7QB3$H7hDjE*%9%1%8%e!<%j%s%0$rMQ$$$?%j%"%k%?
%`!&%7%9%F%`

Real-time System using Continuation and Deterministic Scheduling

2OLn ??<# MH Dr

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Abstract

?7$7$$%j%"%k%?%$%`!&%7%9%F%`$N9=C[K!H7$F!"7QB3$r;}$D8@8l CbC Kh$k%7%9%F%`9=C[<jK!$K$D$$$F9M;!$9$k!#=>Mh$N<jK!$G$N3d$j9~$_$N%*!<%P%X%C%I$N860x$r9M;!$7!"= Mh$N RTOS + %"%W%j%1!<%7%g%s$H$$$&OHAH!"OS + %H%i%C%W$H$$$&J}<0$G$O$J$/!"3d$j9~$_$r>uBVA+0\$H$H$7$F$H$i$(!"%7%9%F%`$N1~Ez@-$r>e$2k3Hr9M$($k!#K\<jK!$G=EMWJk CbC $G3d$j9~$_$r<B8=9k>uBVA+0\5-=RKD$$$F9M;!9k!#

1 =>Mh$N%j%"%k%?%$%`!&%7%9%F%`$r1[$($F

6aG/$N%j%"%k%?%$%`!&%7%9%F%`XNMW5a$O!"
=>MhNbNH!"Bg$-$/0[JCF-$F$$$k!#%M%C%H
%o!<%/$d CPU $NB.EY$N8~>eHHbK!"%j%"%k%?%
%$%`$NF02h:F@8$d!"%f!<%6$K%j%"%k%?%$%`$G1~
Ez9k 3D %0%i%U%#%C%/%9%O!<%I%&%'%"HNO"78
$,$J1l$P!"$3li$NMW5a$KEz$($k3H$O=PMh
J/JjDD$"$k!#

K\O@J8GO!"7QB3Cf?4H9$k=>Mh$H$O0[$J$k
%W%m%0%i%_%s%0C10L$rF3F~$9k3HKhj$"
%O!<%I%&%'%"$H%=%U%H%&%'%"
;EMM5-=R$H<BAu5-=R
JI$NJ,N%$r>h$j1[$($F!"?7$7$$%j%"%k%?%$
%`!&%W%m%0%i%_%s%0$N<jK!$rDs0F9k!#

3l$^$G$N%j%"%k%?%$%`!&%7%9%F%`$O!"RTOS
(%j%"%k%?%$%`!&%+!<%M%k) $rCf?4$H7F!"%?%9
%/$rDj5A$7!"%7%9%F%`%3!<%kKh$j!"CPU
JI$r%+!<%M%k$,;q8;$r4IM}$9$k<jK!$rHC$F
$$$k!#RTOS $NCf?4$O!"%9%1%8%e!<%iG"$j!"%a
%b%j$d CPU $N;q8;$,bCHb=EMWG"C?;~Be
$N@_7W$HJC$F$$$k!#

%j%"%k%?%$%`!&%7%9%F%`$G=EMW$JMWAG$O30It
$N%$%Y%s%HXNBP1~G"$k!#$3li$O!"
D74|E*$K30It%G%P%$%9$r8+$K9T$/%]!<%j%s%0
30It$+$i$N?.9f$Khj=hM}$r6/@)E*$KJQ$($k3d
$j9~$_
$NFs<oN`$,$"$k!#3liN30It%G%P%$%9$O!"
RTOS NCfGI8=`E*$J API Kh$j%"%/%;%9$9$k
L-MW$,$"$j!"FCJL$J;q8;H7$F RTOS 8GM-$J$b
NH7FDj5A5lk3H,B?$$!#J#?t$N%W%m%;%C
%5$r;}$D%7%9%F%`GO!"F14|$r9T$J$&%;%^%U%)$J
Ib RTOS $N%G%P%$%9H7$FDj5A$5lk!#

0lJ}$G!"%O!<%I%&%'%"$O!"Verilog $d VHDL $N
h&$J%O!<%I%&%'%"8@8l$GJL$K5-=R$5$l!"RTOS
$+$i$N;q8;4IM}$HOJLK5-=R5l$F$$$k!#%O!<
%I%&%'%"$N=8@QEY$O7`E*$K>e$,CFMhF*$j!";q
8;$NM-8zMxMQ$hjO!"=EMWJN$O>CHqEENO$dB.
EYKJQoCFMh$F$$$k!#%O!<%I%&%'%"%l%Y%kGN
J#?t;q8;$N6%9g$O!"DL>o$O!"%P%9$N@jM-=hM}H7
FI=lk!#3liO!"%"!<%S%?$H8F$Plk@lMQ$N
J2sO)$G<B8=$5lkN,IaDLG"$k!#

1.1 =>Mh$N%j%"%k%?%$%`!&%7%9%F%`$NLdBjE@

RTOS $H%O!<%I%&%'%"$N4V$O!"%O!<%I%&%'%"B&$,Dj5A9k API K7$?$,CF9TJolkN,IaDLG"$j!"$3l,!"%O!<%I%&%'%"B&$N=hM}$NJ#;(5N860xKJkHHb$K!"%=%U%H%&%'%"$r4^$`%7%9%F%`$N%G%P%C%0JIrFq7$/$7$F$$$k!#3l$,<B5!$N$J$$>uBVGN%7%9%F%`8!>Z$d!"ICE (In-Circuit Emulator) H4$-$G$N%G%P%C%0$rIT2DG=K7$F$$$k!#

%j%"%k%?%$%`!&%7%9%F%`$r9=@.9kNO!"5^6^$J<B:]$N=hM}$r9T$J$&%?%9%/$G$"$k!#%?%9%/$O!"%O!<%I%&%'%"!&%=%U%H%&%'%">e$G!"C`<!$"$k$$$OF1;~$K=hM}$5$l$k!#J#?t$N%?%9%/$,FCDj$N;q8;$r6&M-$9$k>l9g$O!"F14|$r$H$k$3$H$,I,?\$G$"$k!#$7$+$7!"%O!<%I%&%'%">e$NF14|J}<0$H!"%=%U%H%&%'%">e$NF14|J}<0$O!"JL$JJ}K!$G<B8=$5$l$F$$$k!#$3$l$,%7%9%F%`5-=R$rJ#;(K7$F$$$k!#

RTOS GO!"3d$j9~$_$H%?%9%/@ZBX$(Kh$k%*!<%P%X%C%I$r8:i9$3$H$,=EMW$G$"$k!#7+$7!"RTOS $N2pF~$Khj!"$`$7$m!"$=$N%*!<%P%X%C%I$OA}$($k798~K"$k!#

AH$_9~$_%7%9%F%`$G$O!"%a%b%j$O8B$i$l$?;q8;$G$"$k!#$7$+$7!"9=B$2=%W%m%0%i%_%s%0$d%*%V%8%'%/%H;X8~%W%m%0%i%_%s%0$O!"%9%?%C%/$K0MB8$7$F$$$k!#86M}E*$K;HMQNL$rM=B,$7$E$i$$%9%?%C%/$N;HMQ$OAH$_9~$_%7%9%F%`$K8~$+$J$$!#7?$,$C$F!"9=B$2=%W%m%0%i%`$"$k$$$O!"%*%V%8%'%/%H;X8~%W%m%0%i%`$rA4LLE*$K:NMQ9k3H$,$G$-$J$$!#

2 7QB3$rCf?4$H7? C 8@8l CbC

CbC (Continuation based C) [2] $O!"K\8&5f<<$G3+H/7?!"%k!<%W$H%5%V%k!<%A%s%3!<%k$r;}$?$J$$C 8@8lG"$k!#DL>o$N%5%V%k!<%A%sNBej$K!"$9YF$O!"code $H8F$PlkC10L$rMQ$$$F%W%m%0%i%_%s%0$5$l$k!#0J2<$NNcGO!"state1 $O!"F~NO>uBV input $O!"interface $H8F$Plk9=B$BN7?state $G5-=R$5lF$$$k!#state1 $O!"%Q%i%a%?$U$- goto J8$GJ,4t5lk^GN=hM}$r5-=R$9$k!#

```
code state1(state input,state arg) {
    if (input_cond1(input)) {
        goto state2(arg);
    } else if (input_cond2(input)) {
        goto state2(arg);
    } else if (input_cond3(input)) {
        goto state3(arg);
    }
}
```

Stack $rL@<(E*$K<h$j07$&3HKKhj!"DL>o$N C 8@8l$r!"CbC $X%3%s%Q%$%k9k3H$b2DG=$G$"$k!#

code $O goto J8$N9T$-@h$G$"$j!"9T$-@h$r4V@\E*$K;XDj$7$?$bNO!"7QB3$H8F$Plk!#9JoA!"CbC $O!"7QB3$N$_$r;}$D C 8@8l$@$H$$$&3H$,$G$-$k!#

3N8@8l$O!">uBVA+0\$r5-=R9k$?$a$N8@8l$G$"$j!"C $G5-=R$7$?%=%U%H%&%'%"ItJ,$H!"VHDL JI$G5-=R$7$?%O!<%I%&%'%"ItJ,$NN>J}$rF1;~$K5-=R9k3H$,0l$D$NL\I8$HJC$F$$$k!#$^$?!">uBVA+0\$r5-=R9k3HKh$j!">uBVA+0\5-=R$Khk;EMM5-=R$b!"$3$N8@8l$rMQ$$$F5-=R9k3H$,$G$-$k!#

9=B$2=%W%m%0%i%_%s%0$"$k$$$O!"%*%V%8%'%/%H;X8~%W%m%0%i%_%s%0$G5-=R$5l?bN$r!"CbC $KJQ49$9k3HKhj!"%j%"%k%?%$%`1~Ez@-$dA4BN$N;q8;$N;HMQNLJIrOC-$jM=B,$9k3H,=PMhkh$&$K9k3H$,K\8&5f$NL\E*G"$k!#K\0@J8$G$O!"FC$K>uBVA+0\$r;HCF RTOS $N%*!<%P%X%C%I$J7K3d$j9~$_$r=hM}$9$kJ}K!$r9M;!9k!#(fig.1)

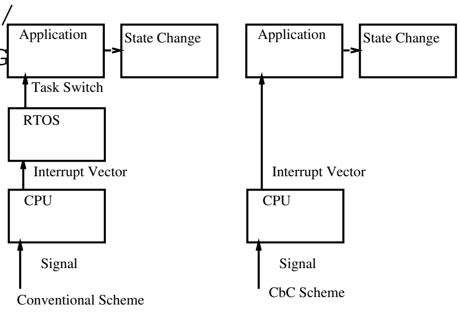

Fig1 New Real-time Scheme

3 CbC $N%?%9%/$H%9%1%8%e!<%i

CbC GO!"code $N<B9T$N%7!<%1%s%9$,<+A3$K%?%9%/$r9=@.$9$k!#code $O!"%k!<%W$r4^$^$J$$$N$G!"<B:]$N<B9TKh$j<B9T;~4V$rB,Dj9k3H$,2DG=$G$"$k!#%?%9%/$NFbIt>uBV$O!"Bg0hJQ

?t$H interface Kh$j7hDj$5$1$k!#D^$j!"=>Mh $N%9%?%C%/7?8@8l$H0[Jj!"8F$S=P$5$1$? code $,$9YF$N>uBV$rL@<(E*$K;}$C$F$$$k!#

7?$,$C$F!"CbC $N%?%9%/@ZBX$($O!"7h$^C? interface $r;}$D0lDN code G"$k%9%1%8%e!<%i $r8F$S=P$9$3HKhC$F<B8=$G$-$k!#%9%1%8%e!<%iGO!"interface $K3JG<$5$1$?>uBV$r!"E,Ev$J Bg0hJQ?t%?%9%/%-%e!<$K3JG<$7!"JL$J%?%9%/$KBP 1~7? interface >uBV$r<h$j=P7F!"E,@Z$J code $X goto $9$1$PNI$$!#

=>Mh$N%9%?%C%/7?$N%W%m%0%i%_%s%08@8lGO!"3Nh&$JA`:n$O!"K\<AE*$K5-=R$9k3H,G-$J$$!#$=$1$O!"%9%?%C%/$K3JG<$5$1$?4D6-$XD>@\%"%/%;%9$9$k3H$,$G$-$J$$$+iG$"$k!#7?$,$C$F setjump JIh&$KFCJL$J API $rMQ0U$9kI,MW,$"$k!#

3.1 %j%"%k%?%$%`!&%7%9%F%`$G$N3d$j9~$_=hM}

3d$j9~$_$O!"%j%"%k%?%$%`%7%9%F%`GO!"=EMW$JMWAG$G$"$k!#3d$j9~$_$O!"DL>o$O!"CPU $N FCJL$J5!G=H7$F<B8=$5$1$F$$$k!#3d$j9~$_$O%s%H%m!<%i$JINJd=uE*$J5!9=$rMQ$$$k3H$b $"$k$,!"4pK\E*$K$O

CPU KO!"3d$j9~$_$rH/@8$5$;$kFCJL$J1.9f @~$,MQ0U$5$1F*$j!"CPU $N2sO)$,$=$N?.9f@~ $r>o$K%A%'%C%/7F$$$k!#?.9f$,Mh$k$H!"CPU $O!"8=:_<B9TCf$NL?Na%Q%$%W%i%$%s$rCfCG$7!"Fb It>uBV$r%;!<%V$9$k!#<!$K($"$k$$$O!"$=$1$HJB 9T$7J,$i) ?.9f@~$KBP1~7?3d$j9~$_%Y%/%? rFI_9~$$`!#%Y%/%?K7$?$,CF!"?7$7$$=hM} $r?J$a$k!#$3l, CPU KHCF$N3d$j9~$_$G$" $k!#3d$j9~$_%Y%/%?$O!"8=:_GO!"3d$j9~$_%3%s %H%m!<%i$+$iM?$($ilk3Hb"$j!"2>A[5-21 JI$N=hM}b+$isGJ#;(G"$k!#3d$j9~$_$O!" CPU KHCF$OFCJL$J>uBVG"$j!"$3lr2r=| 9k;EAH$_$,I,MWG"$k!#DL>o$O!"3d$j9~$_>uBV $,2r=|$5$1$k$^$G?75,$N3d$j9~$_$O!"<u$1IU$1 k3HO$"$CFb!"=hM}$5$1$J$$!#3l$r=hM}$9 k3HK9k$H!"CPU $N%;!<%V$7$?>uBV$d!"3d $j9~$_MW5a@h$N>uBV$,<:ol$k2DG=@-$,$"$k!#

- 3d$j9~$_?.9f8!CN
- 8=<B9T>uBV$N3JG<
- 3d$j9~$_%Y%/%?7hDj
- 3d$j9~$_=hM}%k!<%A%s$N8F$S=P$7
- 3d$j9~$_>uBV$+$i$NI|5"

RTOS $+$i8+$?3d$j9~$_=hM}$O!"$=$N8e$K;O $^$k!#DL>o!"RTOS $O!"HFMQ$N3d$j9~$_=hM}%k!<%A%s$r;}$CF*$j!"$=1,8F$S=P$5$1$k!#7+ $7!">u67$O!"5i$KJ#;($G$"$k!#

[CPU 7?] CPU $+$i$N3d$j9~$_$rD>@\=hM}9k **RTOS** $KB0$5$J$$%k!<%A%s

[Call 7?] CPU $N3d$j9~$_>uBV$O2r=|9k$,!"%?%9%/@ZBX$($rH<$o$J$$ **RTOS** $N3d$j9~$_=hM}%k!<%A%s

[Task 7?] %?%9%/@ZBX$($rH<$&=hM}

$N;0<oN`$N=hM}$r;}$C$F$$$k>l9g$,B?$$!#(3liNL>A0$O>!<j$JbNG"$k) $=$1$>$l!"FCD'$,$"$j!"

[CPU 7?] 9bB.1~Ez$,2DG=$G$"$k$,!"**RTOS** $N;q8;$r;H$&$3HO0l@Z=PMh$J$$!#B>$N3d$j9~$_$r<u$1IU$1k3H,=PMh$J$$!#

[Call 7?] $"$kDxEY$N **RTOS** $N;q8;(%9%?%C%/$d%1%8%9%?) $r;H$&3H$,$G$-$k$,!"D9;~4V$N=hM}$r9T$JC?$j!"**RTOS** $NB>$N%G%P%$%9$K%"%/%;%9$9$kh&J3HOG-$J$$!#**CPU** 7?0J30$N3d$j9~$_=hM}$r9TJ&3H$,$G$-$J$$!#

[Task 7?] 1~Ez;~4V$,$bCHb+$+$k$,!"**RTOS** N9YF$N;q8;$K%"%/%;%9G-$k!#

$H$$$&h&KJCF$$$k!#%G%P%$%9%I%i%$%PGJIN=hM}$O!"%"%/%;%9$k;q8;$O!"%G%P%$%9N_$K8B$k$?$a$K!"Call 7?$G==J,J3H,B?$$!# Unix JI$N9bEY$J OS GO!"CPU 7?$N3d$j9~$_$r=hMQ9k3HO[HsIJ$$!#RTOS $O!"<B:]$N%"%W%j%1!<%7%g%s$NFbMF$K$O!"4X$oiJ$$!#@8$8$?3d$j9~$_$r%"%W%j%1!<%7%g%s$KH?1G9k3H$O!"%?%9%/@ZBX$($,H<$&NG!"I,$: Task 7? $N3d$j9~$_=hM}$,I,MWG"$k!#

D^$j!"<B:]$N3d$j9~$_=hM}$O!"

CPU 7? "* **Call** 7? "* **Task** 7?

$H$$$&<j=grF's$G%"%W%j%1!<%7%g%s$KH?1G$5$1k3HKJk!#Nc$($P!"Unix GO!"3d$j9~$_$N7k2L$O!"%"%W%j%1!<%7%g%sB&GO!"0J2<Nh$&$KH?1G$5$1$k!#

read/write JI$N%7%9%F%`!&%3!<%k$+iNI|5"

FC$K **select** %7%9%F%`!&%3!<%k$+$i$NI|5"

%7%0%J%k%O%s%I%i$N8F$S=P$7

%7%0%J%k%O%s%I%i$r7PM3$7$J$$%W%m%;%9$N>uBV$NJQ99

3liO!"9Y$F!"$Jsi$+$N%$%Y%s%HBT$A%k!<%W$rMW5a$9kN$,IaDL$G$"$k!#D^$j!"30It$HAj8_:nMQ9k%"%W%j%1!<%7%g%s$O!"$9YF!"

```
for(;;) {
```

```
        fds = select(...);
        do_service();
    }
```

Nh$&$J7A$r<h$k3HKJ$k!#Unix $N daemon $O!"$3Nh$&$JbN$NE57?$G$"$k!#3l$r $3$3GO!"%a%$%s%k!<%W<jK!$H8F$V!#

%"%W%j%1!<%7%g%s4V$NDL?.$b!"3Nh&$J7A $G<B8=$5lF$$$k3H$,B?$/!"<B:]$N30It%$%Y%s %H$,%"%W%j%1!<%7%g%s$N5sF0$KH?1G$5lk$^$G KO!"

3d$j9~$_ "* %a%$%s%k!<%W "* %+!<%M%kMW5a $N7+$jJV7rB??t$($k3HKJ$k!#

3liN7+jJV7$,!"FC$K Unix GN!"3d$j 9~$_1~Ez$NB.EYDc2<$r0z$-5/$3$7$F$$$k!#<B:]$K $O!"%?%9%/@ZBX$(KO!"2>A[5-214XO"$N=hM}$bF~ k?aK!"5i$K%*!<%P%X%C%I$,A}$($F7^$&!# 3l$,!"2>A[5-21%5%]!<%H$,%j%"%k%?%$%`%7%9 %F%`GO6X;_$5lk860xGb$"$k!#

7+$7!":#$O!"2>A[5-21$r;}$Dh&$J5pBg$J %7%9%F%`$K$3$=%j%"%k%?%$%`1~Ez@-$,MW5a$5$l $F$$$kNG$"$j!"$3$3$G=R$YFMh?h&$J3d$j9~ $_1~Ez$N%*!<%P%X%C%I$r86M}E*$K4^$^$J$$$h$& $J30It%$%Y%s%H$N=hM}$N;EAH$_$,I,MWG"$k!#

Bg$-$J%7%9%F%`!"Unix $d Windows $N1~Ez@-$, CPU B.EY$N8~>e$K8+9g$&Dx!"9bB.$K$J$C$F$$ $J$$$O!"BN46>e$b;v<B$G$"$j!"$J$s$i$+$N86M}E* $J2r7h$,I,MW$G$"$k!#%F%l%S%2!<%`$d!"%S%G%*=h M}%7%9%F%`$J$I$N1~Ez@-$O7h$7$F0-$/$J$$$G$" $j!"$3$l$O!"%O!<%I%&%'%"$d%=%U%H%&%'%"$N8B=& $H8@$&$h$j$O!"8=:_$N%=%U%H%&%'%"$r4^$`%W%m %F%/%A%c$N8B3&$G$"$k$H9M$(il$k!#

4 %O!<%I%&%'%">eGN3d$j9~$_

EE;R2sO)$=$NbNKO!"3d$j9~$_$H8@$&35G0 $OB8:_$7$J$$!#3d$j9~$_$r8!=P$9$k?.9f@~$O!"FC $KFCJL$JbNGO$J$$!#8=:_$N%O!<%I%&%'%"$O!" M-8B>uBVA+0\$G5-=R5l$F$$$kN,IaDLG"$k!# D^$j!"3d$j9~$_$O!"$=$N>uBVA+0\@)8f9k?.9f @~$N0lIt$G7+$J$$!#

7+$7!"%O!<%I%&%'%"$,J#;(KJkKDl$F!"$=Nh$&$JC1=c$J%$%a!<%8GO!"3d$j9~$_$r@5$7$/M}2r$7$?$3HKOJiJ$$!#8=:_$N%O!<%I%&%'%"$O!"C1=c$J 1 %l%Y%k$N>uBVA+0\7OGOJ/!"J# ?t$N>uBVA+0\7O$N9g@.HJCF$$$k!#$=$l$>$l$N 2sO)$O!"DcEENO2=JIN?aK!"EE8;$,6!5k$5$l $F$$$J$+$C$?$j!"CY$$%/%m%C%/$G6nF0$5lF$$$? j9$k!#FC$K!"%Q%$%W%i%$%s>e$N=hM}$r%O!<%I %&%'%"$G9T$J$&$3HO!"bO$dIaDL$G$"$j!"G$0U $N;~E@$G!"G$0U$N>uBV$K0\9T$9k3HO!"%O!<%I %&%'%"Gb4JC1J3HGOJ$/$JCF$$$k!#

%Q%$%W%i%$%s!&%"!<%-%F%/%A%c$N3d$j9~$_$O!" 30It$+$i8+$($kY-%O!<%I%&%'%"$N>uBV$H!"FbIt GN>uBV$,0lCW$7$F$$$J$$$H$$$&3H$r9MN8$9 kI,MW,$"$k!#3d$j9~$_$r<u$1$?CJ3,$G!"%O!<%I %&%'%"$O!"3d$j9~$_>uBV$K0\9T9k$,!"$=lO!" %O!<%I%&%'%"$N<u$1IU1?F~NOMzNr$NFCDj$NCJ 3,$G>uBV$r0\9T7?7ArHkI,MW,$"$k!#%Q%$ %W%i%$%s<B9T$dEj5!E*<B9TGO!"FbIt$N>uBV$r!" $=$NFCDj$N>uBV$K<}B+5;kI,MW,$"$k!#$=$N $?$aKO!"%Q%$%W%i%$%s$r9=@.$9$kJ#?t$N>uBV A+0\5!3#$rF14|$5$;$kI,MW$,$"$j!"I,A3E*$K;~4V $,$+$+$k3HKJ$k!#

3lrHr1$kJ}K!$N0lDO!"3d$j9~$_$r<u$1 IU1k%O!<%I%&%'%"rJLKMQ0U9k3HG"$k!# Nc$($P!"3d$j9~$_$r<u$1IU$1$J$$ CPU JI$rFH N)$KMQ0U9k3HKh$j!"3d$j9~$_$N%*!<%P%X%C %I$r2<$2k3H,G-$k!#$7$+$7!"3l$O!"3d$j 9~$_$N1~EzB.EY$r>e$2k3HK$O7k$SIU$$$F$$ $J$$!#

5 %3!<%k%P%C%/

%=%U%H%&%'%"$+$i8+$?3d$j9~$_$O!"%a%$%s%k!<%W$G3NJ}K!H7FO!"%3!<%k%P%C%/$H$$$&<j K!$G<u$1IU1k3H$,$G$-$k!#%3!<%k%P%C%/$O!" %$%Y%s%H%O%s%I%i$K!"$"$k%?%9%/Fb$K$"$k%5%V %k!<%A%s$r0zEO$9!#%$%Y%s%H%O%s%I%i$O!"$=$N %k!<%A%s$r30It%$%Y%s%HK7$?$,CF8F$S=P$9!#

3NJ}K!$O!"$bHb$H%$%Y%s%H6nF07?$K=q$$ F"$k%"%W%j%1!<%7%g%s$K$OM-8z$G$"$k!#Nc$($P!"GUI %"%W%j%1!<%7%g%s$N%\%?%sKh$K%3!<%k %P%C%/$r3djEvFk3HKhj!"%\%?%s>uBV$rBg 0hJQ?t$KH?1G9k3H$O4JC1$G$"$k!#Bg0hJQ?t $O!"%a%$%s%k!<%W$N?6Iq$rJQ$($k$?$a$K;H$o$l kN$,IaDLG"$k!#D^$j!"Bg0hJQ?t$rJQ99$9$k <jK!GO!"%a%$%s%k!<%W<jK!$H1~Ez@-$H8@$&E@ GO;9$,$J$$!#

Unix $N signal $b%3!<%k%P%C%/!&%k!<%A%s$N0l <oG"$k!#$7$+$7!"signal $O!"30It>uBV$rD>@\EO

$9$3HO=PMh$J$$!#signal $r<u$1$?%?%9%/$O!"JL$^$lkh$&$K9k3H$,3d$j9~$_$N%*!<%P
ES!"signal $N860x$rD4Yk$?$a$K!"$Jsi$+$N%X%C%I8:i9$3$HKDJ,kH;Wol$k!#
%P%$%9$K%"%/%;%9$9$kI,MW$,$"$k!#$=$ND4$Y$k%O!<%I%&%'%"$G$b!"J]B8$9Y->uBV$,%/%m%C
%k!<%A%s$O!"%a%$%s%k!<%W$+$i8FPl$J$$$H$1%C%9L$"$k$$$O!"L?NaC10LG"k3H,!"LdBj$r
kH!"I,A3E*$K!"%W%m%0%i%`A4BN$r%^%k%A%9%l%F9$7$/7F$$$k!#3d$j9~$_$,5/$-$?;~$K!"8=:_$N
%I$G9=@.$9kI,MW,$"$k!#$=$N$?$aKO!"J#?t$N#Q%$%W%i%$%s>uBV$hjbBg$-$JC10LGN>uBV$K
%9%l%C%I$,%;%^%U%)$JINF14|rI,MWH$7!"$$$9k3H,G-lP!"hj%O!<%I%&%'%"9=@.$,4J
$,!"$^$?!"JL$J%*!<%P%X%C%IKJ$k!#K\Mh!"M>7WC1$KJk2DG=@-$,$"$k!#
$JF14|$rHr1kY/F3F~5l$?%3!<%k%P%C%/$,!"
M>7W$JF14|$rF3F~7F$$$k3HKJ$k!#(fig.2)

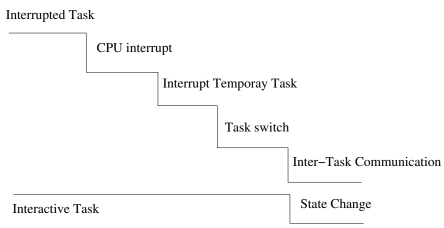

Fig2 Interrupt Overhead

6 3d$j9~$_$H>uBVA+0\

3l$^$G!"8+FMh?3d$j9~$_$N<jK!$O!"F1$8$3H,7+jJV7I=lF$$$kN,J,$+$k!#$=$l$O!"3d$j9~$_$NK\<A$O!">uBVA+0\$G$"$j!":G=*E*$J%?%9%/$N>uBVrJQ(kH$$$&L\E*$r2L$?9?aK$O!"$5$^$6$^$J>uBVA+0\$rCfCG5;kI,MW,$"$k$H$$$&3HG"$k!#

7+$7!"30It%$%Y%s%HKhCFF0:nrJQ($k%"%W%j%1!<%7%g%s$N>uBVA+0\$,bCHb=EMWJNG"$j!"%O!<%I%&%'%"%l%Y%k$G$N3d$j9~$_$D>@\%"%W%j%1!<%7%g%s$N>uBV$rJQ$($k3H$,$^$7$$$3HO8@$&$^Gb$J$$!#

LdBj$O!"%"%W%j%1!<%7%g%s$=NbN,>uBVA+0\$r<u$1IU$1k3Hr9MN8$7$F$J$$$3H,JN$@$H;Wol$k!#CPU $N;}$D%Q%$%W%i%$%s@.$d!"%?%9%/$r9=@.9k;q8;<+BN$,!"30It$N>uBVKhCF>uBVA+0\$9k3HrCf?4$K:n$ilF$$J$$$3H,!"3d$j9~$_=hM}$N%*!<%P%X%C%I$=NbNKJC$F$$$k!#

%"%W%j%1!<%7%g%s$,%a%$%s%k!<%W$G9T$JCF$$$k3H$O!"4pK\E*$K$O%]!<%j%s%0$G$"$k!#%j%s%0HO!"%$%Y%s%H$,5/$-$F$$$k$+$I$&$+CG9k5!9=$rDj4|E*$K8F$S=P$9$3$HG"$k!#$N%]!<%j%s%0$,<+F0E*$K%"%W%j%1!<%7%g%s$N

7 CbC GN3d$j9~$_

%5%V%k!<%A%s$r;}$?$J$$ CbC GO!"3d$j9~$_$O!"C1=c$J>uBVA+0\$G$"$k!#$=$l$O!"%9%1%8%e!<%i$rMQ$$$F4V@\E*$K5-=R$9k3Hb=PMhk7!"goto J8$N4V$K!"JL$J code $r<B9T$9kh$&$J7A$G!"0EL[E*$K5-=R7F$bNI$$!#$^$?!"code NCfK!"D>@\!"3d$j9~$_$r<($9>uBVJQ?tXN%"%/%;%9$H$$$&7A$GL@<(E*$K5-=R9k3H$b=PMh$k!#(fig.3)

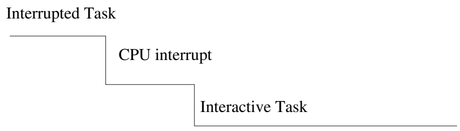

Fig3 Interrupt in CbC

7?$,$C$F!"CbC GN3d$j9~$_=hM}$O!">uBVA+0\$r CbC NCfGINh&$K5-=R$9k+$H8@$&3H$K5"Ce$5lk!#

3d$j9~$_?.9f$O!"CPU 7?$N3d$j9~$_Kh$jBg0h$JQ?t$NJQ99$K5"Ce5l$k!#JQ99$O!"C1=cJCMNJQ99G"$k$$$O!"Bg0hJQ?t>e$K9=@.$5l?%-%e!<$NJQ99$HJk!#%-%e!<$NJQ99$N>l9g$N%3%s%7%9%F%s%7!"09gE*$J%-%e!<$NJQ99$NJ]>Z) $O!"$Js+iNJ}K! (Nc$($PFI$_=P$7;~$N3d$j9~$_6X;_) $GJ]>Z$5lkI,MW$,$"$k!#

7.1 CbC GN>uBVA+0\I=8=

CbC GO!"C 8@8l$HF1MM$J>uBVA+0\$NI=8=rHk3H,G-$k!#$7$+$7!"C 8@8lGO!"%5%V%k!<%A%s$r;H$C$?%9%?%C%/$r0\F0$5$;$kI=8=$,;Holk,!"CbC $N>l9g$O!"goto J8$r;H$C$?D>@\E*$JI=8=$,2DG=$G$"$k!#4pK\E*KO!"D>@\I=8=!"4V@\I=8=!"%9%1%8%e!<%iI=8=$N;0<oN`$,9M$($ilk!#

7.2 D>@\I=8=

D>@\I=8=$O!"code Cf$N>r7oJ8H7$F>uBVA+0\ $r5-=R$9$kJ}K!$G$"$k!#9bB.$G%3%s%Q%/%H$@$,!" %3!<%I$NJQ99JIOG$-$J$$!#

```
code state1(state input,state arg) {
    if (input_cond1(input)) {
        goto state2(arg);
    } else if (input_cond2(input)) {
        goto state2(arg);
    } else if (input_cond3(input)) {
        goto state3(arg);
    }
}
```

7.3 4V@\I=8=

4V@\I=8=$O!"%F!<%V%kCf$K goto J8$N9T$-@h$r 3JG<$9k3HKhC$F>uBVA+0\$r5-=R9k!#%F!< %V%k$N=q$-49$($Khj>uBVA+0\$rF0E*$KJQ99$9 k3H,G-$k!#$7$+$7!">uBVA+0\@h$O!"$9YF F1$8 interface $r;}$DI,MW$,$"$k!#

```
code state1(state input,state arg) {
    goto (state1[input_cond(input)])(arg);
}
```

7.4 %9%1%8%e!<%iI=8=

%9%1%8%e!<%iI=8=$O!"$h$jJ#;($JJ,4t$r2DG= K9$k%9%1%8%e!<%i$r8F$S=P$9<jK!G"$k!#C;$G $O!"%9%?%C%/4D6-$K%"%/%;%9$9$k API $rF3F~$9 k3HKhC$F!"$3$NI=8=$,2DG=KJ$k!#$3$N<j K!$G$b!"8F$S=P5l$kB&$O!"6&DL$N interface $r ;}$DI,MW$,$"$k!#

```
code state1(process_queue q, state arg) {
    goto scheduler(q,arg);
}
```

7.5 %a%b%j6u4V@ZBX$($r4^$`>l9g

0J>e$N 3 <jK!$O!"9Y$FF1$8 %a%b%j6u4V>e$G <B8=$9k?aN<jK!G"$k!#$h$jJ#;($J%7%9%F% GO!"J#?t$N code %7!<%1%s%9$,JL!9$N%a%b%j6u 4V>e$GF0:n7F$$$k>u67$,MW5a$5lk!#(fig4)

%a%b%j6u4V@ZBX$(<+BN$O!"tagged TLB JI $r%5%]!<%H$7$F$$$k8=:_$N%7%9%F%`$G$O!"$=$l $[$IBg$-$J$3%9%H$GOJ$$!#%a%b%j6u4V$O!"code $N interface Cf$K0EL[$K;XDj$5l?B0@-$H9M$($i

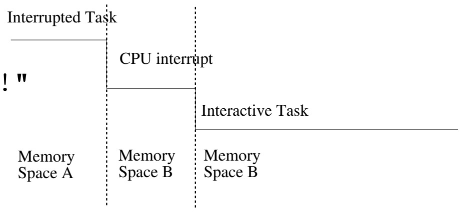

Fig4 Memory Space in CbC

lk!#code <+BN$b!"%?%9%/$,0[Jl$P!"0[$J$k %a%b%j6u4V>e$KG[CV5l$k2DG=@-$,$"$k!#

3d$j9~$_KhCF!"<!KI$N%?%9%/(code %7!< %1%s%9)$,<B9T$5lk$+$O!"7h$^$C$F$$$J$$!#$7 $?$,CF!"=>Mh$N%7%9%F%`$H$O0[$J$j!"J#?t$N%a %b%j6u4V>e$KB0$9$k code $H interface $r goto J8 $G9T$-Mh$9$k$h$&$J%7%9%F%`$HJk!#=>Mh$N%7 %9%F%`$G$O!"$J$s$i$+$N%7%9%F%`%3!<%k$,J1 lP!"%a%b%j6u4V$N@ZBX$($O5/$3iJ$+$C$?!#$7 $+$7!"CbC GO!"J#?t$N%a%b%j6u4V$rF1;~$K07 $&I,MW$,$"$k!#

3l$^$G!"$=$Nh&$JJ#?t$N%a%b%j6u4V$rF1 ;~$K07$&$3H,=PMhJ+C?NO!"0lIt$N%W%m%0 %i%`$,!"M?$($il?%?%9%/$N8"8B$r1[$($F!"B>$N %a%b%j6u4V$K%"%/%;%9$9$k3HrKI0$?$aG" $k!#$7$?$,CF!"mmap JI$N6&M-%a%b%j$rMQ $$$k3HKh$j!"5v2D$5l?%a%b%j6u4V$r<+J,$N %a%b%j6u4VKFI_JQ$($F%"%/%;%9$9$k3H$O5v 5l$F$$$?!#

7?$,$C$F!"$3Nh$&$JJ#?t$N%a%b%j6u4V$G $N43>D$rKI0?aK$O!"VFCDj$N%a%b%jNN0h7+ %"%/%;%9G-$J$$!W$H$$$&@-<A$r8!>Z$9$kI,MW $,$"$k!#8!>Z$G$-$J$$ code $N>l9g$O!"J#?t$N%a %b%j6u4V$,6&B8$9$k7AGN<B9TrG'ak3HO 4m81$9$.$k!#

7.6 %]!<%j%s%0

DL>o$N%"%W%j%1!<%7%g%s$NbCHbNI$/$"$k >u67$O!"idle %k!<%WG"$j!"idle %k!<%W>e$GJ#?t $N%a%b%j6u4V$r6&B8$5$;k3HK$OLdBj$O$J$$!# Jsi+$N%;%-%e%"$G$J$$%?%9%/$,Av$C$F$$$k>u 67GO!"Jsi+$NJ}K!$G%;%-%e%"$J code $rDj 4|E*$K8F$S=P$9I,MW$,$"$k!#

%1%"%k%?%$%`1~Ez$O!"8=:_GO CPU $NB.EY KHfY$FCY$$$N$,IaDL$G$"$k!#Nc$($P!"CPU $, GHz $GF0$$$F$$$k;~$K!"%S%G%*$N0l?eJ?@~$KMW

5a5l$k1~EzB.EY$O!"MHz 0J2<G"$k!#$7$?$,CNh&$J>u67$G!"FCDj$N;~E@$G@8$8$k2DG=
$F!"$3$N%]!<%j%s%0$O!"1/1000 DxEY$N%*!<%P%X%C$"$k%$%Y%s%Hr9YFCNCF$$$k3H$O!"IT
%I$GNI$$!#0lJ}$G!"%?%9%/@ZBX$($r4^$`3d$j9~$GOJ$$$H;Wol$k!#
$_=hM}$KMW5a5l$kL?Na?t$O!"K\%7%9%F%`GO7$+$7!"F~NO%G%P%$%9$NDI2C!"$"$k$$$O!"%=
CPU 7?3d$j9~$_$H1%8%c%s%WL?Na$G$"$k!#3H%&%'%"$N@ZBX$(JI$G!"30It%$%Y%s%H$N=8
$O!"%?%9%/@ZBX$($KMW5a$5lk?tI4L?NaKHfYJQ99$5$lk3HO$"$j$($k!#$=$NMM$J>l9g
lP6KaF>.$5$$!#3l$O!"$D$^$j!"0.1 kO!"4V@\K!!"$"$k$$$O!"%9%1%8%e!<%iK!JI
3d$j9~$_$N1~Ez@-$r!"1000 G\$K9k5;=QG"$k!#Q992DG=$J>uBVA+0\7O$r<B8=$9k3HGBP
(fig.5) 1~2DG=G"$k!#$^$?!"?7$7$$>uBVA+0\$rI=8=7?
code $r@8@.$9k3HKhj!"hj9bB.$J<B8=$,
2DG=HJ$k!#

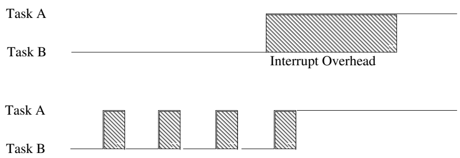

Fig5 Polling

9YFN%"%W%j%1!<%7%g%s$, CbC $G=q$+lF$$$k>u67Ji$P!"goto J8$NESCfK=Nh$&$J3H$r9MN8$7$?%W%m%0%i%_%s%0$rMW5a5l$k!#
code $r64$_9~$`$h$&$K$9$l$PNI$$!#$3$l$O!"0lPMh>e$,$C$?:G=*E*$J%W%m%0%i%`$O!"5pBg$J<o$N%W%m%0%i%`JQ49$G$"$k!#$3$N$h$&$J%W%m%0%i%`JQ49$r OS $NCf?4$H7F:NMQ7?bNH7$F!"Synthesis OS [1]$,M-L>G"$k!#K\%7%9%F%`$N>uBVA+0\$H$J$k!#$3$l$O!"K\Mh!"?M4V$+=q$1$k$h$&$J$b$N$G$O$J$$!#$^$?!"V;_$a$FD4$Y$F:F<B9T!W$N$h$&$J<jK!$G$O%G%P%C%0$9$k$3$H$,$G$-$J$$!#$G$O!"%7%9%F%`A4BN$r7QB3$rCf?4$H9k3HKh$j!"%7%9%F%`A4BN$r5pBg$J>uBVA+0\7O$H$7$F<B8=$5$l$k!#>uBV?t (code) <+BN$O!"$=$l$[$IBg$-$/$J$$$H$j07$&$3$H$K$J$k!#K\%7%9%F%`$G$N>uBV?t$O!"%"%W%j%1!<%7%g%s$NAm%9%F!<%H%a%s%H?tDxEY$HJk!#>uBVA+0\?t$O!"F~NO>uBV$KHfNc$7!">uBV?t$r$+$1$?$bNHJk$,!"F~NO>uBV?t$O!"F~NO%G%P%$%9$N?tDxEYHJkH9M$($ilk!#7k2LE*$K!"code <+BN$,$"$kDxEYNBg-5r;}$D>l9g$O!"=>Mh$N<jK!$hjbB?>/%3!<%I?t$,Bg$-$/$J$kDxEY$G9`$H;W$olk!#code $,?tL?NaDxEY$NbNP+jG$"$k$H!"=>Mh$N<jK!$N?tG\$N%3!<%I$rMW5a$9$k>l9g$b$"$k!#

8 CbC Kh$k%j%"%k%?%$%`!&%7%9%F%`@_7W

CbC $r;H$C$?%j%"%k%?%$%`!&%7%9%F%`@_7W$O!"%]!<%j%s%0$r;H$&$?aK!"FCDj$N;~E@$G@8$8$k2DG=@-N"$k%$%Y%s%Hr9YFCNCF$$$kI,MW$,$"$k!#$D$^$j!"3N0UL#$G!"$3$N%7%9%F%`$O!"F0:n$,F~NO$K$h$C$F40A4$K7hDj$5$l$k%7%9%F%`$HJC$F$$$k!#
$=$N%$%Y%s%H$N<oN`<+BN$OHs>o$KB?$$$H9M$($ilk!#7+$7!"%$%Y%s%H$N85$O!"%"%W%j%1!<%7%g%s$N;}$DF~NO%G%P%$%9?t$GM^$($ilk!#0lDN%3%s%T%e!<%?$K?tI4$N%G%P%$%9$,IU$/$3HO$"$j$($J$$!#$=$Nh&$J>l9g$O!"C10l($"$k$$$O>/?t$N) $N%M%C%H%o!<%/$r@\B3$7!"$=3+$iF~NO$rF@kN$,IaDL$G$"$k!#D^$j!"B??t$NF~NO$N=hM}$O!"LZ9=B$$Nh&$JJ}K!$G>/?t$N6%9g$9$kF~NO$KCV-49(il$k!#

8.1 7hDjE*%9%1%8%e!<%j%s%0$NLdBjE@

K\<jK!$r;H$C$?%j%"%k%?%$%`!&%7%9%F%`$O!"=>Mh$N%a%$%s%k!<%W7?$N%"%W%j%1!<%7%g%sHO!"$^$C$?$/0[Jk!#K\<AE*$K%$%Y%s%H6nF07?$N%W%m%0%i%`$r9T$J$$!"$"$ifk;~E@$G!"B>$N%$%Y%s%H$r;}$D<+BN$O!"%"%W%j%1!<%7%g%s$NAm%9%F!<%H%a%s%H?tDxEY$HJk!#
0lJ}$G!"$h$j:Y$+$$C10LGN5-=R$r9T$J$&$?aK!"hj:Y$+$$ code 6&M-$r2DG=$K9k3H$,4|BT$5lk!#$=$N>l9g$O!"=>Mh$N<jK!hj$b!">.$5$J%3!<%I$G==J,G"$k!#
0lJ}!"F~NO%G%P%$%9$,JQ99$5$l$k!"$"$k$$$O!"%"%W%j%1!<%7%g%s$,F~$lBXokh&$J>l9g$O!"code $r<B9T;~$K@8@.9kI,MW$,$"$k!#$3lO!"hjB?$/$N;q8;$rMW5a$9k3HKJk!#

8.2 7hDjE*%9%1%8%e!<%iNBg-$5

7hDjE*%9%1%8%e!<%j%s%0$O!"%9%1%8%e!<%i%s%0$N;H$&$3HKhj!"Hs7hDjE*%9%1%8%e!<%j%s%0KHfYFJo9k3H,G-$k!#K\Mh!"%3%s%T%e!<%?!&%7%9%F%`$O7hDjE*$JNG!"Hs7hDjE*%9%1%8%e!<%j%s%0$O!"$bHb$HLOJo<jK!$G7+J+C?!#

7hDjE*%9%1%8%e!<%j%s%0$O!"7hDj@-%*!<%H%^%H%s$HHs7hDj@-%*!<%H%^%H%s$HF1$8$/!"7hDjE*$JJ}$,!"$hjBg-$/$J$k798~$,$"$k!#Nc$($P!"a $H b $H$$$&FsDN%$%Y%s%H$,$"$k>l9g!"Hs7hDjE*$J%9%1%8%e!<%i$N>l9g$O!">uBVA+0\$O 3 DGNI$$!#

7+$7!"7hDjE*$J%9%1%8%e!<%i$N>l9g$O!"0J2<Nh$&$J 4 DN>uBV$r5-=R$9kI,MW,$"$k!#01HLE*$K!"F~NO%$%Y%s%H$N;X?t>h$N>uBVA+0\$r5-=R9kI,MW$,$"$k!#

3l$r2r7h$9k?aK$O!"Fs$D$NJ}K!$,$"$k!#0lDO!"JQ?t$r8+$k=g=x$r8GDj$7$F!"8+3]$1>e!"@~7A$N?t$N>uBVA+0\$K5"Ce5;$kJ}K!$G$"$k!#3NJ}K!GO!">uBV?t$OA}$(k3HKJk!#

b&0lDO!"=EMWGJ$$%$%Y%s%H$NAH9g$;$r$L5;k$9$kJ}K!$G$"$k!#3l$O!"%O!<%I%&%'%"[9]$G$N don't care $NMxMQ$HF1$8$3HKJk!#

IAiN<jK!rHkK$;$h!"7hDjE*%9%1%8%e!<%iNBg-5rM^$($k$?$aKO!"Jsi+$N:GE,2=<jK!$,I,MWHJkH;Wol$k!#DL>o!"30It%$%Y%s%H$O!"6K>/?t$JNG!"3NLdBj$O!"IaDL$N>l9gO"$^$jLdBjHOJi$J$$!#

9 $^$H$a

K\O@J8GO!"?7$7$$%j%"%k%?%$%`!&%7%9%F%`$N9=C[K!H7$F!"7QB3$r;}$D8@8l CbC Kh$k%7%9%F%`9=C[<jK!KD$$$F9M;!7?!#

=>Mh$N<jK!$G$N3d$j9~$_$N%*!<%P%X%C%I$N860x$r9M$($k3HKh$j!"%*!<%P%X%C%I$NCf?4$O!">uBVA+0\$r9MN8$7$J$$%"!<%-%F%/%A%cG"k3Hr;XE&7?!#

=>Mh$N RTOS + %"%W%j%1!<%7%g%s$H$$$&OHAH!"OS + %H%i%C%W$H$$$&J}<0GOJ/!"3d$j9~$_$r>uBVA+0\$HH7FHi(!"%7%9%F%`$N1~Ez@-$r>e2k3H$rL\;X$7$F$$$k!#

=>MhNbNHBgI}$K0[$Jk?aK!"5^6^$JLdBj$,$"$k$,!"$3$3$G$O!"CbC $G3d$j9~$_$r<B8=9k>uBVA+0\5-=RKD$$$F9M;!7?!#

References

[1] Calton Pu, Henry Massalin, and John Ioannidis. The synthesis kernel. In *Computing Systems*, Vol. 1. The MIT Press, 1988.

[2] 2OLn ??<# . 7QB3$r;}$D C $N2<0L8@8l$Khk%7%9%F%5-=R . F|K\%=%U%H%&%'%"2J3X2qBh 17 2sBg2qO@J8=8, September 2000.