l$PMBP-Core $K=hM}$r0\$9!#%/%i%9%?FbGJD8$F$$$k>l9g$O!"MMC <+?H$,1~Ez%Q%1%C%H$r%/%i%9%?%P%9$KAw?.9k!#

MBP-Core $+$i$NMW5a$N>l9g$O!"$=$NMW5a$K=>CF%/%i%9%?%a%b%j%"%/%;%9$r9T$C$?$j!"%/%i%9%?%P%9$XMW5a$rAw?.9k!#

RDT I/F RDT HN%Q%1%C%H$NAw<u?.$r9T$&!#E,MW$J>l9g$OMBP-Core $K3d$j9~$_$r$+$1$F=hM}$r0\$9!#

MMC $HRDT GN=hM}$O%O!<%I%&%'%"$G9bB.$K<B9T$5lk!#3li,!"MBP-Core $K3d$j9~$_$r$+$1$:$K9T$&=hM}$O!"MBP-Core $+$iA4$/IT2D;k$G$"$k!#

2.3.2 %Q%1%C%H$N=hM}

MBP-Core $OL?Na21bit!"%G!<%?16bit $N%W%m%;%C%5$G$"$j!"<!Nh$&$JMWAG$,MQ0U$5lF$$$k!#

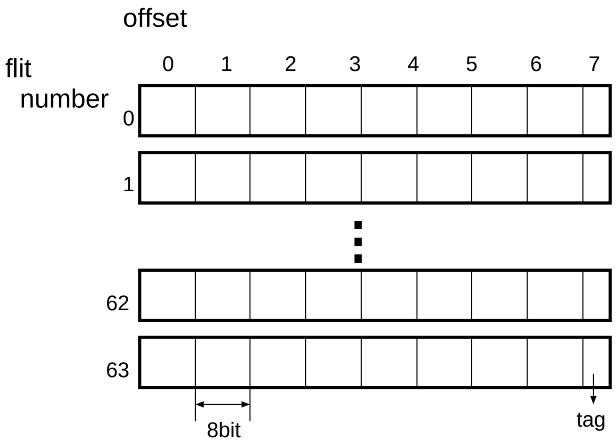
HFMQ%l%8%9%?**(GPR: General Purpose Register)** GPR $O16bit I}$G$"$j!"16K\MQ0U5l$F$$$k!#

FbIt%a%b%j FbIt%a%b%jKO!"MMC $dRDT I/F $r@)8f$9k?aN%l%8%9%?$d%P%C%U%!$JI,%^%C%T%s%0$5$l$F$$$k!#$^$?!"8e=R9k%Q%1%C%HE~CeK*1k3d$j9~$_Kb;Hol$k!#

FbIt%a%b%j$O64bit %"%I%l%C%7%s%0$G$"$j!"GPR 5Z$S8e=R$9$kPBR HN4V$G%G!<%?$NdjHj$,2DG=G"$k!#%"%/%;%9$O1 %5%$%/%k$G2DG=G"$k!#

%Q%1%C%H3JG<MQ%l%8%9%? **(PBR: Packet Buffer Register)** %Q%1%C%H=hM}!"%/%i%9%?%a%b%j"%/%;%9N?aN%l%8%9%?G"$k!#1%U%j%C%H$KD-1K\3djEvFilF*$j!"HFMQ$NbN$,64K\!"RDT HNAw<u?.MQK=l>$l8K\×3AH$:$DMQ0U$5lF$$$k!#

%m!<%+%k%a%b%j %m!<%+%k%a%b%j$OMBP-Core KBP9$k<g5-21G"$j21bit×64K $N6u4V$r;}$D!#DSM 4IM}%W%m%0%i%`$d<o!9$N%F!<%V%k$r3JG<7F$$$k!#L?Na%a%b%j$H%G!<%?%a%b%j$OJ,N%7F$*$i$:!"%-%c%C%7%e$r;}CF$$$J$$$?$a!"%m!<%I/%9%H%"$K$O1 %5%$%/%k$N%9



?^4: PBR $N9=@.

%H!<%k$rH<$&!#$^$?64K $,I/O %G%P%$%9N?aKJL$KM?$(il$F$$$k!#

MBP-Core $G<B9T$5lkDSM 4IM}%W%m%0%i%`$N9T$&Y-=hM}$O!"%Q%1%C%H$N<oJL$rH=CG$7E>Aw9k$@$1GOJ/!"%G!<%?It$K4^$^lk%?%0$b%W%m%H%3%k$K4X78$7$F$/$k$?$a!"%G!<%?It$r4^$a$?%Q%1%C%HA4BN$rPBR $K3JG<$7$F=hM}$r9T$&$3H,G-$k!#$^$?!"%G!<%?It$H%X%C%@It$rJ,N%$7$F3JG<$9k3H,G-k3H+$i=@Fp@-$N9b$$=hM}$,2DG=$G$"$k!#

%Q%1%C%H$N%X%C%@$N%U%#!<%k%ID9$O8bit 0JFb$K<}$^$k3H$,B?$$$?$a!"PBR K*$$$F$O?^4 $K<($9h&$K8bit C10L$G%"%I%l%C%7%s%0$5$l$F$$$k!#PBR $N%"%/%;%9L?Na$O8bit!"16bit!"64+2bit C10LG"$j!"PBR-PBR 4V!"PBR-GPR 4V!"PBR-B(CM4V$N1i;;!"%G!<%?E>Aw$,2DG=HJCF$$$F!"%Q%1%C%H$N%X%C%@$N:n@.$d=hM}$,9T$$d9/JC$F$$$k!#

MBP-Core K*1kDSM 4IM}%W%m%0%i%`$N<B9T$O!"%Q%1%C%HE~Ce$K$h$k3d$j9~$_$K$h$C$F;O$a$i$l$k!#%Q%1%C%H$,E~Ce$9$k$H!"FbIt%a%b%j$NFCDj$N%"%I%l%9$K3JG<$5$l$F$$$k!"%m!<%+%k%a%b%j$N%"%I%l%9$KMBP-Core $N@)8f$,0\$k!#$7$?$,$C$F!"3d$j9~$_@h$G9T$&$Y$-%W%m%0%i%`$,3JG<$5lF$$$k%m!<%+%k%a%b%j$N%"%I%l%9$r!"$"$i$+$8$a!"FbIt%a%b%j$NFCDj$N%"%I%l%9$K3JG<7F$*$/I,MW$,$"$k!#

3N3d$j9~$_$K:]$7$F!"3d$j9~$^$l$?;~E@$N%W%m%0%i%`%+%&%s%?$H>r7o%U%i%0$,!"%O!<%I%&%'%"Kh$jFC<l$J%l%8%9%?$K3JG<$5lk!#8e=R9k3d$j9~$_4X78$NL?Na$Khj!"3N%l%8%9%?$+$iCM$r<h$j=P$9$3H,2DG=G"$j!"B?=E$J3d$j9~$_$,2DG=$J9=B$$KJC$F$$$k!#

2.3.3 L?Na%;%C%H

MBP-Core $N;}$DL?Na%;%C%HKD$$$F@bL@$r9T$&!#

L?Na%;%C%H$O0J2<$Nh&$KJ,N`$G$-$k!#

- 4pK\RISC L?Na!&&&GPR-GPR 4V1i;;!"GPR-B(CM4V1i;;!"J,4t!"%m!<%+%k%a%b%j;2>H$NL?Na$G$"$k!#
- PBR L?Na !&&&PBR-B(CM4V1i;;!"PBR-GPR 4V1i;;!&0\F0!"PBR-PBR 4V0\F0$NL?Na$G$"$k!#PBR $OGPR $r%]%$%s%?H7$F;2>H$9kI,MW,$"$k!#

  B(CM4V1i;;$O8bit!"GPR 4V1i;;$O16bit C10LG"$k!#PBR-GPR 4V0\F0$O8bit!"16bit C10LNbN,$"$k!#$^$?PBR-PBR 4V0\F0$O8bit!"16bit!"64+2bit C10LNbN,$"$k!#

  PBR $K3JG<$5l?CM$O!"1 slot $N4V;HMQ$G$-$J$$$H$$$&@)8B$,$"$k!#
- FbIt%a%b%j;2>H!&&&FbIt%a%b%j;2>HL?NaG"$j!"GPR!"PBR HN%m!<%I/%9%H%"L?NaG"$k!#

  A0=R7?h&$KFbIt%a%b%j$O64bit C10L$G%"%I%l%C%7%s%0$5lF$$$k!#GPR HN%m!<%I/%9%H%"GO!"%"%I%l%9$G<($5l?2<0L16bit $,;2>H$5lk!#PBR HO64bit $G%G!<%?$NdjHj$,9T$olk!#
- RDT L?Na !&&&RDT XN%Q%1%C%HAw=PL?Na!"5Z$SRDT $+$i$N%Q%1%C%H3MF@L?Na$G$"$k!#
- MMC L?Na !&&&%/%i%9%?%P%9HN%Q%1%C%HAw<u?.L?Na!"5Z$S%/%i%9%?%a%b%j%"%/%;%9L?NaG"$k!#
- 3d$j9~$_4X78L?Na !&&&A0=R7?h&$K!"DSM 4IM}%W%m%0%i%`$O%Q%1%C%HE~CeKh$k3d$j9~

$_$KhC$F5/F0$5lk!#$=$N3d$j9~$_$K4X$7$F!"3d$j9~$_$N5v2D/IT2D$NL?Na$d!"La$jHVCO$NI|5"L?NaJI$,$"$k!#

- FC<lL?Na!&&PBR $NFCDjItJ,$N%0%C%7%eCMrH$k!"GPR $N2<0L8bit $N1 $N?t$r%+%&%s%H9k!"JI$,$"$k!#

MBP-Core $+$i$N%/%i%9%?%a%b%j%"%/%;%9$K$O!"%Q%1%C%H$r@8@.$7MMC $KAw?.$9kI,MW,$"$k!#3N%"%/%;%97k2L$O!"L5Ii2Y>uBV$G$b10 ?t%5%$%/%k8e$KH?1G$5lk!#3N4V!"%"%/%;%9$N%Q%1%C%H$HH7$F;HMQ$7$F$$$kPBR 5ZS=$NPBR $r;X$9GPR $K%"%/%;%9$7FOJi$J$$!"$H$$$&@)8B$,$"$k!#$3N?$a!"7k2L$,H?1G5lk^$G<B9T$r%9%H!<%k5;$k%a%b%j%P%j%"L?Na$,Hw$($ilF$$$k!#%a%b%j%P%j%"L?Na$^$G$K!"4X78$N$J$$L?Na$r9T$&3H$O2DG=$G$"$k!#

3 MBP-light $rBP>]$H7?C%3%s%Q%$%i

K\>OGO!"<!>O$K=R$Y$kDSM 4IM}%W%m%0%i%`3+H/$K;HMQ7?MBP-light $rBP>]$K7?C %3%s%Q%$%i$N<BAuKD$$$F=RYk!#

:#2s$N<BAu$G$O!"GNU C Compiler(GCC) $r0\?"$9$kJ}K!$rHC$?!#

3.1 GCC $NFCD'

GCC GOCf4V8@8lH7$F!"Register Transfer Language(RTL)[5] $H$$$&%j%9%H7A<0$N8@8l$rMQ$$$:GE,2=Ey$N=hM}$r9T$&!#

GCC $N%W%m%;%C%5$X$N0\?"$O<!$N2 DN%U%!%$%k$r5-=R9k3H$G9T$&!#

Target Description Macro BP>]HJ$k%W%m%;%C%5$N%O!<%I%&%'%"9=@.KD$$$F5-=R9kB>!"HFMQ%l%8%9%?$N;H$$J}!"%9%?%C%/$N9=@.K!!"%"%;%s%V%j%U%!%$%k$N=PNO$NJ}K!JI$N@_Dj$r9k!#

callee save %l%8%9%?!"caller save %l%8%9%?$N@_Dj$d!"0z?t$N3JG<$N5,B'$r@_Dj$9k3H,G-$k!#

Machine Description File(MD %U%!%$%k) ;HMQ$9$kL?Na$r!"$=$NL?Na$N9T$&A`:n$rI=$9RTL $H0lBP0l$KBP1~5;$F5-=R$9$k!#

MD %U%!%$%k$N5-=RK*$$$F$O!"I8=`7?$H8F$P$l$kA`:n$K4X7F$N5-=R$r9T$&I,MW$,$"$k!#I8=`7?$NA`:n$O!"CM$N3JG<!"Hf3S!">r7oJ,4t!"4X?t8FSJIG$"$j!"4pK\E*$JA`:n$G$"$k!#I8=`7?$O!"9=J82r@O$N7k2L$+$iRTL $r@8@.$9$kCJ3,$G;Hol$k!#I8=`7?$rI=o7$F$$$k!"RTL $HL?Na$NBP1~$K!"7h$ail$?L>A0$rIU1k3H$G@_Dj$G$-$k!#

I8=`7?$rI=$9A`:n$,J#?tL?Na$G$J$$$HI=8=G-$J$$$>l9g$O!"$=l>lNL?Na$KBP1~$9$kJ#?t$NRTL $N@8@.$r9T$&$3Hb2DG=G"$k!#

RTL $+$iL?NaNs$r=PNO$9$kCJ3,$G$O!"$9YF$NBP1~$,;Hol0lBP0l$G%"%;%s%V%jL?Na$KJQ49$5$l$k!#

$^$?MD %U%!%$%k$K$Odelay slot $N@_Dj$b2DG=HJCF$$$k!#

3N2 DN%U%!%$%k$O%3%s%Q%$%k$N=hM}Cf$K>o$K;2>H5l$k!#

3.2 GCC $HMBP-light HNIT?FOB@-

MBP-light $OA0>O$G=RY?h&$KFC<l$J%W%m%;%C%5G"$j!"GCC $r0\?"$9kK$O<!$Nh&$JLdBjE@$,$"$k!#

J#?t$N%a%b%j$KBP9k%"%/%;%9 2.3@a$G=R$Y$?$h$&$K!"MBP-Core $+$i%"%/%;%9$9$k3HNG$-$k%a%b%j$O%m!<%+%k%a%b%j!"FbIt%a%b%jG"$k!#$^$?PBR $bHFMQ%l%8%9%?4V@\$G%"%/%;%9$9$k3H$+$i!"%W%m%0%i%`$r5-=R$9$kCJ3,$G$O%a%b%j$H9M$($ilk!#

3N3 DO!"%"%I%l%9NN0hKhCF6hJL5lkNGOJ/!"L?NaKhCF6hJL5l$k!#$7$?$,CF!"3liN%a%b%j%"%/%;%9$NRTL I=8=$K$*$$$F!"%"%I%l%9$r<($9%l%8%9%?$,$I$N%a%b%j$KBP9kbNJN$+$O6hJLG-J/Jj!"%m!<%+%k%a%b%j%"%/%;%9$NL?Na$7$+=PNO$G$-$J$$!#

MBP-light FCM-$NL?Na 2.3.39`$G=RY?MMC @)8fL?Na!"RDT @)8fL?Na!"FC<lL?NaJI$O!"D>$K

C 8@8l$GI=8=$9k3HO:FqG$"$k!#F1MM$KRTL G=$NA`:n$rI=8=9k3H$b:$FqG"$k!#

3Nh&$JLdBj$KBP7F!":#2s$O!"4pK\RISC L?Na$NItJ,$K4X$7$FGCC $N0\?"$r9T$$!"$=$l0J30$NL?Na$OC1=c$K%=!<%9%*%Z%i%s%I$r0z?tH9$k4X?t8F$S$GI=8=$7$F!"%3%s%Q%$%iKhCFBP1~7?L?Na$r=PNO$5$;$k3H$GBP1~$7$?!#

$=$NM}M3$O!"%3%s%Q%$%i$K9T$o$;$?$$:GE,2=$O!":GE,$JHFMQ%l%8%9%?3djIU1$r5a$a!"%m!<%+%k%a%b%j;2>H5Z$S1i;;?t$r8:>/5;k3H@$+$iG"$k!#

3.3 C %3%s%Q%$%i$N<BAu

A0@a$G=R$Y$?$h$&$K!":#2s$O!"4pK\RISC L?Na0J30$NL?Na$O4X?t8F$S$GI=8=$7%3%s%Q%$%i$KhC$FBP1~$7$?L?Na$r=PNO5;kH$$$&J}K!rHC?!#

MD %U%!%$%k$K$*$$$F!"RTL $HL?Na$r0lBP0l$GBP1~$5$;$k3H$G!"RTL $+$i%"%;%s%V%jL?NaXNJQ49$,9T$olk$,!"RTL $K4^$^lk>pJsKhCF=PNO5l$kL?Na$rJQ$($k3H$,2DG=$G$"$k!#4X?t8FSrI=8=9kRTL KO!"$=$N>pJsH7$F4X?tL>$,4^$^$l$F$$$k!#7?$,$C$F!"FCDj$NL>A0$r;}$D4X?t8FSNRTL $r!"BP1~$7$?L?Na$KJQ49$5$;k3H,2DG=G"$k!#

0J9_!"FCDj$NL?Na$rC 8@8l$GI=8=$9k?aK;H$&4X?t$r!"!VFCJL$J4X?t!W$H5-=R9k!#

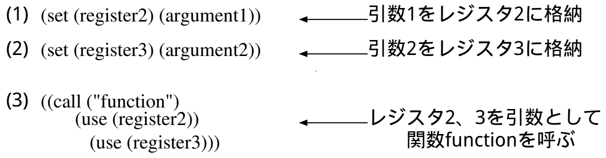
7+$74pK\RISC L?Na0J30$NL?Na$K4X$7$F!"4X?t8F$S$GI=8=$9k3HKhC$F5/$3$kLdBj$,$"$k!#

0J2<!"$=$NLdBjE@H=$N2r7hK!$K$D$$$F=RYk!#

%*%Z%i%s%I$N:GE,$J%l%8%9%?3djEvF 4X?t8FSG$O!"0z?t5Z$S$=$NJVjCMO4X?t4V$N%$%s%?!<%U%'%$%9$rHk$?$a!"Djail?5,B'$G%l%8%9%?$K3JG<5l$k!#$=N?$a4X?t8F$S$GI=8=$5lkL?Na$OFCDj$N%l%8%9%?7+%*%Z%i%s%IH7$F;H$($J$$3HKJk!#

0z?t5ZSJVjCM$r3JG<$9$k%l%8%9%?$K4X7F$O!"Target Description Macro $G@_Dj$9$k!#JV$jCM$N%l%8%9%?$K4X7F$O!"4X?t$NL>A0KhCF@_Dj$rJQ99$9k3H,!"3NMacro K*$$$F2DG=G"C?$?$a!":GE,$J%l%8%9%?$r3djIU1k3H,G-$?!#$7$+$7!"0z?t$r3JG<$9$k%l%8%9%?$O!"Macro GO4X?t$NL>A0$KhC$FJQ99$9k3H,IT2DG=G"C?!#

4X?t8FSK$"$?CF!"9=J82r@O8e@8@.5l$kRTL $O?^5$Nh&KJ$k!#$3$N?^$ORTL $r4JN,2=$7$?$bNG$"$j!"<B:]Ob$&>/$7J#;(G"$k!#Nc$O!"0z?t2 8D$N4X?t$N>l9gG"$j!"0z?t$O%l%8%9%?2 !&3 $K3JG<$9$k!"$H@_Dj7F$"$kbNH9$k!#



```
(1)  (set (register2) (argument1))
(2)  (set (register3) (argument2))

(3)  ((call ("function")
         (use (register2))
           (use (register3)))
```


?^5: 4X?t8FSNRTL

$3$3$Gargument $H=q$$$F$"$kItJ,KOB(CM!"b7$/$O%l%8%9%?$,$"FO$^$k!#

%l%8%9%?2 !&3 $NItJ,$,:GE,2=KhCFJQok3HOJ$$!#

3l$,FCJL$J4X?t$N>l9g!"argument $K%l%8%9%?$,$"$FO^kJ$i!"$=$N%l%8%9%?$r$=$N$^$^%*%Z%i%s%IH7$F0l$(kK$b4X$oi:!"0z?tMQ%l%8%9%?KCMr3JG<7F$+$i!"4X?t$KBP1~$7$?L?Na$,=PNO5lk3HKJk!#3N3JG<L?Na$OL5BL$G$"$k!#

$^$?0z?tMQ%l%8%9%?NCMr!"Ev3:L?Na$NA08e$KEOCF;H$$$?$$$H$-!"$=NCMNB`Hr!&I|5"$r9T$J$&L?Na$r=PNO$9$k$3$H$K$J$j!"$3$NA`:n$bL5BL$G$"$k!#

7+$7?^5$K$*$1$k(1)(2) $NRTL I=8=$O!"(3) $NI=8=$rMD %U%!%$%k$N4X?t8FSNI8=`7?$N5-=R$KhC$F=PNO$7h&H9kH$-$K$O!"JQ99$9k3HOG-$J$$!#

$=$3$GFCJL$J4X?t$K4X$7FO9=J82r@O8e!"?^6Nh$&$JRTL $,@8@.$5lkh&$KMD %U%!%$%k$r5-=R$7$?!#

$3$3$G!"pseudo register $H=q$$$F$"$kItJ,$O:GE,2=$NCJ3,GE,EvJ%l%8%9%?$KCV49$5lk!#

9JoA!"?^5K*1k(3) $NI=8=$H7F!"%l%8%9%?2 !&3 rJLN%l%8%9%?$K3JG<$7F+$i(E@@~It)!"$=$N%l%8%9%?$r0z?tH7$F4X?t8F$Sr9$k!"$H$$$&RTL $r@8@.$9kh$&$KI8=`7?$N5-=R$r7?!#

3Nh&K7F*1P:GE,2=$NCJ3,$G%l%8%9%?2 !&3 XN3JG<L?Na$OL5BL$G$"$kH7$F>J$+$l!"pseudo register $K:GE,$J%l%8%9%?$,3d$jEvFilk!#>l9gKhCF$OE@@~It$N3JG<L?Na$b>J$+lk!#3N

```
(set (register2) (argument1))
(set (register3) (argument2))

(set (pseudo register1) (register2))
(set (pseudo register2) (register3))

((call ("special_function")
   (use (pseudo register1))
      (use (pseudo register2)))
```

?^6: FCJL$J4X?t8F$S$NRTL

J}K!Kh$j4X?t8F$S$GI=8=$5lkL?Na$N%=!<%9%*%Z%i%s%I$KBP7F$b:GE,$J%l%8%9%?$,3d$jEvFilk3HKJ$k!#

B(CM%*%Z%i%s%I$NLdBj 4pK\RISC L?Na0J30$NL?NaK*$$$F!"%*%Z%i%s%I$KB(CM$rI,MWH9kbNK<!Nh$&$JbN$,$"$k!#

- PBR $N%"%I%l%9$N%*%U%;%C%H
- FbIt%a%b%j$"%/%;%9L?Na$N%"%I%l%9$N%*%U%;%C%H
- PBR-B(CM4VL?Na

C8@8l$G5-=R$9$k:]!"$3li$NL?Na$O4X?t8FSGI=8=9k3HK7$?$,!"$=$N0z?tH7$FB(CM$G=PNO7?$$IatJ,$r;XDj$7F7$^$&$H!'$=$NRTL I=8=$O?^6Nh$&$KB(CM$GI=8=$7$?$$IatJ,$bpseudo register H7$FI=8=$5lk!#

pseudo register $NItJ,$K$O!"B(CM$b5vMF9k5-=R$,2DG=$G$"$k$,!"%l%8%9%?$r6X;_9k3HOG$-$J$$$?aK!"%"%;%s%V%j$KJQ49$9$k;~$KO3$NItJ,$NRTL I=8=$,$IAiKJk+o+iJ$$!#

pseudo register $NItJ,$,!"B(CMGb%l%8%9%?GbBP1~9kL?Na$,B8:_$9$k>l9g$K$O4V0c$$$N$J$$L?Na$,=PNO$5lk!#PBR-B(CML?NaK*$$$F$O0lIt$=Nh$&$JL?Na$,B8:_$7$?$?$a!"$=lK$D$$$F$O%5%]!<%H$G$-$?!#PBR-B(CML?NaK*$$$F$O!"<B:]$K;Hol$kL?Na$O8Bil$F$$$k$,!"%5%]!<%H$G$-$?L?Na$G==J,$G$"$C$?!#

7+$7PBR!"FbIt%a%b%j$N%*%U%;%C%H$K4X$7FO!"RTL I=8=$G%l%8%9%?$,8=lk$H=PNO$9$kL?Na$,B8:_7J$$!#

$=$3$GPBR $K4X$7FO!"$=$N%*%U%;%C%H$K;H$($k?t$,!"?^4$K<($9h&$K0$+$i8$^GG$"$kNG!"PBR $NL?Na1 8D$KD-!"9<oN`$N4X?tL>$rMQ0U7F!"$=$lKhCF%*%U%;%C%H$NItJ,$r=PNO9k3HK7$?!#

FbIt%a%b%j$K4X$7FO!"$=$N%"%/%;%9MQES$O8B$ilF$*$j!"hC$F%"%I%l%9$b%W%m%0%i%^!<$K<+L@$JbNP+jG$"$kNG!"%*%U%;%C%H$O>o$K0H7$?!#

MBP-light $NL?NaNsFCM-$N@)8B;v9` 2.3.39`$K=R$Y$?$h$&$K!"L?NaNsKO<!Nh$&$J@)8B;v9`$,$"$k!#

1. PBR $K3JG<$7$?CM$O1 slot $N4V;HMQ$G$-$J$$!#
2. %/%i%9%?%a%b%j%"%/%;%9$K;HMQ$7$?PBR 5Z$S$=$NPBR $r;X$9GPR $O!"$=$N%"%/%;%9$N7k2L$,H?1G$5lk$^$G;HMQ9k3H$,$G$-$J$$!#

MD %U%!%$%k$G$O!"$"$kL?Na$KhC$F3JG<$5l?CM$O2?slot $N4V%"%/%;%9$9k3H,G-$J$$!"$H$$$&@_Dj$r9T$&3H$,$G$-$k!#

7+$79`L\1 $K4X$7$F!"MD %U%!%$%k$G@_Dj$9$k$3$H$O$G$-$J$$!#$=$NM}M3$O!"PBR L?Na$O4X?t8F$S$GI=8=$7$F$$$k$?$a!"%3%s%Q%$%i$O$=$NL?Na$,PBR $KCM$r3JG<$9$kA`:n$G$"$k!"$H$$$&3H$OH=CG$G$-$J$$$?aG$"$k!#3NLdBjKBP7FO!"%3%s%Q%$%i$O4V0cC?L?NaNs$r=PNO$9$k2DG=@-$,$"$k!#7?$,$C$F!":#2s$O=PNO5l$?L?NaNs$r0lEYAv::7F!"LdBjHJ$kItJ,$K$O!"4V$K0UL#NJ$$L?Na!"NOP $rA^F~$9k3HGBP=h7?!#

9`L\2 $K4X$7$F$b!"%/%i%9%?%"%/%;%9L?Na$r4X?t8F$S$GI=8=$7$F$$$k$?$a!"F1$8M}M3$GMD %U%!%$%k$G@_Dj$9$k$3$H$O$G$-$J$$!#$7$+$7$3$N>l9g$O!"C8@8l$G%W%m%0%i%`$r5-=R$9$kCJ4V$G!"%a%b%j%P%j%"L?Na$r=PNO$9$k4X?t$r%/%i%9%?%"%/%;%9L?Na$ND>8e$K8FV3HG!"4V0cC?L?Na$r=PNO$9k3HO$J$$!#

$=$NB>$NLdBj $=$NB>$KLdBj$HJC$?$3HO!"DSM 4IM}%W%m%0%i%`K*$$$F$O!"<!>O$G=RYk%W%m%;%94IM}$r9T$&I,MW$,$"$k!#%W%m%;%94IM}$K$*$$$F$O!"%9%?%C%/%]%$%s%?$N@Z$jBX$($d%3%s%F%/

%9%H@ZjBX(;~$NA4%1%8%9%?$NJ]B8JI$N=hM}$r9T$&$3HG$"$k!#

3liN=hM}$bC 8@8l$G$OD>$K$OI=8=$G$-$J$$=hM}G"$k!#

:#2s$O!"$3li$b4X?t8F$S$GI=8=$7!"FCDj$NL?NaNs$r=PNO5;k3HGBP1~7?!#

0J2<!"<BAu7?%3%s%Q%$%i$NFCD'KD$$$F5s2k!#

- 4pK\RISC L?Na0J30$NL?Na$O4X?t8FSG9T$&!#$3liO[$\%"%;%s%V%jL?Na$H0lBP0l$KBP1~$7$F$$$k!#PBR-B(CM4VL?Na$O%5%]!<%H$7$F$$$J$$$bNb$"$k!#
- $=$NB>!"C 8@8lGOI=8=$,:$Fq$JF0:n!"Nc$($P<!@a$N%W%m%;%94IM}$K=R$Y$F$$$k%3%s%F%-%9%H@ZjBX(K*1kA4%1%8%9%?J]B8$N=hM}Ey!"$b4X?t8FSK7F!"FCDj$NL?NaNs$r=PNO5;$k!#
- inline Dj5AKh$j!"4X?t$N%$%s%i%$%sE83+$r9T$&3H$,$G$-!"4X?t8F$S$N%*!<%P!<%X%C%I$rJ/$9$3H,G-$k!#%W%m%0%i%^!<$O!"%$%s%i%$%sE83+$r%3%s%Q%$%iG$$;K7!"3N3H$r0U<1$;$:$K%W%m%0%i%`$r3+H/$9k3H,2DG=G"$k!#
- %/%i%9%?%a%b%j%"%/%;%9$r9T$C$?>l9g$O!"D>8e$K%a%b%j%P%j%"L?Na$rI=8=9k4X?t$r8F$PJ1lJPJiJ$$!#

  $^$?3N3HKh$j!"%/%i%9%?%a%b%j%"%/%;%9$N%1%$%F%s%7$r1#JC$9k3H,IT2DG=KJCF$$$k!#

4 DSM 4IM}%W%m%0%i%`

K\>OGO!"MBP-light $K<BAu$7$? DSM 4IM}%W%m%0%i%`$K$D$$$F=RYk!#

4.1 %W%m%0%i%`$N4pK\9=B$

MBP-light GN=hM}$O!"%Q%1%C%H$KE~CeKhCF5/F0$5$l$k!#

%Q%1%C%H=hM}$N<B9T=g=x$K4X7F$O!"%Q%1%C%H$NE~Ce=g$K=hM}$r9TCF$$$/$H$$$&J}K!$,9M$(il$k!#

DL>o!"MBP-light $N=hM}$9$k%Q%1%C%HMW5a$O!"%V%m%C%/C10LGNMW5aG"$k!#0lJ}!"2.2.19`$G=RY?h&$K!"%Z!<%8C10L$NMW5a$H$$$&!"Hs>o$K=hM};~4V$,D9$$%Q%1%C%H$bB8:_$9$k!#

MBP-light K*1k!"%V%m%C%/C10L$NMW5a$N=hM};~4V$H!"%Z!<%8C10L$NMW5a$N=hM};~4V$K$OB?$-$J:9$,$"$kG"m&!#

3l$r%Q%1%C%HE~Ce=g$G=hM}$r9T$C$?$NGO!"<B9T;~4V$,D9$/=hM}$N6[5^EY$,Hf3SE*Dc$$%Q%1%C%H=hM}$K!"MBP-light $,FH@j$5lF7^$$!"6[5^EY$N9b$$%Q%1%C%H$N=hM}$,CYlF7^$&2DG=@-$,$"$k!#

$=$N$?$a%Q%1%C%H$N<B9T=g=x$K4X7F0J2<Nh$&$J3H$r9MN8$9k3H,I,MWG"$k!#

- =hM}$KHs>o$KD9$$;~4V$,$+$+$j!"6[5^EY$NHf3SE*Dc$$%Q%1%C%H=hM}$K4X$7FO3d$j9~$_$r5v2D$9$k!#
- IaDL$N%Q%1%C%H=hM}$Nh&$KHf3SE*C;;~4V$G=*N;9kh&JbNO!"3d$j9~$_$rIT2D$H7F0l5$$K<B9T7F7^$&!#

3l$r:#2s$O!"E~Ce7?%Q%1%C%H$N=hM}$rM%@hEYIU$-$N%W%m%;%9H9k3HG<B8=7?!#7?$,$C$F!"DSM 4IM}%W%m%0%i%`$O!"%W%m%;%94IM}3,AX$H%Q%1%C%H=hM}%W%m%;%9$N2 3,AX$G<B8=$G$-$k!#

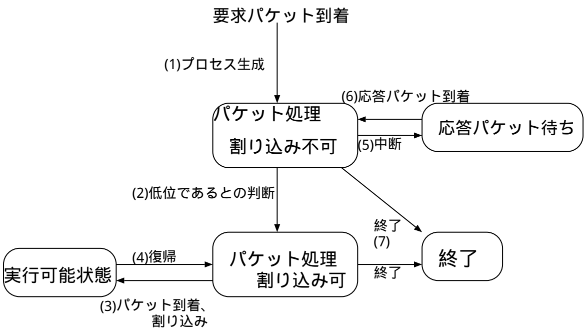
4.2 %W%m%;%94IM}

MBP-light $KE~Ce$7$?%Q%1%C%H$KBP7F@8@.5l$k%W%m%;%9$N4IM}$H!"%9%1%8%e!<%j%s%0$r9T$&%W%m%0%i%`$N9=@.$r<($9!#

%Q%1%C%H$NE~Ce$Khj@8@.5l$k=hM}%W%m%;%9$N>uBVA+0\$NMM;R$r?^7$K<($9!#

0J2<!"%W%m%;%94IM}%W%m%0%i%`$NF0:n$K$D$$$F@bL@9k!#

%W%m%;%94IM}%W%m%0%i%`$O!"3d$j9~$_$,5v2D5l$F$$$k>uBV$G!"MW5a%Q%1%C%H$,E~Ce9k$H!"%W%m%;%9%9%?%C%/$N3NJ]$r9T$C$F%W%m%;%9$r@8@.$7!"3+;O$5$;$k(?^7 (1))!#%W%m%;%9$N@8@.$O%9%?%C%/NN0h$N3NJ]$r0UL#9k!#%W%m%;%9%9%?%C%/$O3F%W%m%;%9$N:n6HNN0hH7$F;HMQ$5lkB>!"%W%m%;%9$,3d$j9~$^$l$?$H$-$N%3%s%F%/%9%HJ]B8$K;H$olk!#



?^7: %W%m%;%9$N>uBVA+0\

%W%m%;%9$NM%@hEY$H7F!"A0@a$K=R$Y$?$3Hr9MN8$7$F<!$N 2 DrMQ0U9k!#

- 9b0L!&&DL>o$N DSM 4IM}$N=hM}$GC;;~4V$G=*N;9kbN!#3d$j9~$_IT2DH9$k!#
- Dc0L!&&$=$NB>$N=hM}$G!"Hs>o$KD9$$;~4V$,$+$+$kbN!#3d$j9~$_2DH9$k!#

%W%m%;%9$NM%@hEY$O!"%W%m%;%9$r<B9T$9k^GCNk3H$,$G$-$J$$$N$G!":G=i$O3d$j9~$_IT2DH7$F=hM}$r?J$a!"%Q%1%C%H=hM}%W%m%;%9Cf$KDc0L$G$"$k$HH=CG$7$?;~E@$G3d$j9~$_$r5v2D$9$k(?^7 (2))!#3d$j9~$_$r5v2D9kD>A0KO!"<!NCMr%m!<%+%k%a%b%j$K3JG<$9kI,MW,$"$k!#

- Ev3:%Q%1%C%H$,3JG<$5lF$$$k PBR HV9f
- %W%m%;%9%9%?%C%/XN%]%$%s%?

3d$j9~$_$,H/@8$9kH!"FbIt%a%b%j$K%^%C%T%s%0$5l?%"%I%l%9$K=hM}$,0\$k3H$+$i!"J]B8$9$Y$-$3liNCM,8+$($J$/$JCF7^$&$+iG$"$k!#

Dc0L$N%W%m%;%9<B9TCf$K!"%Q%1%C%H$,E~Ce$9kH!"%W%m%;%9$O3d$j9~$^$l$k(?^7 (3))!#$3$N:]!"%W%m%;%94IM}%W%m%0%i%‘$O!"<!$Nh&$J=hM}$r9T$&!#

1. A4FN%l%8%9%?$r%W%m%;%9%9%?%C%/$KB‘Hr9k!#$^$?!"Ev3:%Q%1%C%H$rHFMQ PBR $KB‘Hr$9$k!#
2. <B9T2DG=%-%e!<$K!"%W%m%;%9$NEPO?$r9T$&!#
3. E~Ce7?%Q%1%C%HKBP7$F%W%m%;%9$N@8@.$r9T$&!#

<B9T2DG=%-%e!<$O!"JV$jHVCO!"Ev3:%Q%1%C%H!"%W%m%;%9%9%?%C%/XN%]%$%s%?$J$I!"%W%m%;%9$,I|5"9kNKI,MW$J%G!<%?$rJ]B8$7$F$$$k!#

<B9T2DG=%-%e!<$KEPO?$5l?%W%m%;%9$O!"9b0L$N%W%m%;%9$,B8:_$7$J$$>l9g$K8B$j!"%G%#%9%Q%C%A5l$k(?^7 (4))!#$3lODc0L$N%W%m%;%9$N$_<B9T2DG=%-%e!<$KEPO?5lk+iG$"$k!#

1~Ez%Q%1%C%HBTAKJC$?%W%m%;%9$OCfCG5l$k(?^7 (5))!#$3NH$-%Z%s%G%#%s%0!&H%i%s%6%/%7%g%s!&F!<%V%k(0J2<!"PTT H9$k) $H8F$Plk%F!<%V%k$KEPO?$5$l!"MBP-light $r2rJ|$9$k!#PTT $D$$$F$O8e=R$9$k!#

3NH-!"%W%m%;%9%9%?%C%/$N2rJ|$O9ToJ$$!#3l$O1~Ez%Q%1%C%H$,JVCF$-$?H-$K%W%m%;%9@8@.$N<j4V$r>J$/$?$aG"$k(?^7 (6))!#

%Q%1%C%H=hM}$r=*N;$9kH!#%W%m%;%9%9%?%C%/$N2rJ|$,9Tol!"%W%m%;%9$,=*N;$9$k(?^7 (7))!#

PTT $O%W%m%;%94V$N6%9grKI0$?$a$KMQ$$$ilk!"%"%I%l%9$r%-!<$H9kO"A[%F!<%V%kG"$k!#%W%m%;%93+;O;~$K PTT $r8!:w$7$F!"$9GKF10l%"%I%l%9$KEPO?$,$"$l$P!"$=$N%"%I%l%9$O=hM}CfG"k3Hr0UL#$7!"$=$N%W%m%;%9$b PTT KDJ,lFBT$A%W%m%;%9$HJk!#BT$A%W%m%;%9$O!"9G$KEPO?$5lF$$$?%W%m%;%9$N1~Ez%Q%1%C%H$,E~Ce$72rJ|$5lk$H!"<B9T$5lk!#3lKh$jF10l%"%I%l%9$KBP9k%W%m%;%9$O!"=hM}$N=g=x$,F~$lBXok3HOJ$$!#

4.3 %Q%1%C%H=hM}%W%m%;%9

:#2s<BAu7?%Q%1%C%H=hM}%W%m%;%9K*1k%W%m%0%i%‘$O<!$Nh&$JF0:n$r9T$&!#

- %X%C%@ItJ,$+$i%Q%1%C%H$N<oJL$rH=JL$7!"<oN‘$K1~8?=hM}$KJ,4t$9$k!#
- %/%i%9%?4V%3%R!<%l%s%9J];}N?aN%Q%1%C%H$r!"%/%i%9%?%P%9$b7/$O RDT XNE>Aw9k!#
- %G!<%?$N6&M->uBV$r<($9%/%i%9%?%a%b%j$N%?%0$r99?7$9$k!#
- %/%i%9%?%a%b%j$N%G!<%?$=NbNr99?7$9$k!#
- %/%i%9%?%P%9$N%m%C%/5Z$S$=$N2r=|

%/%i%9%?%a%b%j$d!"$=$N%?%0$N99?7KO%Q%1%C%H$N%X%C%@$r@8@.9kI,MW$,$"k,!"3F=hM}$KBP1~$7$?%X%C%@$N%F%s%W%l!<%Hr"i+8aHFMQPBR>e$K:n@.$7F*$/$3HG9bB.2=$r?^$C$F$$$k!#
<BAuK*$$$F9MN8$7$?;vJA$r=R$Y$k!#

%X%C%@$N%F%s%W%l!<%H$N:n@. %/%i%9%?%a%b%j$d!"$=$N%?%0$N99?7KO%Q%1%C%H$N%X%C%@$r@8@.9kI,MW$,$"k,!"3F=hM}$KBP1~$7$?%X%C%@$N%F%s%W%l!<%Hr"i+8aHFMQPBR>e$K:n@.$7F*$/$3HG9bB.2=$r?^$C$F$$$k!#

%/%i%9%?%a%b%j$N99?7 2.2.19 `$G=RY?h&$K99?7MW5a=hM}$K$*$$$F$O!"%Q%1%C%H$N%G!<%?It$KIU?o$9$k%?%0$KhC$F!"4Byte C10L$G$N99?7$,J5lk!#
7?$,$C$F!"99?7MW5a$K$*$1$k%/%i%9%?%a%b%j99?7$r9T$&$H$-$K$O!"%?%0$r;2>H7F!"M-8zG"$k%G!<%?$N$_$r99?7$9$Y$-$G$"$k!#$=$N$?$a!":#2s$OEv3:%"%I%l%9$N%/%i%9%?%a%b%j$N%G!<%?1%V%m%C%/$r0lC6FI$_=P$7F+$i!"%?%0$K<(5l$k%G!<%?$N$_$r%3%T!<7F!"%/%i%9%?%a%b%j$K=q$-La$9!"$H$$$&=hM}$r9T$C$F$$$k!#
FI$_=P$7MW5aK*1k%/%i%9%?%a%b%j=q$-9~$_GO!"1%V%m%C/C10L$G9T$olk3H$+$i99?7MW5aNh$&$K0lC6FI$_=P$9I,MWOJ$$!#

%/%i%9%?%P%9$N%m%C%/ %/%i%9%?%P%9$N%m%C%/$O!"<!$Nh&$J>u67$rKI0?aK9TCF$$$k!#

1. RDT $+$iMW5a%Q%1%C%H$,E~Ce$7$F!"%/%i%9%?%a%b%j$N$3$1$^$GEv3:%/%i%9%?FbKJD8$F$$$?$"$k%"%I%l%9$K4X$7$F6&M->uBV$r<($9%?%0$r99?7$7$h$&$H9k!#
2. %/%i%9%?%P%9$+$iF10l%"%I%l%9$K4X$7FNMW5a$,5/$3$k!#
3. MMC $O!"$^$@99?7$5lF$$$J$$%?%0$r8+$F1~Ez%Q%1%C%H$r%/%i%9%?%P%9$KJV$9!#

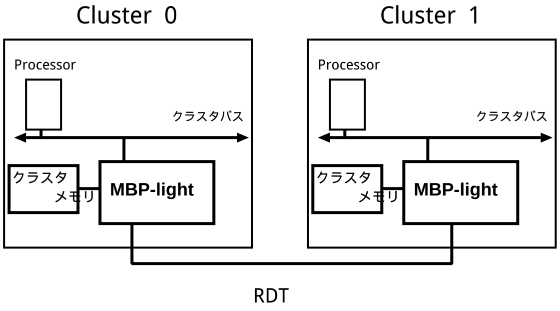
K\Mh$J$i$P!"Ev3:%/%i%9%?$KJD8F$$$J$$$?$aMBP-light $K=hM}$r0\$9Y-G"k,!"%/%i%9%?Fb$G=hM}$r=*N;7F7^$&$3HKJk!#7?$,$C$F!"%/%i%9%?%a%b%j%"%/%;%9$rGS=|$9k?aK%/%i%9%?%P%9$N%m%C%/$r9TCF$$$k!#

%/%i%9%?%P%9$N%m%C%/$K$OFbIt%a%b%j$K%^%C%T%s%0$5$l$F$$$k@)8f%l%8%9%?$K=q$-9~$`$3HG9Tol$k!#

5 @-G=I>2A

5.1 I>2A4D6-

:n@.7?%W%m%0%i%`$r VHDL $GO@M}9g@.2DG=$Jh&$K5-=R$5l?@_7W%G!<%?$rMQ$$!"Mentor Graphics <R$NVHDL %7%_%e%l!<%?!<qhsim v8.5_4.6c $rMQ$$$F%7%_%e%l!<%7%g%s$r9T$C$?!#$7$?$,CF%5%$%/%k?t$O<B:]NbNHF1$8$G$"$k!#JUMP-1 $O50MHz $GF0:n$9kN$G1 %5%$%/%k$O20ns G"$k!#
L5Ii2Y>uBV$G%/%i%9%??t$O2!"3F%/%i%9%?KO%W%m%;%C%5$r1 DH7?(?^8;2>H)!#



?^8: I>2A4D6-

DSM 4IM}%W%m%0%i%`$O C 8@8l$G5-=R$73>O$G=RY?%3%s%Q%$%i$rMQ$$$F!":GE,2=%l%Y%k3 $G%3%s%Q%$%k7?%3!<%I$r%7%e%_%l!<%7%g%s$7$?!#4X?t$O9Y$F%$%s%i%$%s@k8@$7F"$k!#
:#2s$O!"L5Ii2Y>uBV$N@_DjN?aK!"%/%i%9%?FbItGOMW5a%Q%1%C%H$,Aw?.$5lkH=$N%"%I%l%9$KBP7F CC $+$i$N<!$NMW5a$,H/9T$5lJ$$!#3N$?$a!"PTT $O<BAu$5lF$$$J$$!#$^$?Home %/%i%9%?KO6&M->uBV$r<($9%G%#%l%/%H%j$O:n@.$;$:!"%Z!<%8%F!<%V%k$b=jM-7F$$$J$$!#7?$,$C$F<B:]$NJUMP-1 GO5i$K=hM};~4V$,A}Bg9k3H$r9MN8$5l?$$!#:#2s$N%W%m%0%i%`$G$O6&M->uBV$NH=CG$O%/%i%9%?%a%b%j$N%?%0$rMBP-light $,FI$_=P$9$3HG9TCF$$$k!#

5.2 3F=hM}KMW9$k%5%$%/%k?t

FI$_=P$7MW5a!"99?7MW5aK*1k=jMW%5%$%/%k?t$rI=1<($9!#

I=1: 3F%Q%1%C%H$N=hM};~4V

=hM}FbMF	;~4V(%5%$%/%k)
FI$_=P$7MW5a	922
99?7MW5a(Initiator)	422
99?7MW5a(Home)	440

FI$_=P$7MW5aK*$$$F$O!"Initiator %/%i%9%?$,!"Owner %/%i%9%?G"$kHome %/%i%9%?$KMW5a$rAw?.$9$k>l9g$G$"$k!#Home %/%i%9%?$N2<!%-%&%C%7%e$KM-8z$J%G!<%?$,B8:_7FkbNH7F$$$k!#;~4V$O!"FI$_=P$7MW5a$,%/%i%9%?%P%9$KN.$lF+$i!"1~Ez%Q%1%C%H$,%/%i%9%?%P%9$KN.$lk^GN;~4VG"$k!#

99?7MW5a$K4X$7FO!"$=$l$>$l$N%/%i%9%?$K$*$1$k%Q%1%C%H=hM}$N;~4VG"$k!#

3NCM$O%"%;%s%V%i$G5-=R5l$?%W%m%0%i%`$hjbB?>/;~4VN+$+$k7k2LG"C?!#

$=$l$>$l$NMW5a$K$*$$$F!"3F%/%i%9%?$G9T$olF$$$k=hM}$rI=2!"3$K<($9!#

I=2: FI$_=P$7MW5aKBP9$k=hM}

%/%i%9%?	=hM}
Initiator %/%i%9%?GN=hM}1	%Q%1%C%H$NH=JL
	RDT Aw?.MQ$N%X%C%@$N:n@.5Z$SAw?.
Home %/%i%9%?GN=hM}1	%Q%1%C%H$NH=JL
	%/%i%9%?%P%9$XMW5a%Q%1%C%H$rN.$9
Home %/%i%9%?GN=hM}2	%Q%1%C%H$NH=JL
	%/%i%9%?%a%b%jXN=q$-9~$_
	%?%0$N99?7
	RDT Aw?.MQ$N%X%C%@$N:n@.5Z$SAw?.
Initiator %/%i%9%?GN=hM}2	%Q%1%C%H$NH=JL
	%/%i%9%?%a%b%jXN=q$-9~$_
	%?%0$N99?7
	%/%i%9%?%P%9$X1~Ez%Q%1%C%H$rN.$9

I=3: 99?7MW5aKBP9$k=hM}

%/%i%9%?	=hM}
Initiator %/%i%9%?GN=hM}	%Q%1%C%H$NH=JL
	%/%i%9%?%a%b%j$N99?7
	RDT Aw?.MQ$N%X%C%@$N:n@.5Z$SAw?.
Home %/%i%9%?GN=hM}	%Q%1%C%H$NH=JL
	%/%i%9%?%P%9XN%m%C%/
	%/%i%9%?%a%b%j$N99?7
	%/%i%9%?%P%9$XMW5a%Q%1%C%H$rN.$9
	%/%i%9%?%P%9XN%m%C%/$N2r=|
	Renter %/%i%9%?XNRDT Aw?.MQ$N%X%C%@$N:n@.5Z$SAw?.

5.3 9M;!

:#2s<BAu7?DSM 4IM}%W%m%0%i%`$N=hM}G=NO$K$D$$$F=RY?NA!"<BAu;~K*1k2]BjKD$$$F=RYk!#

5.3.1 DSM 4IM}%W%m%0%i%`$N=hM}G=NO

%7%_%e%l!<%7%g%sKhCFF@il$?7k2L$+$i!"JUMP-1 $N%W%m%;%C%5$G$"$kSuperSPARC+$+$i$N%G!<%?$NJ?6QFI$_=P$7;~4V$r5a$a$?!#

1<!%-%&%C%7%eXNFI$_=P$7$O1 %5%$%/%k!"2<!%-%&%C%7%eXO5 %5%$%/%k!"%/%i%9%?%a%b%j%X$O29 %5%$%/%k$+$+$k!#3<!%-%&%C%7%e%_%9$r5/$3$7$?>l9g$O!"FI$_=P7KMW9k;~4V$O(922+6) %5%$%/%k$+$+$k!#$=3G1<!!"2<!5Z$S3<!%-%&%C%7%e$N%R%C%HN(r\alpha_1$%!"$\alpha_2$%!"$\alpha_3$%$H2>Dj9k$HJ?6Q%l%$%F%s%7L $O

$$L = 1 \times \alpha_1 + 5 \times (1-\alpha_1)\alpha_2 + 29 \times (1-\alpha_1)(1-\alpha_2)\alpha_3 + 928 \times (1-\alpha_1)(1-\alpha_2)(1-\alpha_3)$$

$GM?$(il$k!#3F%R%C%HN($KhkJ?6QFI$_=P$7;~4V$rI=4$K<($9!#

%-%&%C%7%e%R%C%HN($,2<$kKDlF!"J?6QFI$_=P$7;~4V$,$+Jj$N3d9g$GA}2C7F$$$/3H$,$o$+$k!#

7?$,$C$F!":#2s$NDSM 4IM}%W%m%0%i%`$O!"FI$_=P$7MW5a$K4X7F$O!"$+Jj9b$$%-%&%C%7%e%R%C%H$r<($9>l9gG"kHA j1~$N@-G=$r<(9G$"$m$&$,!"%-%&%C%7%e%R%C%HN($,2<$,$k>l9g$K$O!"=hM}G=NO$N8~>e$,5a$ail$k!#

5.3.2 %W%m%0%i%`$N<BAu$K$*$1$k2]Bj

=hM};~4V$NA}Bg$K$O!"<!$Nh&$JMBP-light $N<eE@$,5s2ilk!#

- 4.3@a$K=R$Y$?$h$&$K!"%/%i%9%?%a%b%j99?7;~KO!"0lC6Ev3:%"%I%l%9rFI_=P7F$+$i!"

I=4: J?6QFI$_=P$7; ~4V

α_1 (%)	α_2 (%)	α_3 (%)	L(%5%$%/%k)
95	97	99	1.249
90	93	95	1.883
80	85	90	5.217
75	80	85	9.943

%?%0$K< ($5$1$?%G!<%?N_%3%T!<7F=q$-La 9H$$$&A`:n$r9T$C$F$$$k!#%/%i%9%?%a%b%j %"%/%;%9KO%Q%1%C%H$r:n@.$9kI,MW,$"$j!" $^$?%G!<%?$N%3%T!<$O%G!<%?%U%j%C%H4 K\J, 9T$&I,MW$,$"$k!#3N$?$a!"%G!<%?9?7;~$N %5%$%/%k?t$,A}Bg$7$F$$$k!#

- %/%i%9%?%P%9$N%m%C/$H2r=|KO!"FbIt%"%I %1%9$K%^%C%T%s%0$5$1$F$$$k%1%8%9%?$K=q$-9~$`I,MW$,$"$k!#=q$-9~$`$Y$-%1%8%9%?$O3 K\$"$j!"$^$?=q$-9~$`$Y$-%G!<%?$OPBR $K3JG<$7$F%"%/%;%9$9kI,MW,$"$k!#$=$N%G!<%?@8@.$K;~4V$,$+$+CF$$$k!#
- %m!<%+%k%a%b%j$N%m!<%I/%9%H%"$K$O1 %5%$%/%k$N%9%H!<%k$,H<$&!#$3N?$a%m!<%+%k%a%b%j%"%/%;%9$,IQ=P9k%W%m%;%94IM}K*$$$F%5%$%/%k?t$,A}Bg7F$$$k!#

:#2s$N<BAu$K$*$$$FMQ$$$?C %3%s%Q%$%i$K5/0x 9kLdBjKO<!$NE@$,5s2ilk!#

%/%i%9%?%a%b%j%"%/%;%9$KH<$&%9%H!<%k

:#2s$NC %3%s%Q%$%i$O!"3.3@a$K$*$$$F=R$Y $?$h$&$K!"%/%i%9%?%a%b%j%"%/%;%9L?Na$ND> 8e$K%a%b%j%P%j%"L?NarCV/h&$J<BAu$K$7 $F$$$k!#

$=$N$?$a:#2s$NDSM 4IM}%W%m%0%i%`$O!"%/%i%9%?%a%b%j%"%/%;%9$KH<$&%9%H!<%k$,:GD9 KJCF$$$k!#

L5BL$J%9%?%C/L?Na

%3%s%Q%$%i$O4X?t$N;O$a$K callee save %1%8%9%?$N%9%?%C/XNB`Hr$r9T$&L?NaNs$r=PNO 9k!#

7+$7:#2s$NDSM 4IM}%W%m%0%i%`$G$O!"$3$NB`Hr$,L5BL$J4X?t$,$"$k!#$3lO<!Nh$&$J4X?tG"$k!#

MBP-light >e$NDSM 4IM}%W%m%0%i%`$O!"%Q%1%C%H$N3d$j9~$_$KhC$F5/F0$5lk!#3NH-!"FbIt%a%b%j$K%^%C%T%s%0$5l?%"%I%l%9$K!"MBP-light $N=hM}$,0\$5lk3H$G5/F0$5lk!#3N3d$j9~$_@h$G9T$olk=hM}$b4X?t$H7FC 8@8l$G5-=R$7$?!#

MBP-light $,2?$b=hM}$r9T$C$F$$$J$$%"%$%I%k>uBV$+$i3d$j9~$_@h$X=hM}$,0\$5l?>l9gKO%1%8%9%?$N%9%?%C/B`Hr$OI,MW$J$/!"%Q%1%C%H=hM}C$G$"$k$3$H$rH=CG$7$?$H$-$KA4%1%8%9%?$NB`Hr$r9T$ (Ph$$!#

C %3%s%Q%$%i$K4X9kLdBjKO2~A1$NM>CO$,$"$k$?$a!"$=$N2~A1$,9T$ol?>l9g$NM=A[=hM};~4V$r5aaF$_$?!#

:#2s$N%W%m%0%i%`$G$O!"%/%i%9%?%a%b%j%"%/%;%9$K4X$9$k%9%H!<%k;~4V$O!"%/%i%9%?%a%b%jF I$_=P$7;~KO11 %5%$%/%k!"=q$-9~$_$K$O13 %5%$%/%kG"C?!#

%3%s%Q%$%i$K$*$$$F3N:GE,2=$,9T$o$l!"4X?t8$NJL?Na$,A^F~$G$-$KJi$P!":#2s$N%W%m%0%i%`K*$$$F$O!"0J2<$K< (9@1N%5%$%/%k?t$N:o8:$,?^$l$k!#

- F I$_=P$7MW5a !&&2 DN%/%i%9%?4VK*$$$F!"%/%i%9%?%a%b%j=q$-9~$_$,9g7W4 2s9T$olF$$$k$?$a!":GBg52 %5%$%/%k$N:o8:$,$G$-$k!#
- 9 9?7MW5a !&&2 $D%/%i%9%?$H$b!"%/%i%9%?%a%b%j=q$-9~$_!"F I$_=P7,$=$l$>$l$,1 2s9T$olF$$$k$?$a!":GBg24 %5%$%/%k$N:o8:$,$G$-$k!#

:o8:%5%$%/%k?t$N:GBgCM$O!"%9%H!<%k$r5/$3$5$J$$DxEY$KL?Na$,A^F~G-$?>l9g$G$"$k!#

$^$?L5BL$J%1%8%9%?B`Hr$O!"F I$_=P$7MW5a=hM}GO9g7W81 %5%$%/%k!"9 9?7MW5a=hM}$G$O!"21 %5%$%/%kB8:_7?!#

I=5$K!"%/%i%9%?%a%b%j$KH<$&%9%H!<%k$r5/$3$5$J$$DxEY$KL?Na$rA^F~G-!"L5BL$J%9%?%C/A`:n$r4 0A4$KGS=|$G$-$?>l9g$KM=A[$5lk=hM};~4V$r< ($9!#

I=5: %3%s%Q%$%i2~A18e!"M=A[$5$1$k=hM};~4V

=hM}FbMF	M=A[;~4V (%5%$%/%k)	2~A1A0HNHf (%)
FI$_=P$7MW5a	789	85.8
9 9?7MW5a(Itnitiator)	377	89.3
9 9?7MW5a(Home)	395	89.8

%3%s%Q%$%i$N2~A1Kh$j!":G9b10 ?t%$N9bB.2=$,$J5l!"%"%;%s%V%j$G5-=R$5l?bNhj$b=hM};~4V$,B.$/$Jk3H,4|BTG-$k!#$3lO:#8e$N2]Bj$G$"$k!#

6 $*$ojK

K\9FGOJUMP-1 K*1kMBP-light $rBP>]$H7?C %3%s%Q%$%i$N<BAu5Z$S!"$=lr;HMQ7?%/%i%9%?4VJ,;66&M-%a%b%j4IM}%W%m%0%i%`$N<BAu$K$D$$$F=RY?!#

<B:_9k%"%W%j%1!<%7%g%s$rF0$+$9$3H,G-lP5i$K@5$7$$I>2A$,$G$-$kG"m&$,!"JUMP-1$,L$40@.$N$?$a!"K\9FGOL5I}2Y>uBVGNI>2A$r9T$C$?!#$3$NI>2A$KhjFI$_=P$7MW5a%Q%1%C%H$,H/9T$5lF$+$i1~Ez%Q%1%C%H$,E~Ce$9k^GK$+$+$k;~4V$,Ev=i$NM=Dj$hjb7.3 G\$N;~4V$,$+$+$k7k2LHJC?!#

:#2s<BAu7?C %3%s%Q%$%i$G$O!"%/%i%9%?%a%b%j%"%/%;%9K*1k:GE,2=$,9T$olJ$$!#3N7k2L<BAu5l$?%W%m%0%i%`$K$*$$$F!"%/%i%9%?%a%b%j%"%/%;%9$K$*$$$F:GD9$N%9%H!<%k$,H/@8$7$F$7$^$&!#$^$?!"%3%s%Q%$%i$O4X?t$N;O$a$K$O%1%8%9%?B`Hr$r9T$&L?Na$r=PNO9k3H$+$i!"3d$j9~$_@h$N4X?t$K$*$$$F$OL5BL$J%1%8%9%?B`Hr$r9T$&!#3N3H$,A4BN$N=hM}$N%5%$%/%k?t$rA}Bg$5$;$kMW0xHJCF$$$k!#3NLdBj$r2r7h$9$kC %3%s%Q%$%i$N2~A1$,:#8e$N2]Bj$G$"$j!"3lKh$j:G9b10 ?t%Q!<%;%s%H$N9bB.2=$,$J5l!"%"%;%s%V%i$G5-=R$5l?bNhj$b=hM};~4V$,B.$/$Jk3H,4|BT5l$k

<U<-

K\8&5f$N5!2q$rM?$($F$/$@5j!"E,@Z$J8f;XF3$r;roC$?IYEDbC<#65<x$K?<?S$J<U0U$rI=7^$9!#

$^$?!"5.=EJ4=u8@$r$$$?$@$$$??9bC0lO:=u65<x!"8^Eg@5M5=u<j$K?<$/46<UCW7^$9!#

5i$K!$6&F18&5f<TG"$k;3K\9M?-;a!"GiC+2m;K;a!"DEED7r;a!"A0@nJY;a!";3FbAo;arO8aH7$F!$F|:"$+$i8fJ\Z%2<5C$?5~ETBg3XBg3X1!>pJs3X8&5f2JDL?.>pJs%7%9%F%`@196IYED8&5f<<$N=t7;$K46<UCW7^$9!#

F|:"$+$i5.=E$J8f0U8+$rD:$$$F$$$kJ8It>J=EE@NN0h8&5f6&F18&5f<T3F0L$K46<UCW$7$^$9!#

$^$?!"%a%s%?!<!%0%i%U%#%C%/%9!%8%&%Q%s3t<02q<R$NHigher Education Program $N014D$H7F@=IJ$H%5!<%S%9$r$4Ds6!D:$$$?3H$K46<U$7$^$9!#

;29MJ88%

[1] :4F#=<B>!'!D6JBNs%^%7%sJUMP-1 N?aNJ,;66&M-%a%b%j4IM}%W%m%;%C%5!W"JBNs=hM}%7%s%]%8%&%`JSPP '97, pp. 265-272.

[2] ;3K\9M?-B>!!D6JBNs7W;;5!JUMP-0.5 K*1kJ,;66&M-%a%b%j4IM}<jK!!W>p=h8&Js97-ARC-125, pp. 85-90!%

[3] J!Eg D>?M!'!A+0\E*L7=b$r5vMF$9$k%a%b%j!&%b%G%k$K4pE/014S@-@)8fJ}<0!W"=$;NO@J8,5~ETBg3X(1996)

[4] JUMP-1 @_7W%0%k!<%W!MBP-light %^%K%e%"%k(1997 12/5)

[5] Richard M.Stallman : Porting GNU CC