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Human-robot Cooperative System with Fault Tolerance*

Masayuki Shimokura

Abstract

In recent years, there appear various types of robots in our environment , for example the cleaning robot. Function which is expected to these robots is working together because functions which they can do by themselves are still limited.

On the other hand, disadvantage of cooporative system with multiple robots is that fault of any robots may cause unexpected effects to the whole system.

In this paper, we propose a method to solve the above problem. If the robot doing a task happens a trouble, the task is succeeded to other robots as possible or continued by the robot which is restored afterword.

The method is achieved by status management and support restoration. Status in the environment is managed by *Environment Agent.* Restoration is supported by *Confirm Agent.*

The method is adopted to the environment in which various kinds of autonomous robots and people coexist. When one of robots has a trouble, the system generates a new plan without the troubled robot or a request to human to repair the robot. When the robot is restored, the system can continue the original task.

Keywords:

fault tolerance, robot, agent, coopolation, status management

*Master's Thesis, Department of Information Processing, Graduate School of Information Science, Nara Institute of Science and Technology, NAIST-IS-MT9651058, February 13, 1998.

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@a) $H8F$Plk<B@$3&%(!<%8%'%s%H$NDL?.$r9T$J$&%(!<%8%'%s%H$K4IM}5lF*
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=j$rF~NO$7Fbi& [3] 3H$G!$%m%\%C%H$r4D6-$KLa$7!$%?%9%/$r<B9T$^$?$O7Q
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7?%m%\%C%HODjail$?86E@0LCV$XLa$k!%$b$7!$0z$-7Q$,lF$$$J$$$JiP!$
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3.1 APOSEk:\HBAwMQ9TF07?%m%\%C%H **(Kappa1a)**

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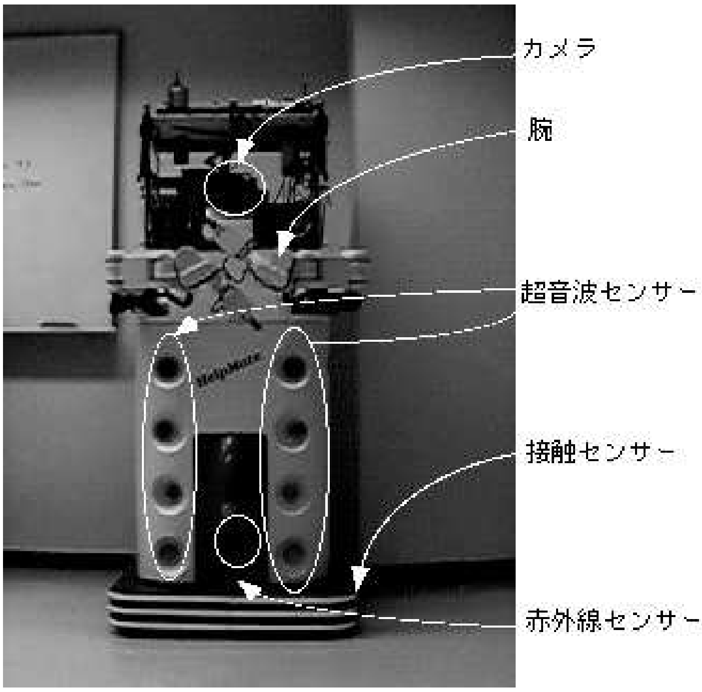
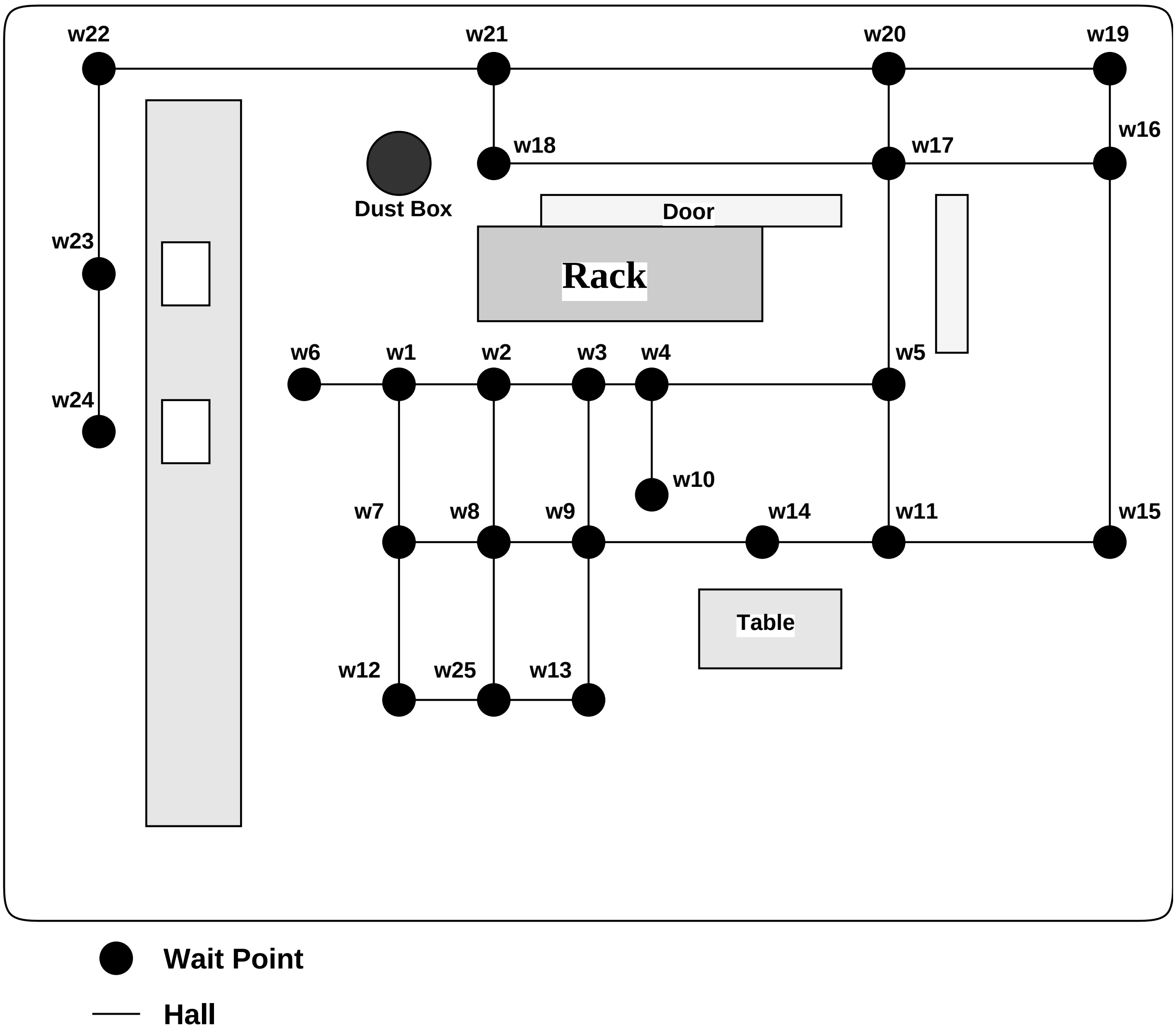
K\5!$O 2 Bf$N%+%a%i!$16 8D$ND62;GH%;%s%5!<!$1 DN@V30@~%;%s%5!<!$%P%s%Q!<A4BN$N@\?(%;%s%5!<!$6 <+M3EY$G%0%j%C%Q!<$r;}$D 2 BfNOSrM-9k<+N'Av9T7?%m%\%C%HG"$k!%$"i+8aF~NO5l$F$$$kDd;_>l=j (wait point) $HDLO) (hall) $+$iJk4D6-CO?^rbHK!$<+N'E*$K0\F0$9$k3H$,$G$-$k!%0\F0$N:]$K$OD62;GH%;%s%5!<!&@V30@~%;%s%5!<!&@\?(%;%s%5!<Kh$j<~0O$N>c32J*$r<+F0E*$K46CN$7!$$=li$N>c32J*$r2sHr9k3H$,2DG=$G$"$k!%

3N%7%9%F%`$O%b%H%m!<%i!<<R 68040 $N%\!<%I>e$G2TF/$9$k%j%"%k%?%$%`OS $G@)8f$5$l!$L5@~ LAN $G%M%C%H%o!<%/$KDJ$,$C$F$$$k!%3NDL?.ItJ,$O PCAUX $H8F$Plk MS-DOS Kh$j9T$Jol$F$$$k!%CPU $O%$%s%F%k<R 80386SX G"$k!%0\F0$O!$4D6-CO?^$K4pE/COE@4V<+N'0\F0$r9T$J$&F0:n%b!<%I$+!$$3Ai$+$i;XDj7?J}8~!&5wN%$r0\F0$9$k%b!<%I$G9T$J$$!$Aj8_$N@ZBX$($,2DG=G"$k!%4D6-CO?^$NNc$r?^ 3.2$K<($9!%



?^ 3.1 APOSEk:\HBAwMQ9TF07?%m%\%C%H$N304Q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Dust Box
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Rack
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w10
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w11
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Table
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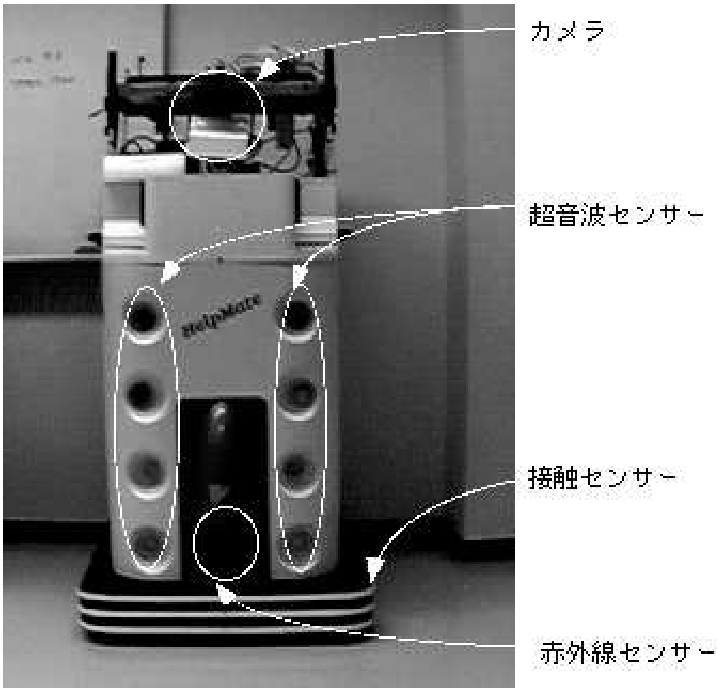
w13
Wait Point
Hall

?^ 3.2 4D6-CO?^

3.2 HBAwMQ9TF07?%m%\%C%H (Kappa1b)

K\5!$O!$J*$NHBAw$r<gL\E*H7!OSrEk:\$7$F$$$J$$E@0J30$O Kappa1a $HF1MM$N;EMMG"$k!%304Q$r?^ 3.3$K<($9!%



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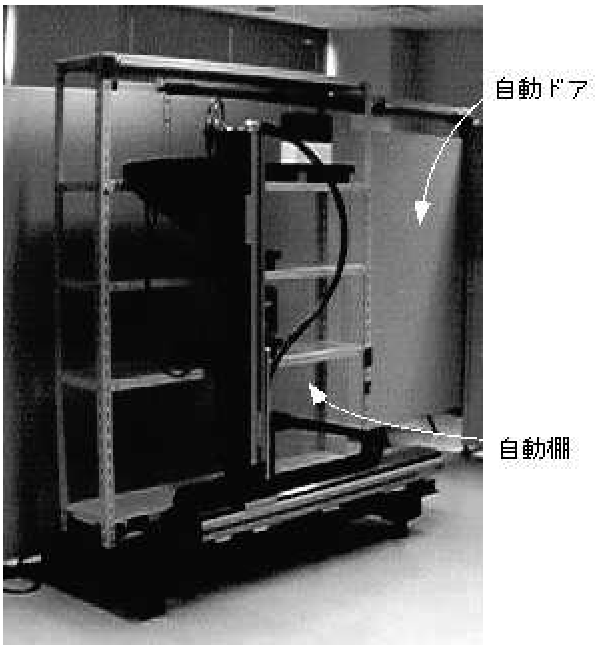
3.3 <+N’7?C*

K\5!$N304Q$r?^ 3.4$K<($9!%C*$H<}G<$*hS<h$j=P$7F0:n$r9T$J$&HBAw%F!<%V%k$+$i9=@.$5lF$*$j!$%M%C%H%o!<%/>e$N7W;;5!$+$i%7%j%"%k2s@~ (RS–232C) GDJ,C?AuCVKhCF@)8f9k!%?^$K<+N’7?C*$N9=B$$r?^ 3.5<($9!%C*$O9g7W 9 8D$N%;%k$+$i9=@.$5lk!%5i$K!$HBAw%F!<%V%k$N0LCV$rI=$9 21 8D$N%]%$%s%H$,@_Dj5l$F$$$k!$%]%$%s%HHV9f (0!A20) $r;XDj$9k3HKhj!$BP1~$9$k0LCV$X$N0\F0$r9T$J$$!$;XDj$5l?%;%kHV9f (1!A9) $+$i<}G<J*$N<h$j=P7r9TJ&3H$,2DG=$G$"$k!%

3N<+F07?C*$+$iJ*$r<u$1Hk3H$,2DG=$JNO Kappa1b $@$1G"$j!$Kappa1a $O<u$1Hk3H$,$G$-$J$$!%3l$O!$Kappa1a $H Kappa1b $N2YBf$N9b5,0[JkNKBP$7!$<+F07?C*KOJ*rEO9>l=j$O0l2U=j$7$+@_Dj$G$-$J$$$?aG$"$k!%



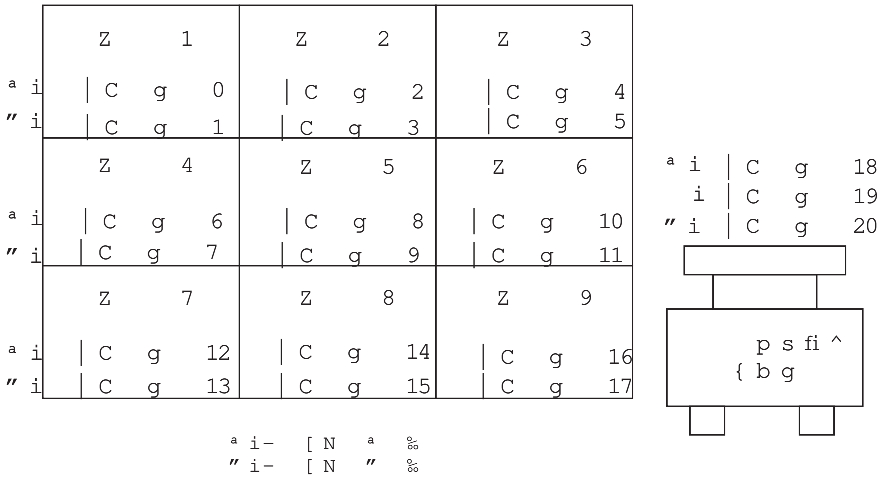
?^ 3.4 <+N'7?C*$H%I%"$N304Q

3.4 <+N'7?%I%"

K\5!$N304Q$r?^ 3.4$K<($9!%Hb$N6nF0It$H7W;;5!$+$i9=@.5l$F$$$k!%%M%C%H%o!<%/>e$N7W;;5!$+$i!$%7%j%"%k2s@~ (RS–232C) GDJ,C?@)8fAuCVKhjHbN3+JD$r9T$J$&!%

3.5 2hA|=hM}7W;;5!

K\5!$O!$9TF07?%m%\%C%H$+$i%=%1%C%HDL?.Kh$jAw?.$5l?2hA|$rF~NO$7!$2hA|=hM}$r9TJ&$?$a$N7W;;5! (%7%j%3%s%0%i%U%#%/%9<R@= INDY) G"$k!%C*$K<}



?^ 3.5 <+N'7?C*$N9=B$

G<7F$$$kJ*$NFCD'?'$rCN<1H7$F;}$A!$;XDj$5l?J*$,<}G<$5lF$$$k>l=j$r3d$j=P$9$3H,2DG=G"$k!%$^$?!$?M4V$NF0$-$+$i%?%9%/$NH/@8$r8!=P9k%W%m%0%i%`$bEk:\$5lF$$$k!%

3.6 2;@<9g@.AuCV

9TF07?%m%\%C%H$N2;@<=PNO$N$?$a$K NTT %G!<%?DL?.3t<02q<R@=$N2;@<9g@.AuCV!V$7cYjsK7 XG!W$rMQ$$$?!%$"$i$+$8$aEPO?$7F*$$$?F|K\8l$N%a%C%;!<%8$rDL?.%7%9%F%`$r2p$7$F9TF07?%(!<%8%'%s%H$N%9%T!<%+$+$i=PNO9k3H$,$G$-$k!%

3.7 DL?.KD$$$F

K\8&5fGO!$$3li$N%m%\%C%H4V$NDL?.$r%$%j%N%$Bg3X$G3+H/5l$? MBUS (Message BUS) $rMQ$$$F<B8=7?!%3NDL?.%7%9%F%`$OK\Mh$OM-@~$N%M%C%H$o!<%/MQ$K3+H/$5l?bNG"k?aK!$L5@~ LAN Kh$kDL?.$NHj3\$7$,H/@8

7?>l9g$K<+F0:FAw$,9TJolJ$$!%$=$N$?$a!$L5@~ LAN $G@\B3$5lF$$$k%m %\%C%HHNDL?.GO3NG'r7J,$iDL?.$r9TJ&3HK7$F$$$k!%

Bh **4** >O

%(!<%8%'%s%H $N9=@.

K\>OGO!$$3l^GN8&5f$G9=C[$5l? Kappa %7%9%F%`$N%(!<%8%'%s%H$N9=
@.$r=R$Y$k!%Kappa %7%9%F%`$H$OEv8&5f<<$G3+H/5l$F$$$kJ#?t$N%m%\%C%H$K$h
$k6(D4%7%9%F%`$G$"$k!%K\8&5f$r3+;O$9$k;~E@$G<B8=5l$F$$$?6(D4:n6H$O!$0[
<o$N%m%\%C%H$H?M4V$,:.:_$9$kCf!$?M4V$+$i$NHsF14|$KMW5a5l$k:n6H$r%m%\%C
%HKh$k=@Fp$J6(D4<B9T$,2DG=$G$"$C$? [4]!%$=7F?M4V$+$i$N0U;V$rEA$($k$?$a
$K%8%'%9%A%c!<$KhkEAC#J}K!$,9M0F$5lF$$$k [5]!%

K\O@J8K*$$$F!"%W%m%0%i%`%b%8%e!<%kGOJ/!"%(!<%8%'%s%H$H8F$s$G$$$k
NO8D!9$N%b%8%e!<%k$,<+N'E*$KF0:n$7!"$^$?B>$N%b%8%e!<%k$H6(D4$9$k3H$+
iG$"$k!#

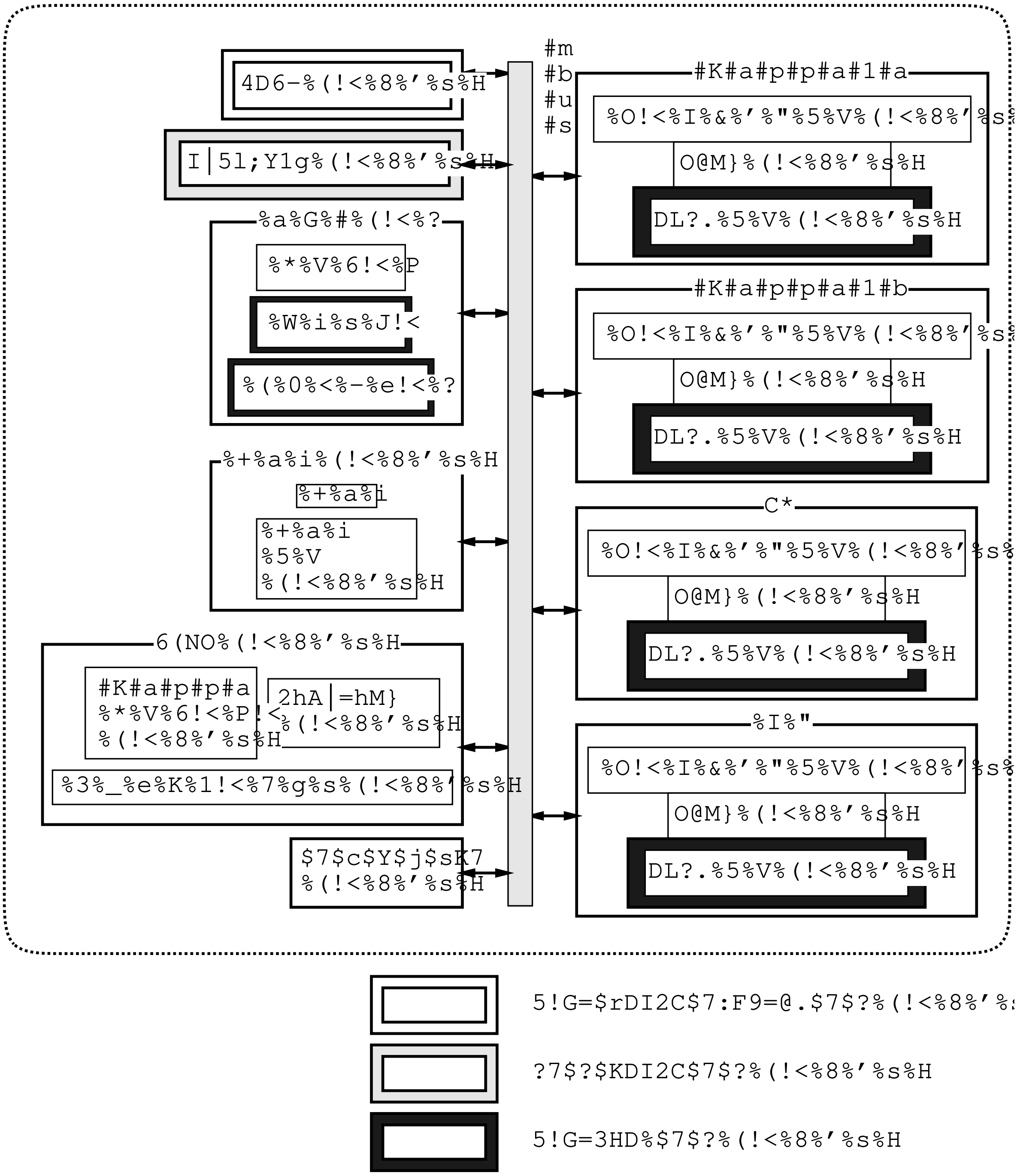
K\8&5f$GDI2C!&3HD%$5l?%(!<%8%'%s%H$r4^$`!$A4BN$N9=@.$O?^ 4.1$G<($9!%4D
6-%(!<%8%'%s%HObHb$H%&%)%C%A%c$H$$$&%(!<%8%'%s%H$+$i:F9=@.5l$?$b$N
G"$k!%I|5l;Y1g%(!<%8%'%s%H$OK\8&5f$G?7$?$K:n@.$5l?%(!<%8%'%s%HG"$k!%
$^$?!$DL?.%5%V%(!<%8%'%s%H$O5!G=3HD%$r9T$JCF$"$k!%3liNDI2C!&3HD%$5
l?%(!<%8%'%s%HKD$$$F$O 5 >O$G>\$7$/=R$Y!$K\>O$G$OK\8&5f$r3+;O9k;~E@
$G<B8=$5lF$$$? Kappa %7%9%F%`$N%(!<%8%'%s%H$K$D$$$F=RYk!%

4.1 %a%G%#%(!<%? (Mediater)

%a%G%#%(!<%?$O!$%?%9%/$,?M4V$r4^$`B>$N%(!<%8%'%s%H$+$i0MMj5l$?;~$K4D
6-%(!<%8%'%s%H$,5/F0$9$k!%%a%G%#%(!<%?$K$O#3$D$N5!G=$,$"$k!%3lir4JC1
$K=R$Y$k!%

- %W%i%s%J!< **(Planner)**

  0MMj5l$?%?%9%/$r<B9T9k%m%\%C%H$r3d$jEv$F!$0MMj5l$?%?%9%/$r%m



?^ 4.1 Kappa %7%9%F%`$N%(!<%8%'%s%H9=@.

%\%C%H$,<B9T2DG=$J%l%Y%k$^$GJ,2r$7!$%?%9%/Ns$r@8@.$9$k!%

- %*%V%6!<%P **(Observer)**
  9G$KB>$N%m%\%C%HKhCF3NJ]5l$F$$$k7PO)rDLi$J$$$h$&$K7PO)@_Djr7!$$=$N7PO)$rB>$N%m%\%C%H$K;Hol$J$$$h$&$K3NJ]9k!%

- %(%0%<%-%e!<%? **(Executer)**
  %W%i%s%K%s%0$5$l$?%?%9%/Ns$r=g<!3F%m%\%C%H$NO@M}%(!<%8%'%s%H$KAw$k!%

4.2 %&%)%C%A%c(Watcher)

%&%)%C%A%c$O8=:_$O 5.2@a$G@bL@$9$k4D6-%(!<%8%'%s%H$K3HD%5l$F$$$k!%$3$3GO!$4D6-%(!<%8%'%s%H$N%Y!<%9HJC?%&%)%C%A%c$N5!G=$r4JC1K^Ha$k!%

- B>$N%(!<%8%'%s%H$+$i%?%9%/$r0MMj5l$?$i!$%a%G%#%(!<%?$r5/F0$7!$0MMj5l$?%?%9%/$r%a%G%#%(!<%?KEO9!%

- %W%i%s%K%s%0KI,MWJ4D6-$NCN<1$r;}$A!$B>$N%(!<%8%'%s%H$+iNLd9g$;$KEz$($k!%

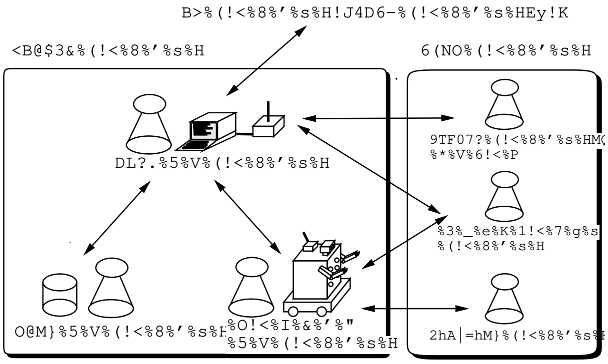
4.3 <B@$3&%(!<%8%'%s%H$N9=@.

K\O@J8GO!$<B@$3&%(!<%8%'%s%HHO!$%(!<%8%'%s%H2=$5l?%m%\%C%H!$$*hS?M4V$r;X$9!%

?^ 4.2$G<($9h&$K!$<B@$3&%(!<%8%'%s%H$OO@M}%5%V%(!<%8%'%s%H!$DL?.%5%V%(!<%8%'%s%H!$%O!<%I%&%'%"%5%V%(!<%8%'%s%H$+$iJj!$$3$N<B@$3&%(!<%8%'%s%H$r%5%]!<%H$9$k6(NO%(!<%8%'%s%H$+iJ$k!%0J2<$N@a$G3F!9$NLr3dKD$$$F=RYk!%

4.3.1 O@M}%5%V%(!<%8%'%s%H

O@M}%5%V%(!<%8%'%s%H$O<B@$3&%(!<%8%'%s%H$NF,G>$KAjEv9k!%3N%(!<%8%'%s%H$OM?$(il$?%?%9%/$r%O!<%I%&%'%"%5%V%(!<%8%'%s%H$,M}2r$G$-$k%a%C%;!<%8$KJQ49$9$k!%



?^ 4.2 <B@$3&%(!<%8%'%s%H$N9=@.

4.3.2 DL?.%5%V%(!<%8%'%s%H

DL?.%5%V%(!<%8%'%s%H$O!$B>$N%(!<%8%'%s%H$H$NDL?.ItJ,$rC4Ev9k!%B>$N%(!<%8%'%s%H$+iN%a%C%;!<%8$rO@M}%5%V%(!<%8%'%s%H$H%O!<%I%&%'%"%5%V%(!<%8%'%s%H!$$*hS6(NO%(!<%8%'%s%H$XEAC#$9$k!%$^$?!$3F%5%V%(!<%8%'%s%H$+$i$N%a%C%;!<%8$rB>$N%(!<%8%'%s%H$^$?$OB>%5%V%(!<%8%'%s%H$XEAC#$9$k!%

4.3.3 %O!<%I%&%'%"%5%V%(!<%8%'%s%H

3N%5%V%(!<%8%'%s%H$O!$9TF07?%m%\%C%H$KAjEv$9$k!%DL?.%5%V%(!<%8%'%s%H$+$i%m%\%C%H@)8f$NL?Na$r<u$1Hj<B9T9k5!G=$r;}$D!%F0:nCf$N>uBV$dF0:n$N40N;!$$=7F0[>oH/@8JI$N%a%C%;!<%8$ODL?.%5%V%(!<%8%'%s%H$KEAC#$5lk!%

4.3.4 6(NO%(!<%8%'%s%H

6(NO%(!<%8%'%s%H$O!$<B@$3&%(!<%8%'%s%H$r5!G=LL$G;Y1g$9k?aN%(!<%8%'%s%HG"$j!$<B@$3&%(!<%8%'%s%H$HL)$J4X78$r;}$D!%

5!G=LLGN;Y1g$r9T$J$&6(NO%(!<%8%'%s%H$O!$9TF07?%(!<%8%'%s%HMQ%*%V%6!<%P (4.6.1 @a;2>H)!$$7cYjsK7%(!<%8%'%s%H!$2hA|=hM}%(!<%8%'%s%H$N#3D,$"$k!%

- 9TF07?%(!<%8%'%s%HMQ%*%V%6!<%P%(!<%8%'%s%H
  9TF07?%(!<%8%'%s%HMQ%*%V%6!<%P%(!<%8%'%s%H$O!$9TF07?%(!<%8%'%s%H$, 0\F0$9$k:]!$<B@$3&%(!<%8%'%s%H$+iNLd$$9go;$K1~$8$FCOE@0\F0$N5v 2D$r=P$7!$>WFM$rHr1k5!G=$rJd40$9$k!%

- %3%_%e%K%1!<%7%g%s%(!<%8%'%s%H
  %3%_%e%K%1!<%7%g%s%(!<%8%'%s%H$O?M4V$,?H?6jKhC$F%m%\%C%H$H$N%3 %_%e%K%1!<%7%g%s$r1_3j$K9T$J$&$?aKF3F~5l$?$bNG$"$k!%?M4V$N?H ?6$j$+$i2hA|=hM}KhCF%?%9%/0MMj$N8!=P$7!$%O!<%I%&%'%"%5%V%(!<%8%' %s%H$K%?%9%/<B9T$N;X<($r=P$9!%

- 2hA|=hM}%(!<%8%'%s%H
  2hA|=hM}%(!<%8%'%s%H$O%m%\%C%H (Kappa1b) $N%+%a%i$+iNC*$N2hA|$r=h M}$7!$8=:_5aailF$$$kJ*$NH/8+$r9TJ&!%$=$NJ*$,$I3K$"$k$+$r%; %kHV9fGJV9!%

4.4 %+%a%i%(!<%8%'%s%H

<B834D6-A4Fr8+EO9h$&$K@_CV5l$? CCD %+%a%i$+iN2hA|$r07$&N,$3 $N%+%a%i%(!<%8%'%s%H$G$"$k!%%m%\%C%H$H?M4V$,%3%_%e%K%1!<%7%g%sG-$k>l=j $r>o$K4F;k7F$*$j!$$=$NItJ,$G$N?M$NF0$-$+$i%?%9%/$r@8@.9k!%

4.5 7cYj$sK7%(!<%8%'%s%H

7cYj$sK7%(!<%8%'%s%H$O!V7cYj$sK7 XG!W$r@)8f7F$$$k%(!<%8%'%s%H G"$k!%B>$N%(!<%8%'%s%H$+$i%m%\%C%H$K=PNO$7$FM_$7$$FbMF$,F~$C$?%a%C%;!< %8$,FO$/$H!$$3$N%a%C%;!<%8$r7cYj$sK7$N%a%C%;!<%8$KJQ49$7=PNO7F$$$k!%

4.6 %m%\%C%H$N%(!<%8%’%s%H2=

4.6.1 APOSEk:\9TF07?%(!<%8%’%s%H **Kappa1a**

APOSEk:\9TF07?%(!<%8%’%s%H$O!$%(!<%8%’%s%H$K4X$9$kCN<1$G$"$kCO?^%G!<%?%Y!<%9>e$NCOE@$K4pE/<+N’E*$J9TF0!$%+%a%i$+$i<h$j9~$^l?2hA|Kh$k2hA|=hM}!$J*$r;}$D3H$,$G$-$k%"!<%‘Kh$kF0:n$,G-$k!%0J2<$KAPOSEk:\9TF07?%(!<%8%’%s%H$N9=@.$r=RYk!%

- DL?.%5%V%(!<%8%’%s%H
  APOSEk:\9TF07?%(!<%8%’%s%H$NDL?.%5%V%(!<%8%’%s%H$N5!G=$O0J2<$NDLjG$"$k!%
  - %a%C%;!<%8$K1~$8$FO@M}%5%V%(!<%8%’%s%H!$%O!<%I%&%’%"%5%V%(!<%8%’%s%H!$6(NO%(!<%8%’%s%H!$$*hSB>$N%(!<%8%’%s%H$K%a%C%;!<%8$rEAC#$9$k!%
  - APOSEk:\9TF07?%(!<%8%’%s%H$N>uBV!J8=:_0LCV!$1?sG$$$kJ*$NL>>N!$%"!<%‘$G;}$C$F$$$kJ*$NL>>N!$<B9T7F$$$k%?%9%/$NL>>N!$<B9T7F$$$k%?%9%/$r0MMj$7$?%(!<%8%’%s%HL>!K$r4IM}$7!$%O!<%I%&%’%"%5%V%(!<%8%’%s%H$,%?%9%/$r<B9T$7!$>uBV$KJQ99$,$"$l$P>uBV$N99?7$r9T$J$&!%
- O@M}%5%V%(!<%8%’%s%H
  APOSEk:\9TF07?%(!<%8%’%s%H$NO@M}%5%V%(!<%8%’%s%H$N5!G=$O0J2<$Nh&G"$k!%
  - 0\F0$N0MMj$r<u1?>l9g!$9TF07?%(!<%8%’%s%HMQ%*%V%6!<%P $KB>$N9TF07?%(!<%8%’%s%H$N0\F0>uBV$rLd$$9go;!$0\F07PO)$r:n@.$7!$%O!<%I%&%’%"%5%V%(!<%8%’%s%H$K<B9T$r0MMj9k!%
  - 0MMj5l$?%?%9%/$K4X9k%a%C%;!<%8$r%(!<%8%’%s%H8GM-$N%a%C%;!<%87A<0$KJQ49$r9TJ&!%

  - ?M4V$H%3%_%e%K%1!<%7%g%s$r<h$k%?%9%/$r0MMj5l$?>l9g!$DL?.%5%V %(!<%8%’%s%HrDL7$F%3%_%e%K%1!<%7%g%s%(!<%8%’%s%HK=$N%?%9%/ $r0MMj$9$k!%

- %O!<%I%&%’%"%5%V%(!<%8%’%s%H
  3l$OAPOSEk:\9TF07?%m%\%C%H$G$"$k!%(3.1@a)

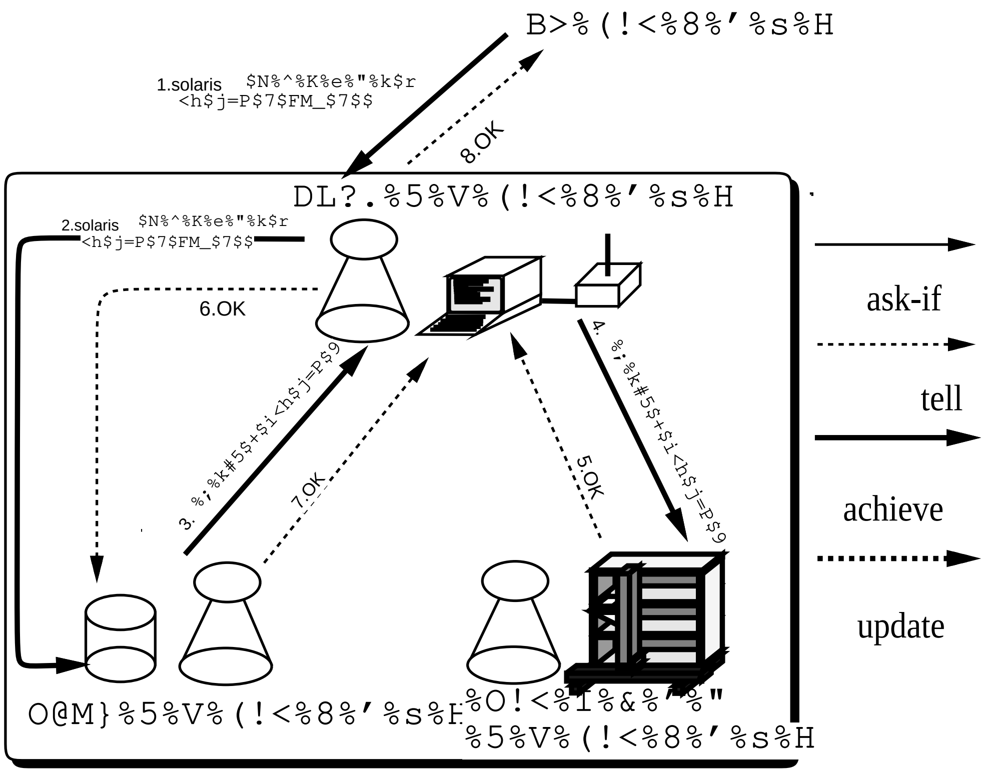
- 6(NO%(!<%8%’%s%H
  - 9TF07?%(!<%8%’%s%HMQ%*%V%6!<%P **(kappa observer)**
    9TF07?%(!<%8%’%s%H$N0\F0$r1_3jK9k?$a%(!<%8%’%s%H$G$"$k!%9TF07?%m%\%C%H$,0\F0$9$k:]!$>WFMrHr1k?aI,MWJ4D6->uBV$rDs6!$9$k5!G=!$$*hSB>$N9TF07?%(!<%8%’%s%H$,>c32HJ$j0\F0$G$-$J$$>l9gKO!$$=li$N9TF07?%(!<%8%’%s%H4V$NCg2p$r9T$J$&5!G=$r;}$D!%
  - %3%_%e%K%1!<%7%g%s%(!<%8%’%s%H
    ?M4VHN%3%_%e%K%1!<%7%g%s$r1_3j$K9TJ&$?$a$N%(!<%8%’%s%H$G$"$k!%2hA|=hM}Kh$j?M4V$N?H?6j+$i0U?^$7$F$$$k3H$r?dB,$7BP1~9k5!G=!$$*hS<B@$3&%(!<%8%’%s%H$N0U;V$r?H?6$j$H2;@<$NAH$_9g$o$;$KhjEAC#9k5!G=$r;}$D!%

4.6.2 HBAwMQ9TF07?%(!<%8%’%s%H **Kappa1b**

J*$NHBAw$r<gL\E*H7 (3.2@a)!OSrEk:\$7$F$$$J$$E@0J30$O Kappa1a $HF1MM$N;EMMG"$k!%$?$@$7!$$3$N%(!<%8%’%s%H$N6(NO%(!<%8%’%s%HH7$F2hA|=hM}%(!<%8%’%s%H$,$"$k!%Kappa1b $,;#$7$?C*$N1GA|$+$i!$:#5a$ail$F$$$kJ*$r?’$+$i<1JL$7!$$=l,I3K"k+$rC*$N%;%kHV9fGEz($k!%

4.6.3 C*%(!<%8%’%s%H

C*%(!<%8%’%s%H$O!$%;%kHV9f;XDj5Z$SJ*$NL>>N$N;XDj$KhjJ*$r<}G<$*hS<h$j=P$9F0:n$r9T$J$&!%J*$NL>>NKh$k<}G<J*$N<h$j=P$7F0:n$r?^ 4.3$N9=@.$G<B8=$9$k!%0J2<$KC*%(!<%8%’%s%H$N9=@.$r7a$9!%


B>%(!<%8%'%s%H
1.solaris $N%^%K%e%"%k$r
<h$j=P$7$FM_$7$$
8.OK
DL?.%5%V%(!<%8%'%s%H
2.solaris $N%^%K%e%"%k$r
<h$j=P$7$FM_$7$$
6.OK
3. %;%k#5$+$i<h$j=P$9
7.OK
4. %;%k#5$+$i<h$j=P$9
5.OK
O@M}%5%V%(!<%8%'%s%H
%O!<%I%&%'%"
%5%V%(!<%8%'%s%H
ask-if
tell
achieve
update

?^ 4.3 Rack $N%a%C%;!<%8

- DL?.%5%V%(!<%8%'%s%H

  %a%C%;!<%8$K1~$8$FO@M}%5%V%(!<%8%'%s%H!$%O!<%I%&%'%"%5%V%(!<%8%'%s%H!$$*hSB>$N%(!<%8%'%s%H$K%a%C%;!<%8$rEAC#$9$k!%

- O@M}%5%V%(!<%8%'%s%H

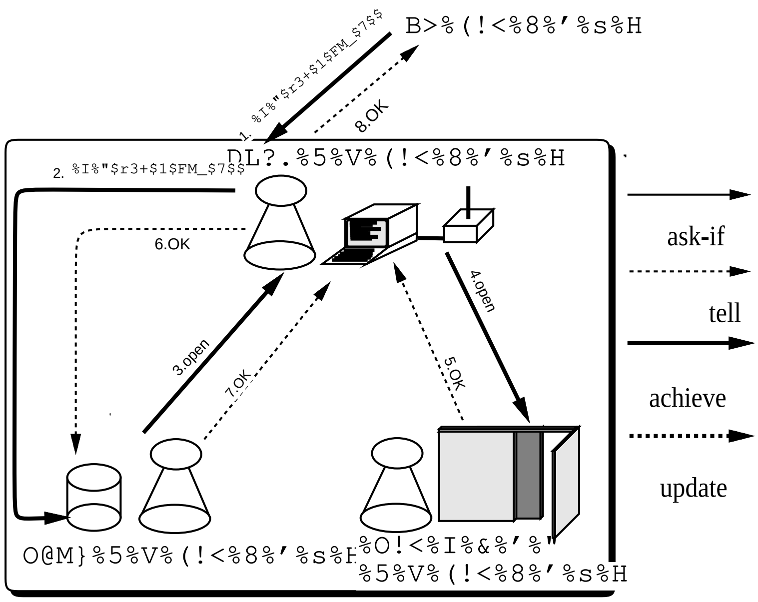
  EAC#5l$?%?%9%/$K4X9kCN<1$r%(!<%8%'%s%H8GM-$N7A<0$KJQ49$r9TJ&!%

- %O!<%I%&%'%"%5%V%(!<%8%'%s%H

  <+N'7?C*%m%\%C%H$G!$<h$j=P$75!G=$H<}G<5!G=$r;}$D (3.3@a;2>H)!%

4.6.4 %I%"%(!<%8%'%s%H

%I%"%(!<%8%'%s%H$O!$%a%C%;!<%8Kh$j%I%"$N3+JD$r9T$J$&!%%I%"$N3+JDF0:n$r?^ 4.4$N9=@.$G<B8=$9$k!%0J2<$K%I%"%(!<%8%'%s%H$N9=@.$r<($9!%$=l>lN%(!<%8%'%s%H$N5!G=$O%O!<%I%&%'%"%5%V%(!<%8%'%s%H$r=|$$$FC*%(!<%8%'%s%H$HF1$8G"$k!%%O!<%I%&%'%"%5%V%(!<%8%'%s%H$O<+N'7?%I%"%m%\%C%H$G!$%I%"$N3+JD5!G=$r;}$D (3.4@a;2>H)!%



?^ 4.4 Door $N%a%C%;!<%8

Bh **5** >O

%U%)!<%k%H%H%l%i%s%9$r<B8=$9$k%(!< %8%'%s%H 7O

3N>OGO%U%)!<%k%H%H%l%i%s%9$r<B8=$9k?aK:#2sF3F~7?%(!<%8%'%s%H KD$$$F=RYk!%3l$^$G$K8&5f$G;HMQ5l$F$$$?DL?.%5%V%(!<%8%'%s%H$r3HD%$7!$$=7F!$$3l^GN8&5f$G;HMQ$5lF$$$?%&%)%C%A%c$H$$$&%(!<%8%'%s%H$r3HD%$7$?4D6–%(!<%8%'%s%H!$$=7F>c32$+$iI|5l7?$+$I$&$+$NH=Dj$r9TJ&I|5l;Y1g%(!<%8%'%s%H$rDI2C$7$?!%

5.1 3HD%5l$?DL?.%5%V%(!<%8%'%s%H

:#$^$G$NDL?.%5%V%(!<%8%'%s%H (4.3.2) $K>uBV4IM}$r9kG=NO$rDI2C$7$?!%K\@a$G$ODL?.%5%V%(!<%8%'%s%H$Khk>uBV4IM}$NJ}K!$r=RYk!%

5.1.1 DL?.%5%V%(!<%8%'%s%HKh$k>uBV4IM}

$3$3GN>uBV4IM}$NJ}K!$O!$I=5.1$HI=5.2$K<($9h&$JCN<1I=8=$rMQ$$$k!%Nc$($P%m%\%C%H$, Wait Point $N W1 $+$i W4 $X0\F0$7$F$$$k;~$G2?$bbN$r;}$C$F$$$J$$$H$$$&h&$J>uBV$G$O!$

((from w1)(to w4)(carry nothing)(task move))

$H$$$&7A$G4IM}$5lk!%EvA3!$0\F0$,=*N;9l$P0LCV>pJs$,=q-49(il!$$bNr;}CF$$$kH9lP!$$=$N>pJs$,=q-49(il$k!%$^$?!$?M4V$H%3%_%e%K%1!<%7%g%s$9$k>l=j$J$I!$FCJL$J>l=j$G$O!$$=$N>pJs$b=q$-2C$(il$k!%JL$NNcH7$F!$%m%\%C%H$, Wait Point $N W14 $G Solaris $N%^%K%e%"%k$r;}CF?M4V (human1) $NA0$K$$$kH9lP!$

((at w14)(carry solaris)(in-front-of human1)(task bring))

$H$$$&h&KJ$k!%

5.2 4D6-%(!<%8%'%s%H (Environment Agent)

3l$^$G$N8&5f$GMQ$$$ilF$-$?%&%)%C%A%c$N5!G=$rA4$F0z$-7Q$.!$$%U%)!<%k%H%H%l%i%s%9$r<B8=$9k?aK3HD%7?bN$,$3$N4D6-%(!<%8%'%s%H$G$"$k!%4D6-%(!<%8%'%s%H$O%m%\%C%H$NF0$/4D6-$K4X9k>pJs$r4IM}$7$F$$$k!%3F%m%\%C%H$N>uBV!$%?%9%/FbMF!$J*$N=j:_COJIG"$k!%$^$?!$%+%a%i%(!<%8%'%s%H$d9TF07?%(!<%8%'%s%H$,0MMj5l$?%?%9%/$K1~8F%a%G%#%(!<%?$r5/F0$9$k!%%?%9%/$N<B9T>uBV$d;HMQ$5lF$$$k%(!<%8%'%s%HJIb3$3$G4IM}5l$F$$$k!%

CN<1I=8=	>uBV$NOUL#	4IM}9k Agent
(from A)	A $+$i=PH/7?	Com. Env.
(to A)	A $K8~$+CF$$$k	Com. Env.
(at A)	A $K$$$k	Com. Env.
(carry B)	B $r;}$C$F$$$k	Com. Env.
(in-front-of C)	C $NA0$K$$$k	Com. Env.
(task D)	D $H$$$&%?%9%/$r<B9TCf	Com. Env.
(open)	%I%"$,3+$$$F$$$k	Env.
(close)	%I%"$,JD$^CF$$$k	Env.

Com. : 3F%m%\%C%H$NDL?.%5%V%(!<%8%'%s%H

Env. : 4D6-%(!<%8%'%s%H

I= 5.1 >uBV4IM}N?aNCN<1I=8=

5.2.1 4D6-%(!<%8%'%s%HKh$k>uBV4IM}

2.3@a$KA4$F$N%m%\%C%H$N>uBV$O4D6-%(!<%8%'%s%H$K4IM}5;kH$$$&3H$r=R$Y$?!%$=$N>uBV4IM}$NJ}K!r3$3$G=RYk!%

>uBV4IM}N?aN%a%C%;!<%8 (I= 5.3) $NH/?.J}8~$r$^$Ha?bN$r?^ 5.1$K<($9!%%m%\%C%H$KF0$-$,$"$kEY$K Executer $+$i>uBVA+0\$N%a%C%;!<%8 (trans) $r4D6-%(!<%8%'%s%H$KH/?.9k3H$,4pK\$HJC$F$$$k!%Executer $+$iAwilk3$N%a%C%;!<%8$NNc$r#2$D$"$2$k!%

```
(trans (kappa1a (from w7)(to w14)(carry nothing)(task move)))
(trans (kappa1b (at w17)(carry solaris)(task bring)))
```

0l$DL\$O!V Kappa1a $, Wait Point W7 $+$i W14 $X2?$b;}$?$:$K0\F0$7$F$$$k!W$H$$$&3H$r<($7!FsDL\$O!VKappa1b $, W17 $K$$$F!$solaris $N%^%K%e%"%k$r1?HBCfG"$k!W$H$$$&0UL#G"$k!%$3Nh$&$JA+0\%a%C%;!<%8rAwilF$-

CN<1I=8=	%?%9%/$N0UL#
nothing	2?b7$F$$$J$$
bring	J*$r1?$s$G$$$k
move	0\F0$7$F$$$k
dump	%4%_<N$F
comm	?MHN%3%_%e%K%1!<%7%g%s
handover	C*$+$i$N<uEO$7
grasp	4_rDO`

I= 5.2 %?%9%/$NCN<1I=8=

$?4D6-%(!<%8%'%s%H$O$=$N<u1HC?;~$N%?%$%`%9%?%s%Wr3$N>pJs$KIU$12C$(!$ 8=:_4D6-%(!<%8%'%s%H$KC_$(il$F$$$k>uBV$N>pJs$r=q49$($k!%

$3$3GN>uBV4IM}$ODL?.%5%V%(!<%8%'%s%H$N4IM}J}K!HO0[Jk!%$=$NNcH7$F!$Kappa1b $, Wait Point $N W14 $G?M4V (human1) $NA0$K Solaris $N%^%K%e%"%k$r;}$A!$Kappa1a O4$_H"$X9T$/ESCf$N W17 G4$_$r;}CF$$$k!$$H$$$&>uBVJi$P!$

```
((kappa1a (from w17)(to w18)(carry dust)(task dump)(3095743076))
 (kappa1b (at w14)(in-front-of human1)(carry solaris)(task bring)(3095742969))
 (rack (carry nothing)(3095742915))
 (door (open)(3095743043))
 (task (kappa1a dump)(kappa1b bring)))
```

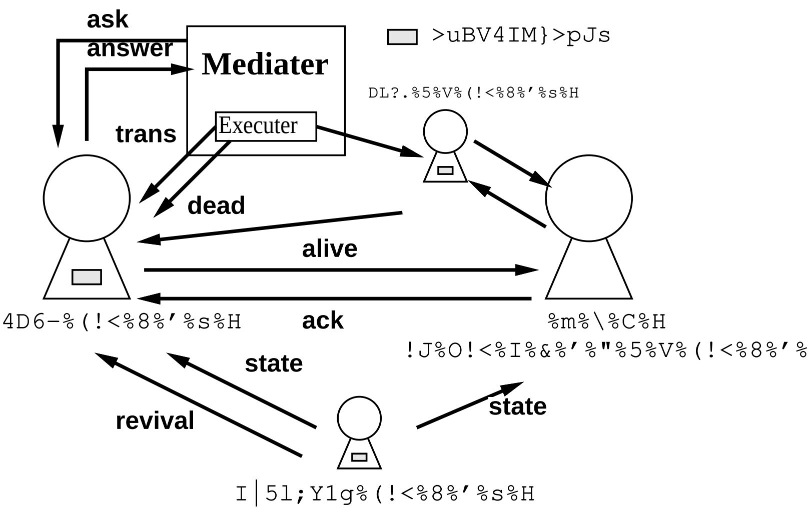
$H$$$&h&$J7A$KJk!%$=$l$>$l$N>uBV$N8e$KB3$/?t;zO=$N>uBV$NA+0\$r<u$1<h$C$?;~$N4D6-%(!<%8%'%s%HNCfG$N;~4V$G$"$k!%3N;~4V$O Common Lisp $N%7%9%F%`;~7W$rF@$k4X?t (get-universal-time) NJVjCM$r;HMQ$7F*$j!$C10LOICG$"$k!%

3NN.lr$^$Hak!%

1. 4D6-%(!<%8%'%s%H$,;}$C$F$$$k>uBV>pJs$,<!$Nh&JbNH9k!%

%a%C%;!<%8	FbMF
trans	>uBVA+0\
ask	>uBVLd9g$;
answer	>uBVJVEz
alive	@8B8Ld9g$;
ack	JVEz
dead	>c32H/@8
revival	I│51DLCN
state	I│518e$N>uBV

I= 5.3 >uBV4IM}%a%C%;!<%8



?^ 5.1 >uBV4IM}%a%C%;!<%8$NH/?.J}8~

```
((kappa1a (at w7)(carry nothing)(task nothing)(3095743076))
 (kappa1b (from w5)(to w17)(carry solaris)(task bring)(3095742969))
 (rack (carry nothing)(3095742915))
 (door (open)(3095743043)))
```

2. Kappa1a $r;H$$%W%i%s%K%s%0$7$?%a%G%#%(!<%?NCfN Executer $+$i4D6-%(!<%8%'%s%H$K

```
(trans (kappa1a (from w7)(to w14)(carry nothing)(task move)))
```

$H$$$&%a%C%;!<%8$,Aw$ilk

3. 4D6-%(!<%8%'%s%H$O%a%C%;!<%8$r<u1HC?;~4V ($3$3GO 3095743521) r=NAwilF$-$?>uBV>pJs$KDI2C$7!$<+J,$NCf$K;}$C$F$$$k>uBV>pJs$N Kappa1a $NItJ,$r=q49$($k!%

```
((kappa1a (from w7)(to w14)(carry nothing)(task move)(3095743521))
 (kappa1b (from w5)(to w17)(carry solaris)(task bring)(3095742969))
 (rack (carry nothing)(3095742915))
 (door (open)(3095743043)))
```

4. <!$K Kappa1b $r;H$C$F%W%i%s%K%s%0$r7?%a%G%#%(!<%?NCfN Executer $+$i

```
(trans (kappa1b (at w17)(carry solaris)(task bring)))
```

$H$$$&h&$J%a%C%;!<%8$,FO$/!%

5. >uBVA+0\$N%a%C%;!<%8$r<u$1HC$?4D6-%(!<%8%'%s%H$O@h$[$I$N<j=g$HF1$8<j=g$G<+J,$,;}$C$F$$$k>uBV>pJs$r99?7$9$k!%

```
((kappa1a (from w7)(to w14)(carry nothing)(task move)(3095743521))
 (kappa1b (at w17)(carry solaris)(task bring)(3095744207))
 (rack (carry nothing)(3095742915))
 (door (open)(3095743043)))
```

6. 0J2<!$F1$8h&$J>uBV99?7$,B3$/

3Nh&$J<j=g$G>uBV$NA+0\$r5/$3$7!$>uBV$r99?7$7$F$$$/!%
B>$N%(!<%8%'%s%H$+iNLd9g$;$KBP9kJVEz$N<j=g$r$^$Hak!%

1. 4D6-%(!<%8%'%s%H$,<!$Nh&$J>uBV>pJs$r;}CF$$$kH9$k!%

```
((kappa1a (from w7)(to w14)(carry nothing)(task move)(3095743521))
 (kappa1b (from w5)(to w17)(carry solaris)(task bring)(3095742969))
 (rack (carry nothing)(3095742915))
 (door (open)(3095743043)))
```

2. $"$k%a%G%#%(!<%?#A$+$i!VKappa1a $N>uBV$r65$($FM_$7$$!W$H%a%C%;!<%8$,4D6-%(!<%8%'%s%H$K>uBVLd9g$;%a%C%;!<%8$,Aw$ilk!%3N;~$N%?%$%`%9%?%s%W$, 309575232 H9$k!%

```
(ask (kappa1a))
```

3. 4D6-%(!<%8%'%s%H$O kappa1a $N>uBV$KIU2C5l$F$$$k%?%$%`%9%?%s%W$HHf3S$7!$#5J,0J>eA0$N>uBV$JNG!$$3$N>uBV$r>C5n$7!$Kappa1a $NDL?.%5%V%(!<%8%'%s%H$K>uBV$r (ask) $H$$$&%a%C%;!<%8$GLd$$9go;$k!%

4. DL?.%5%V%(!<%8%'%s%H$O8=:_$N kappa1a $N>uBV$r4D6-%(!<%8%'%s%HKJV9!%

```
(answer ((at w14)(in-front-of human1)(carry nothing)(task comm)))
```

5. 4D6-%(!<%8%'%s%H$ODL?.%5%V%(!<%8%'%s%H$+iN>uBV>pJs$r<u$1Hk$H!$$=$N;~$N%?%$%`%9%?%s%W (309575283) $rIU2C$7$F>uBV>pJs$r=q49$($k!%$=$7$F!$kappa1a $N>uBV$rLd9g$;$r7F$-$?%a%G%#%(!<%?$KJVEz$9$k!%

```
(answer (kappa1a (at w14)(in-front-of human1)
  (carry nothing)(task communicate)))
```

5.2.2 >c32$NH/@8H=Dj

K\@aGO%m%\%C%H$K>c32$,H/@8$7$?$+$I$&$+$NH=Dj$NJ}K!$r=R$Y$k!%%m%\%C%H$K>c32$,H/@8$7$?>l9g!$$^$:>uBV$N99?7$,$5lJ$$!%$=$7$F!$%a%C%;!<%8rAwCFb1~Ez$,$J$/$J$k!%$3lrMxMQ$7!$K\8&5fGO>c32H/@8$NH=Dj$r9TJC$F$$$k!%>c32H/@8$NH=Dj$NJ}K!$r#2$D$"$2$k!%

%m%\%C%H$,0\F0Cf$H$$$&>uBV$, Executer $+$iAwilF-$?$H9k!%>uBV$NLd9g$;$,B>$N%(!<%8%'%s%H$+$i$"$C$?;~$K!$Ld9g$;N"C?;~4V$H0\F0Cf$H$$$&>uBVA+0\%a%C%;!<%8$,FO$$$?;~4V$N:9$,Bg$-$$>l9g($3$3GO5J,$H@_Dj$7F"$k)$K$O!$$^$:$=$N%m%\%C%H$NDL?.%5%V%(!<%8%'%s%H$K>uBV$NLd9g$;$r9TJ&!%$=$7$F?7$?$K99?7$5l?>pJs$,Aw$ilF3J$$>l9gKO!$0lEY%m%\%C%H$KLd9g$;$r9TJ&!%$3$3$G1~Ez$,J1lP0\F0Cf$K>c32$,H/@8$7$?62l,$"$k$H4D6-%(!<%8%'%s%H$OH=CG$7!$>c32$,H/@8$7$?$H;Wol$k%m%\%C%H$KBP7F3NG'N?aN%a%C%;!<%8 (alive) rAwk!%>c32$,H/@8$7$F$$$J1l$P (ack) $,%m%\%C%H$+iLa5lk$,!$>c32$,H/@8$7$F$$$k>l9gKOJVEz$,$J$$!%3l$rMxMQ$7$F>c32$,H/@8$7$?$+H]$+$rH=Dj$7$F$$$k!%

b&0lDO!$%?%9%/?k9TCf$K Executer $+$i>c32H/@8$N%a%C%;!<%8 (dead) $,4D6-%(!<%8%'%s%H$XAwilF/$k>l9g$G$"$k!%Executer $+$i%a%C%;!<%8rAwkNO!$$dOj%m%\%C%H$+$i$N1~Ez$,$J$$>l9gG"$k!%

3N;~$NH=Dj$NN.lr<!$K=R$Y$k!%

1. Executer $+$i>c32H/@8$N%a%C%;!<%8 (dead) $,FO$/!%$"$k$$$O%m%\%C%H$+$iJVEz$,$J$$!%
2. 4D6-%(!<%8%'%s%H$O%m%\%C%H$KBP7F (alive) $H$$$&%a%C%;!<%8rAwk!%
3. $3$3$G1~Ez (ack) $,$"lP>c32$OH/@8$7$F$$$J$$!$$HH=CG!%
4. 1~Ez$,$J1lP=$N%m%\%C%H$N>uBV$r4D6-%(!<%8%'%s%H$+$iI|5l;Y1g%(!<%8%'%s%H$KAw$j!$$=$N%m%\%C%H$rF0$+$9$?$a$K5/F0$7$F$$$?%a%G%#%(!<%?

$r>CLG$5$;!$$=$N%m%\%C%H$,<B9TCf$N%?%9%/$r<B9T9k$?$a$K%a%G%#%(!< %?$r5/F0$9$k!%3N;~$N%a%C%;!<%8$O

```
(dead-task ((Dd;_$7$?%?%9%/) (>c32$,H/@8$7$?%m%\%C%H$NL>>N)
        (%m%\%C%H$NDL?.$N$"$C$?:G8e$N>uBV)(DL2aITG=$N path)
        (>c32$,H/@8$7$FDd;_$7$F$$$k%m%\%C%H$NNs)))
```

$H$$$&7AKJCF$$$k!%%m%\%C%H$N:G8e$N>uBV$+$i%m%\%C%H$,Dd;_$7$F$$ kH;Wol$k>l=j$rD4$Y!$$=$N>l=j$rDL9TITG= path H7$F@_Dj$7$F$$$k!%

5. $3$3GJLN%m%\%C%H$K%?%9%/$N0z$-7Q$.$,$G$-$l$P>c32$,H/@8$7$?%m%\%C%H KBP7FN%?%9%/OJ$/$J$k!%$7$+$7!$0z$-7Q$.$,G-J+C?>l9g!$I|5l 7F$+$i<B9TG-kh$&!$4D6-%(!<%8%'%s%HK=$N%?%9%/$rJ]B8$7F*$/!%

6. I|5l;Y1g%(!<%8%'%s%H$O%m%\%C%H$NI|5l$r%A%'%C%/$9$k!%$3$NJ}K!$K$D$$$F $O 5.3@a$G>\$7$/=R$Y$k!%

7. I|5l;Y1g%(!<%8%'%s%H$+$i%m%\%C%H$,I|5l$7$?;]$N%a%C%;!<%8$,FO$$$?$i!$ $=$N%m%\%C%H$K:F$S%?%9%/$r<B9T$G$-$kh&$KDd;_$7$F$$$k%m%\%C%HNs$+ i=$N%m%\%C%H$r30$7!$>uBV>pJs$rI|5l;Y1g%(!<%8%'%s%H$+iN>uBV>pJs $K=q49$(!$0z$-7Q$.$G$-$J$+$C$?%?%9%/$r7QB3$9$kh&$K%a%G%#%(!<%?$r 5/F0$9$k!%$^$?3N;~!$DL2aITG= path $K@_Dj$5lF$$$?ItJ,$r%m%\%C%H$, $$$k>l=j0J30$rDL2a2DG=$KJQ99$9$k!%

5.2.3 >c32I|5l8e$N=hM}

$3$3GO!$%m%\%C%H$,I|5l7?;~$N=hM}$r=RYk!%

?M$N<j$KhC$F%m%\%C%H$,I|5l7?>l9g!$I|5l;Y1g%(!<%8%'%s%H$+$iI|5l$7$? ;]$N%a%C%;!<%8 (revival) AwilF/$k!%$=7F!$?M$K65$($FbiC?8=:_0LCV$r DI2C$7$?>uBV>pJs$rI|5l;Y1g%(!<%8%'%s%H$+$iAwilF/$k!%$3lrbH$K>uBV >pJs$r=q49$($k!%

%m%\%C%H$K>c32$,H/@8$7!$Dd;_7?$H;W$olkHO0O$rA4$FDL9TITG=$J path $K@_Dj$7F"C?bN$rDL9T2DG=$K7F!$%m%\%C%H$,8=:_$$$k>l=jN_rDLl$J$$>l=jK9$k!%

B>$N%m%\%C%H$K0z$-7Q$0$3$H$,$G$-$J$+$C$?%?%9%/$rJL$K4IM}$7$F$$$k!%$=$N%?%9%/$r!$I|5l7?%m%\%C%H$K7QB3$5$;$k$?$aK=$N%?%9%/$NFbMF$H%m%\%C%H$N>uBV$r

(revival-task ((Dd;_7?%?%9%/)(%m%\%C%H$NL>>N)(%m%\%C%H$N8=:_$N>uBV)))

$H$$$&7A$G%a%G%#%(!<%?$KAw$k!%$3lKhj!$%a%G%#%(!<%?$,7QB3%?%9%/G"k3HrH=Dj$7!$AwilF-$?>pJs$rbH$K%W%i%s%K%s%0$7!$<B9T$9$k!%

5.3 I|5l;Y1g%(!<%8%'%s%H (Confirm Agent)

3N%(!<%8%'%s%H$O!$%m%\%C%H$+$i$N1~Ez$,J/JC$?;~!$$D$^$j$O2?$i$+$N>c32$,H/@8$7$?;~$K5/F0$5$l$k!%%m%\%C%H$NI|5l$r?M4V$KB%$9%a%C%;!<%8$rN.$7!$I|5l5l$?$+I&$+$r>o$K4F;k$7$F$$$k!%>c32$,H/@8$7$?%m%\%C%H0lBf$KBP$7!$0l$D5/F0$9kh$&$KJC$F$$$k!%I|5l7?>l9gKO!$$=$N%m%\%C%H$K8=:_0LCVJI$r?M4V$+$i65$(Fb$i$$!$$=li$N>pJs$r>c32$+$iI|5l7?%m%\%C%H$NDL?.%5%V%(!<%8%'%s%H$H4D6-%(!<%8%'%s%H$K0zEO$7$F>CLG$9$k!%

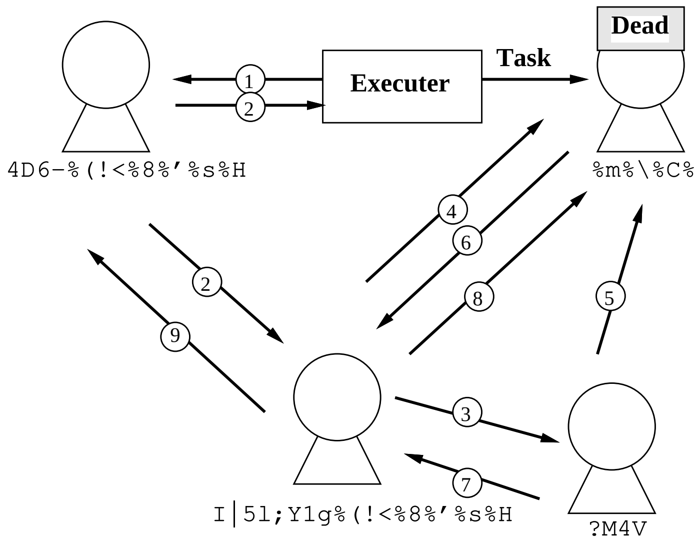
3N;~$NF0:n$NN.lNNc$r?^ 5.2$K<($7!$$=$N?^$N@bL@$r0J2<$K=RYk!%

1. %m%\%C%H$+$i$N1~Ez$,$J$$$3Hr Executer $+$i4D6-%(!<%8%'%s%H$X%a%C%;!<%8 (dead) $,FO$/

2. 4D6-%(!<%8%'%s%H$OI|5l;Y1g%(!<%8%'%s%H (Confirm Agent) $r5/F0$9$k!%5/F0$5lk:]$K!$1~EzNJ$$%m%\%C%HL>!$$=$N%m%\%C%H$N>uBVrCNi5l$k!%$3$N;~!$4D6-%(!<%8%'%s%H$O Executer $r4^$`%a%G%#%(!<%?$rDd;_$9$k!%

3. I|5l;Y1g%(!<%8%'%s%H$O?M4V$K%m%\%C%H$,CO?^>e$NINJUjG1~Ez$,$J$/$JC?$+$r2hLLGCNi$;$F!$I|5l0MMj$r9T$&!%

4. I|5l;Y1g%(!<%8%'%s%H$O#1#0J,$*$-$KI|5l7F$$$k$+$I$&$+$N3NG'$N%a%C%;!<%8r=$N%m%\%C%H$XAw$k!%



?^ 5.2 I|5l;Y1g%(!<%8%'%s%H$N%a%C%;!<%8

5. ?M$N<j$KhjI|5l5l$k!%

6. JVEz$,$"lP%m%\%C%H$OI|5l$7$?$bNH8+J9!%

7. ?M4V$+$i0LCV>pJs$rF~NO$7Fbi&!%

8. 65$($FbiC?0LCV>pJs$HJ;$;$F:G8e$N>uBVr=$N%m%\%C%H$KCNi;$k!%

9. %m%\%C%H$,I|5l$7$?$3HH$=$N%m%\%C%H$N8=:_$N>uBV$r4D6-%(!<%8%'%s%H$KEA$(!$I|5l;Y1g%(!<%8%'%s%H$O>CLG$9$k!%

Bh 6 >O

%7%9%F%`$N<B83$HI>2A

6.1 <B83

K\8&5f$N<B83$H7F!$$^$:<B:]$KH/@8$7F@$k>c32$r5?;wE*$KH/@8$5$;!$$=$N>e GINh$&$KF0:n9k$+$r3NG'7?!%$=$N<B9TNc$r<!@a$G=RYk!%>c32H7FO DL?.$,FO$-K/$$>l=j$,$"$j!$$=$N>l=j$GDL?.$,@Z$lF7$^$C$?$3HrA[Dj9k!%

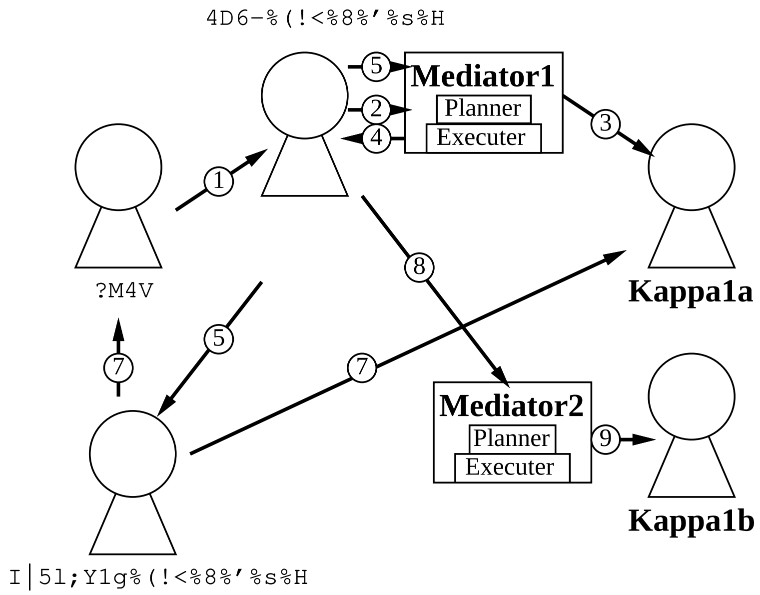
6.2 <B9TNc

?M4V$+$i%?%9%/$r0MMj$5$l!$$=$N%?%9%/$r<B9TCf$K%m%\%C%H$K>c32$,H/@8$7$? H9$k!%$=$N;~$K#2DLjN>l9g$,9M$(il$k!%0lDO<B9TCf$N%?%9%/$,B>$N%m%\%C %H$X0z$-7Q2k>l9g!$$b$&0l$D$O0z$-7Q$.$,G-$J$$>l9gG"$k!%$3li#2DL$j $N>l9g$K$D$$$F@bL@9k!%

6.2.1 0z$-7Q$.2DG=$JNc

0z$-7Q$.2DG=$J%?%9%/$H7F$O!$8=:_$O%m%\%C%H$r8F$S=P$9$H$$$&%?%9%/7+ B8:_7J$$!%3N;~$NN.$l$r?^ 6.1$K<($9!%

1. ?M$, Kappala $N8F$S$@$7r9$k!%
2. 4D6-%(!<%8%'%s%H$,%a%G%#%(!<%?$r5/F0!%?M$N=j$X9T$/$?aN%W%i%s$r@8 @.$9$k!%
3. %W%i%s%K%s%0$,=*N;$7%m%\%C%H$,0\F0$r3+;O9k!%
4. 0\F0ESCf$G2?$i$+$N>c32$,H/@8$7 Kappala $,Dd;_$9$k!%



?^ 6.1 %?%9%/0z$-7Q$.$N%a%C%;!<%8

5. 4D6-%(!<%8%'%s%H$OI|5l;Y1g%(!<%8%'%s%H$r5/F0$9$k$HF1;~$K%a%G%#%(!<%?$rDd;_$5$;$k!%

6. Dd;_7?>l=j$r?dB,$7!$%m%\%C%H$,$$$k$H;W$olk>l=j$rDL9T6X;_6h4V$K@_Dj9k

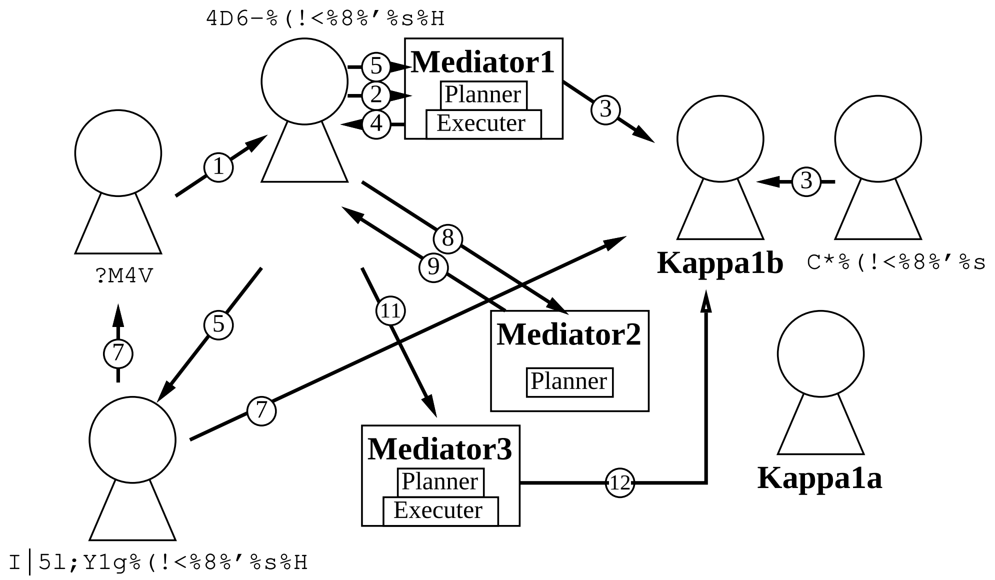
7. 3N4V!$I|5l;Y1g%(!<%8%'%s%H$O Kappa1a $NI|5l$r?M4V$K0MMj$7DDI|5lrBTD!%

8. 4D6-%(!<%8%'%s%H$,%a%G%#%(!<%?$r5/F0$7!$>c32$,H/@8$7$F$$$k%(!<%8%'%s%H$r=|$$$F%W%i%s%K%s%0$r9T$J$&!%

9. Kappa1b $,8F$s$@?M$NH3mX0\F0$9$k!%

6.2.2 I|5l7?%m%\%C%H$,%?%9%/$r:F3+9kNc

8N>c7?%m%\%C%H$N%?%9%/$rJL$N%m%\%C%H$K0z$-7Q$.G-$J$$NcH7$F!$%m%\%C%H$,0MMj$5l?2YJ*$r1?HBCf$KDd;_7F7^C?>l9g$,$"2ilk!%3N>l9g!$%m%\%C%H$N>eK"$k2YJ*$rJL$N%m%\%C%H$,<hk3H,G-$J$$$?aK!$$=$N%?%9%/$ODd;_9k7+$J$$!%$=$3$G!$$3$N%m%\%C%H$,I|5l9kNrBT$A!$I|5l7F$+$iCfCG7F$$$?%?%9%/$r0z$-B3$-<B9T$9$k!%$3$NN.$l$r?^ 6.2$K<($9!%



?^ 6.2 %?%9%/7QB3$N%a%C%;!<%8

1. ?M$+$i%^%K%e%"%k$r1?$s$GM_$7$$$H%?%9%/$r0MMj$5lk!%
2. 4D6-%(!<%8%'%s%H$,%a%G%#%(!<%?$r5/F0$7!$%a%G%#%(!<%?$,%W%i%s%K%s%0$r9TJ&!%
3. %W%i%s%K%s%0$K4p$E$-!$C*$NA0$K0\F0$7$F%^%K%e%"%k$rC*$+$i<u$1Hk!%
4. %^%K%e%"%k$r1?HBCf$K Kappa1b $,2?$i$+$N>c32$,H/@8$7$FDd;_$9$k!%

5. 4D6-%(!<%8%'%s%H$,I|5l;Y1g%(!<%8%'%s%H$r5/F0$9$k!%3l$HF1;~$K%a%G%#%(!<%?$rDd;_$9$k!%

6. 4D6-%(!<%8%'%s%H$ODd;_$7$?>l=j$r?dB,$7!$%m%\%C%H$,$$$k$H;W$olk>l=j$rDL9T6X;_6h4V$K@_Dj9k!%

7. 3N4V!$I|5l;Y1g%(!<%8%'%s%H$O Kappa1b $NI|5l$r?M$K0MMj$7DDI|5lrBTD!%

8. %?%9%/$r0z$-7Q0?aK4D6-%(!<%8%'%s%HOJLN%a%G%#%(!<%?$r5/F0$9$k!%

9. %^%K%e%"%k$,%m%\%C%H$N>eK"kN$G%W%i%s%K%s%0$G<:GT9k!%

10. %m%\%C%H$,I|5l$9k^$G%?%9%/$rCfCG9k!%

11. ?M4V$N<j$Khj%m%\%C%H$,I|5l$7$?$i!$%?%9%/$r7QB3$9$kh&$K4D6-%(!<%8%'%s%H$,%a%G%#%(!<%?$r5/F0$9$k!%

12. %a%G%#%(!<%?$O8=:_0LCV!$:G8e$N>uBV$+$i%W%i%s%K%s%0$7!$%?%9%/$r:F3+9k!%

6.3 9M;!

:#$^$G$N%7%9%F%`$G$O!$0l$D$N%m%\%C%H$,Dd;_$7$F$7$^$C$?$j!$%a%C%;!<%8$r0l$D$H$j$3$\$9$@$1$GA4$F$N%7%9%F%`$K1F6A$r5Z$\$7!$A4BN$,Dd;_9k3H$,$h$/H/@8$7$F$$$?!%7+$7!$K\8&5f$G9=C[$7$?%7%9%F%`$G$O$3$l$i$KBP1~$G$-$k$h$&$K$J$C$?!%$3$l$K$h$j!$2?$i$+$N>c32$,H/@8$7$?>l9g$K!$>c32$,H/@8$7$?%m%\%C%H$N$_$K1F6A$r$H$I$a$k$3$H$,$G$-$k!%$=$7$F!$%m%\%C%H$N>c32$,<h$j=|$+$lI|5l$9$l$P%7%9%F%`$KLak3H,2DG=HJC?!%

$^$?!$>c32$,H/@8$7!$?MK=$NI|5l$rB%$9:]$KBg$^$+$J>l=j$rCNi;k3HGI|5l$K8~$+$&?M$KHCFOHs>o$KC5$7d9$$$H;Wol$k!%$^$?!$$=$N%m%\%C%H$,Dd;_7F$$$k4V!$Dd;_$7$?$H;Wol$k6h4V$N$_$rDL9TITG=K9lPh/!$B+G{$5lF$$$?DLO)A4F,DL9TITG=KJiJ$$$N$G!$B>$N%m%\%C%H$N:n6H$,<B9T$7d9

$/$J$k!%$3lKhC$F!$DLO)$r:I$,lk3HKh$k%W%i%s%K%s%0$N<:GT$,>/$J$/$JC?!%

<B834D6-$K0MB8$7$?LdBj$H7F$O!$Dd;_7?>l=jKhCF$O!$$I$&$7FbDL2a7J1lPJiJ$$%]%$%s%H$,$"$j!$$=$N>l9g$O%W%i%s%K%s%0Cf$K<:GT$9$k!%FC$K0lK\F;$GDd;_$7$?>l9g!$$=$NDLO)$rDL$k%?%9%/$O3N<B$K<:GT$7F7$^$&$H$$$&LdBj$,H/@8$7$?!%$3$NLdBj$O4D6-CO?^$r#2$D$NDLO)$r:nk3HGJd$($k$H9M$(ilk,!$<B83@_HwA4BN$r;HCF$$$k$?$aK3$l0J>e$N3HD%$OIT2DG=$G$"$k!%$=$N$?$a!$:#2s$O3N3NG’$O9T$JCF$$$J$$!%

b&0lDNLdBj$O!$DL?.$N3NG’$r9TJ&3HKhCFDL?.$N?.Mj@-$r>e2F$$$kN@$,!$$3l,DL?.NL$rA}$d$9$3HKJC$F$$$k!%3N$?$a!$%7%9%F%`A4BN$N%?%9%/$N=hM};~4V$,D9$/$J$C$F$7$^$C$?!%$3$l$O4h6/$J%7%9%F%`$N9=C[N?aKOd$`$rF@$J$$$H;Wol$k!%

Bh 7 >O

7kO@$HE8K>

7.1 7kO@

K\8&5fGO!$J#?t$N%m%\%C%H$,F0$/Cf$G!$$"$k%m%\%C%H$K>c32$,H/@8$7$?;~$K I|5l:n6H$r?M4V$H6(D4$7!$$=$N>c32$,H/@8$7$?%m%\%C%H$,<B9T$7$F$$$?%?%9%/$r 7QB3$5$;$k3HNG$-$kh&$J6(D44D6-$r9=C[7?!%

3Nh&$J6(D44D6-$KI,MW$J>uBV4IM}$NJ}K!KD$$$F$OBh 2 >O$K=RY?!%K\8& 5f$G;HMQ$7$?%m%\%C%H$N@bL@$r#3>O$G=R$Y!$$3l^GN8&5f$G3+H/$5l?3F%(!< %8%'%s%H$N@bL@$r 4 >O$G=R$Y$?!%5 >O$G%U%)!<%k%H%H%l%i%s%H$J6(D47O$r9=C[$9 k?aK3HD%!&DI2C5l$?%(!<%8%'%s%H$N>\:Y$J@bL@$r=R$Y!$$=7F#6>O$G<B8= 7?6(D47O$N<B9TH=$NI>2A$r9T$JC?!%

K\8&5f$G3+H/$7$?<jK!$O!$%7%9%F%`A4BN$N>uBV$r4IM}$9k3HH!$I|5l$r;Y1g 9k$?$a$N%(!<%8%'%s%H$rF3F~9k3HG"$k!%>uBV4IM}$r9TJ&3HKh$j!$ $"$k%m%\%C%H$K>c32$,H/@8$7$?3H$r8!=P$G$-$k!%$^$?!$>c32$KhjCfCG5l$? %?%9%/$rJL$N%m%\%C%H$KBe9T5;k+!$I|5l$7$?%m%\%C%H$,7QB3$9$k3H$,2DG= KJC?!%$^$?!$?7$?$KI|5l;Y1g%(!<%8%'%s%H$r:n@.$7!$>c32$,H/@8$7$?%m%\%C %H$NI|5l;Y1g$r8DJL$K9TJC$?!%$3lKhj!$$I$N%m%\%C%H$,!$$I$N>l=j6aJU$G!$ Is$J>uBV$G>c32$,H/@8$7$?$N$+$rL@3NKEA(k3H,G-$k!%$=7F!$I|5l8e $K%7%9%F%`$KLa$k:]$K$b>uBV$rI|85$9$k3HKbLrN)C?!%

7.2 E8K>

K\8&5f$G9=C[$5l?%7%9%F%`$NLdBjE@$H$7$F$O!$0l$D$K$O!$$3$N%7%9%F%`$O?M $,%m%\%C%H$NI|5l:n6H$r9T$J$&$3H,A0DsHJCF$$$k!$$H$$$&3HG"$k!%%m

%\%C%H<+?H!$$"$k$$$O?M4V0J30$N4D6-Cf$N%(!<%8%’%s%HKh$j!$?M$N<j$ro:$i
o9$3$HJ/I|5lG-k3H,K>$^$7$$!%5i$K!$8=:_$O%m%\%C%H$,FsBf$@$1$G
$"$j!$0z$-7Q$.$rG-$k%?%9%/$,>/$J$$$H$$$&E@$bLdBj$G$"$k!%

3liNLdBjE@$+$i!$:#8e$N2]BjH7FO!$0l$D$K;0Bf0J>e$N0[<o$N%m%\%C%H
$,F1$84D6-2<$GF0:n$9$k%U%)!<%k%H%H%l%i%s%H$J4D6-$r9=C[$9k3HG$"$k!%8=
:_$N%7%9%F%‘$G$O9TF07?$N%m%\%C%H$OFsBf$7$+$J$/!$0z$-7Q$.$,2DG=$J%?%9%/$,
>/$J2a$.$k!%$^$?!$0lBf$K>c32$,H/@8$7$F7^$&$H!$;D$j0lBf7+;DCF$$$J$$!%
$=$N$?$a!$$"$^$j8zN(h/%?%9%/r3J;$J$$!%

$^$?!$8=:_$N%7%9%F%‘GO!$%m%\%C%H$NI|5l$O?M4V$N<j$r<Z$jJ1lP$[$H$s
$IIT2DG=$J$?$a!$Hs>o$K?M4VKHCF$O<j4V$G$"$k!%3l$,<+8J$"$k$$$O?M4V0J
30$N%(!<%8%’%s%H$KhC$FI|5l$G$-$kh&$J4D6-$,K>$^$7$$!%3lKHbJ$$!$
>l=j$N3NG’$b4D6-Cf$rJ#?t$N0LCV$+$i%+%a%i$G4F;k$7!$$=$NDd;_0LCV$b<+F0E*$K
H=JL9k!%3lKh$j!$40A4$K?M4V$KMji:$KI|5l$74D6-KLalkh$&$KJk$3
H,4|BTG-$k!%

<U<-

<g;XF36541G"$k@>EDK-L@65<x$K$O!$MM!9JLLG8f;XF3$rD:$-$^$7$?!%$^$?!$
%m%\%C%H$rBP>]$H7?8&5f$K7H$o$k5!2q$rD/CFD:$-$^7?!%$3$3$K?<$/46<U
CW7^$9!%

2#LpD>OB65<xKO!$K;$7$$Cf!$K\8&5f$NI{;XF36541KJCFD:$-$^7?!%$3$3
$K?<$/46<UCW7^$9!%

IpED1QL@=u65<xKO!$8&5f$NJ}8~@-$dFbMF$K$D$$$F8f=u8@$rD:$-$^$7$?!%$3$3
$K?<$/46<UCW7^$9!%

BtEDFF;K=u<j (8=:_!$5~ETBg3X7W;;5!%;%s%?!<=u65<x) KO8&5f2qJIrDL8
$F5.=E$J8f;XF3!&8f=u8@$rD:$-$^$7$?!%$3$3$K?<$/46<UCW$7$^$9!%

>eLnFX;V=u<jKO!$K\8&5f$r?JakK"$?$j!$8f;XF3$H8f=u8@$rD:$-$^$7$?!%
$^$?!$K\O@J8$r$^$HakK"$?$j!$E,@Z$J8f;XF3$H8f=u8@$rD:$-$^7?!%$3$3$K
?<$/46<UCW$7$^$9!%

4dED9@;J;a!$>.NSE81Q;a!$>>867D9,;aKO!$Kappa%7%9%F%`$N7Q>5r5$;$FD:
$-$^7?!%$3$3$K?<$/46<UCW7^$9!%

Gn;N2]Dx$N;{EDOB7{;a!$=$;N2]Dx$NFbED7C5W;aKO!$8&5f2q$rDL8FMM!9$J0U
8+$rD:$-$^$7$?!%$3$3$K?<$/46<UCW$7$^$9!%

=$;N2]Dx#1G/$NJ}!9KO!$%m%\%C%H$N<B83Ey$r<jEA$C$FD:$-$^$7$?!%$3$3$K?<
$/46<UCW$7$^$9!%

8&5f<<$N3'MMJ}$K$O!$8x;dKo$?$j$*@$OCKJj^7?!%$3$3$K?<$/46<UCW$7
$^$9!%

:G8e$K!$8&5f<<GN3hF0$r;Y$($FD:$-$^$7$?>.I[;\J8BeHk=q$K8|$/8fNi?=$7>e
2^$9!%

;29MJ88%

[1] :4F#CN@5, %f!<%S%-%?%9%m%\%F%#%C%/%7%9%F%`, F|K\%m%\%C%H3X2q;o Vol.15 No.4,pp.496–500,1997

[2] :4F#CN@5, <R2q%$%s%U%i%9%H%i%/%A%c$KAjPail$??M9)J*$N5!G==8@QH7FN%m%\%C%H, F|K\%m%\%C%H3X2q;o Vol.16 No.1,pp.8–11,1998

[3] >>0f=S9@, $*$;C+$$%m%\%C%HHb8FPl$k;v>pDL%m%\%C%H$N7W2h,bit vol.29 No.12,1997

[4] >>86 7D9,, <B@$3&%(!<%8%'%s%H$N%^%k%A%?%9%/%W%i%s%K%s%0Kh$k:n6H;Y1g4D6–$N9=C[, Master's thesis, F`NI@hC<2J3X5;=QBg3X1!Bg3X >pJs2J3X8&5f2J, 1997

[5] >.NS E81Q, <B@$3&%(!<%8%'%s%H$N6(D4K*1k?M4V–%m%\%C%H4V$N%3%_%e%K%1!<%7%g%s, Master's thesis, F`NI@hC<2J3X5;=QBg3X1!Bg3X >pJs2J3X8&5f2J, 1997

[6] 4dED 9@;J, %a%G%#%(!<%?$rMQ$$$?<B@$3&%(!<%8%'%s%H$N6(D44D6–$N9=C[, Master's thesis, F`NI@hC<2J3X5;=QBg3X1!Bg3X >pJs2J3X8&5f2J,1996

[7] 4dED9@;J, Bk9g4p9T, BtEDFF;K, IpED1QL@, @>EDK–L@. %a%G%#%(!<%?$rMQ$$$?J*M}%(!<%8%'%s%H$H%=%U%H%&%(%"%(!< %8%'%s%H$N6(D44D6–$N9=C[. EE;R>pJsDL?.3X2q5;=QJs9p, number AI95-42, pages 1-8, 1996

[8] >>867D9,, >eLnFX;V, BtEDFF;K, IpED1QL@, @>EDK–L@. ?M$r4^$s$@<B@$3&%(!<%8%'%s%H$N6(D47O$K$*$1$k%W%i%s%K%s%0$H<B9T. ?M9)CNG=3X2q?M9)CNG=4pACO@8&5f2q SIG-FAI-9603, pages 12-17, 1997.

[9] >.NSE81Q, >eLnFX;V, BtEDFF;K, IpED1QL@, @>EDK–L@. ?M4V$r4^$s$@<B@$3&%(!<%8%'%s%H$N6(D4$N$?$a$N?M4V-%m%\%C%H4V$N%3%_%e%K%1!<%7%g%s. ?M9)CNG=3X2q?M9)CNG=4pACO@8&5f2q SIG-FAI-9603, pages 18-23, 1997.