%*%V%8%'%/%H;X8~%G!<%?%Y!<%9K*1k 7?8!::LdBj$N7W;;NL

@6?e Ur8d[†]!$@P86 LwE[‡]!$4X 9@G7[†]!$0KF# <B[‡]

[†] F`NI@hC<2J3X5;=QBg3X1!Bg3X

630-01 F`NI8)@86p;T9b;3D. 8916-5

E-mail: shougo-s@is.aist-nara.ac.jp

FbMF9<35

%*%V%8%'%/%H;X8~%W%m%0%i%_%s%08@8l$NK\<AE*$JFCD'$N0l$DH7$F!$%a%=%C%I8F=P$75!9=$,5s2ilk!%3N5!9=$O!$%G!<%?$N%+%W%;%k2=$d%3!<%I$N:FMxMQ$N$?$a$K=EMW$JbNG"k,!$<B9T;~$K7?%(%i!<$,5/$3$k4m81@-$,$"$k!%FC$K!$%*%V%8%'%/%H;X8~%G!<%?%Y!<%9!JOODB!K$NLd9g$o$;%W%m%0%i%`$N>l9g$O!$<B9T;~$K7?%(%i!<$,5/$3$k$H!$%m!<%k%P%C%/$r9T$&I,MW$,$"$k!%$7$?$,$C$F!$M?$($i$l$?OODB%9%-!<%^$,7?@09g@-$r;}$D$3$H!$$9$J$o$A!$$I$s$J%G!<%?%Y!<%9%$%s%9%?%s%9$N2<$G$bLd9g$;%W%m%0%i%`$N<B9TCf$K7?%(%i!<$,5/3i$J$$$3HrJ]>ZG-k3H,K>$^$7$$!%K\9FGO!$Hull$iKhCFDs0F5l$?99?7%9%-!<%^$rOODB%9%-!<%^$N%b%G%k$H7F:NMQ$7!$J1!KDd;_@-$rK~$?$9%9%-!<%^$KBP9k7?8!::LdBj, $*$h$S, !J2!K%a%=%C%IDj5ACf$K99?7A`:n$,$J$$%9%-!<%^KBP9$k7?8!::LdBj$,$$$:lb7hDjITG=G"k3Hr<($9!%

1. $^$($,$-

%*%V%8%'%/%H;X8~%W%m%0%i%_%s%08@8l$NK\<AE*$JFCD'$N0l$DH7$F!$%a%=%C%I8F=P$75!9=$,5s2ilk!%3N5!9=$O!$%/%i%93,AX$K1h$C$?7Q>5$Khk%a%=%C%I$NB?=EDj5A$HCY1dB+G{$K4p$E$$$F$$$k!%B?=EDj5AKh$j!$$"$k%a%=%C%IL>m$KBP7F!$J#?t$N%/%i%9$,m$N0[JC$?Dj5A$r;}D3H,G-$k!%%*%V%8%'%/%Ho$KBP7Fm$,8F$S=P5l$?$H$-!$o$,B0$9$k%/%i%9$K=>CFm$NDj5A$N$&$A$N0l$D$,A*Br$5$l!$<B9T;~KmKB+G{5l$k!JCY1dB+G{$^$?$OF0E*B+G{!K!%3N5!9=$O!$%G!<%?$N%+%W%;%k2=$d%3!<%I$N:FMxMQ$N$?$a$K=EMW$JbNG"k,!$<B9T;~$K7?%(%i!<!JNc$($P!mKB+G{9Y$-Dj5A$,B8:_7J$$>l9gJI!K$,5/$3$k4m81@-$,$"$k!%FC$K!$%*%V%8%'%/%H;X8~%G!<%?%Y!<%9$NLd9g$o$;%W%m%0%i%`$N>l9g$O!$<B9T;~$K7?%(%i!<$,5/3k$H!$%m!<

%k%P%C%/$r9T$&I,MW$,$"$k!%$7$?$,CF!$M?$(il$?%*%V%8%'%/%H;X8~%G!<%?%Y!<%9%9%-!<%^ S $,7?@09g@-$r;}D3$H!$$9Jo$A!$$IsJ%G!<%?%Y!<%9%$%s%9%?%s%9$N2<GbLd9go;%W%m%0%i%`$N<B9TCf$K7?%(%i!<$,5/$3$i$J$$$3$H$r!$%3%s%Q%$%k;~!J<B9TA0!K$KJ]>Z$G$-$k$3$H$,K>$^$7$$!%0J2<!$S $,7?@09g@-$r;}$D$+H]$+$rH=Dj$9$kLdBj$r!$S $KBP$9$k7?8!::LdBj$H8F$V!%7?8!::LdBj$r2r$/$?$a$K$O!$DL>o!$3F%a%=%C%I$NJV$jCM$d%a%=%C%IDj5A!J%W%m%0%i%`!KCf$NJQ?t$NCM$,$I$N%/%i%9$N%*%V%8%'%/%HKJ$jF@$k$+$r2r@O9kI,MW$,$"$k!%

%*%V%8%'%/%H;X8~%G!<%?%Y!<%9%9%-!<%^$N%b%G%k$H7F$O!$Hull iKhj99?7%9%-!<%^$H8F$Plk%b%G%k$,Ds0F$5lF$$$k [1]!$[9]!%99?7%9%-!<%^$O!$%/%i%93,AX!$7Q>5!$J#9g%*%V%8%'%/%H$H$$$C$?%*%V%8%'%/%H;X8~%G!<%?%Y!<%9$N4pK\E*$JFCD'r9YF;}$D!%%a%=%C%I$NDj5A$O<jB3$-7?%*%V%8%'%/%H;X8~%W%m%0%i%_%s%08@8l$K4p$E$/!%$7$?$,CF!$%G!<%?%Y!<%9%$%s%9%?%s%9$N99?7$O%*%V%8%'%/%H$NB0@-$X$N%*%V%8%'%/%H$NBeF~H7$FMF0W$K%b%G%k2=5l$k!%

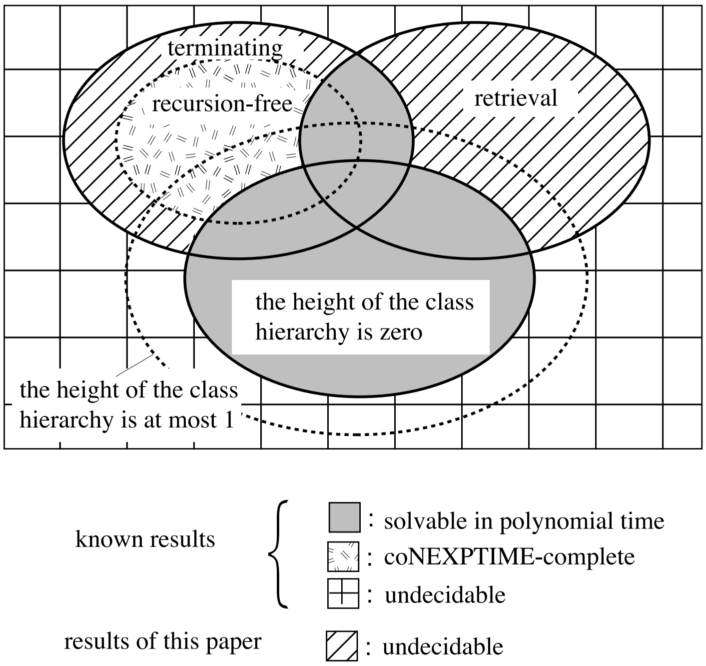
99?7%9%-!<%^KBP9$k7?8!::LdBj$O!$0lHL$K$O7hDjITG=$G$"$k3H$,CN$ilF$$$k [1]!$[9]!%$5iK!$0J2<$Nh&$J99?7%9%-!<%^$NItJ,%/%i%9KBP9$k7?8!::LdBj$N7W;;NL$,CN$ilF$$$k!%

- %/%i%93,AX$N9b$5$, 0 NH$-!$B?9`<0;~4V2D2r [10]!%
- %/%i%93,AX$N9b$5$,9b!91 G"CF$b!$7hDjITG= [10]!%
- Dd;_@-$rK~$?$7!$$+$D%a%=%C%IDj5ACf$K99?7A`:n$,$J$$$H$-!$B?9`<0;~4V2D2r [14]!%
- %a%=%C%IDj5ACf$K:F5"$,$J$$$H$-!$co Hs7hDj@-;X?t;~4V40A4 [10]!%

K\9FGO!$0J2<$Nh&$J99?7%9%-!<%^$NItJ,%/%i%9KBP9$k7?8!::LdBj$,7hDjITG=G"k3Hr<($9!J?^ 1;2>H!K!%

1. Dd;_@-$rK~$?$7!$$+$D%/%i%93,AX$N9b5,9b!91 G"$k%9%-!<%^!%
2. %a%=%C%IDj5ACf$K99?7A`:n$,J/!$$+$D%/%i%93,AX$N9b5,9b!91 G"$k%9%-!<%^!%

K\9FGO!$99?7%9%-!<%^$K0J2<$N 3 DN@)Lsr*$/!%$^$:!$B?=E7Q>5$OB8:_7J$$$H$$$&@)Lsr*$/!%$7$+$7!E,EvJ7Q>55!9=$r2>Dj$9lP!$K\9F$N7k2L$OB?=E7Q>5$,



?^ 1 7?8!::LdBj$N7W;;NL

$"$k>l9gKD$$$F$b@.$jN)$D!%$9Jo$A!$$3$N@)Ls$O5DO@$N4JC1$N$?$aK*$$$?@)LsG"$k!%<!$K!$%a%=%C%IDj5ACf$K$O>r7oJ8$,;H$($J$$$H$$$&@)Lsr*$/!%$7$+$7!$**2.2** $NNc 2$G<(9h$&$K!$99?7A`:n$rMQ$$$F if-then J8$rLOJo$9$k$3$H$,$G$-$k!%:G8e$K!$3F%a%=%C%I$N0z?t$N8D?t$O 1 $G$"$k$H$$$&@)Ls$r$*$/!%$3$N@)Ls$r$*$+$J$$>l9g!$J88% [2] $N7k2L$K$h$j!$Dd;_@-$rK~$?$7!$$+$D%a%=%C%IDj5ACf$K99?7A`:n$,$J$$%9%-!<%^KBP9$k7?8!::LdBj$,7hDjITG=HJk3H,MF0W$K<($;$k!%$=$N0lJ}$G!$%/%i%93,AX$N9b5, 0 $N%9%-!<%^$KBP9k7?8!::LdBj$OB?9`<0;~4V2D2r$G$"$k3H$,<($;$k!%$^$?!$:F5"J7%9%-!<%^KBP7Fb!$7hDj2DG=$G$"$k3H$,M=A[$5lk!%

4XO"8&5fH7FO!$$^$:!$Abiteboul iNJ88% [2] $,5s$2il$k!%$3$NJ88%$G$O!$%a%=%C%I%9%-!<%^$H8F$Plk4X?t7?%*%V%8%'%/%H;X8~%W%m%0%i%_%s%08@8l%b%G%k$,Ds0F$5lF$*$j!$$=$N$$/D+$NItJ,%b%G%k$KBP9k7?8!::LdBj$N7W;;NL$,<(5l$F$$$k!%5i$K!$J88% [15] GO!$:F5"$J$7%a%=%C%I%9%-!<%^$N7?8!::$r9T$&:GE,$J%$%s%/%j%a%s%?%k%"%k%4%j%:%`$,<($5$l$F$$$k!%$^$?!$J88% [12] $G$O!$<jB3$-7?%*%V%8%'%/%H;X8~%W%m%0%i%_%s%08@8l$KBP$9$k7??dO@%"%k%4%j%:%`$,Ds0F$5lF$$$k!%3N%"%k%4%j%:%`$G$O!$%W%m%0%i%`Cf$N3F<0 e KBP7$F e $N7?$rI=$9JQ?t $[\![e]\!]$ $rF3F~$7!$$3

li$NJQ?t4V$N4X78$rI=$9Ey<0$N:G>.2r$r5aak3HKhCF%W%m%0%i%`$N7?@09g@-$r2r@O9k!JJ88% [11]!$[13] $b;2>H$5l?$$!K!%J*!$J88% [4], [5], [14] JI$G!$%*%V%8%'%/%H;X8~%G!<%?%Y!<%9K*1k%a%=%C%I%Y!<%9$N%"%/%;%98"%b%G%k$,Ds0F5l$F$$$k$,!$$3li$N%b%G%k>e$G$N%"%/%;%98"$NH=DjKO7?8!::$N5;=Q$,I,MWG"k3H,CNil$F$$$k!%

0lJ}!$J88% [3] $d [6] GO!$3F%a%=%C%I$N%7%0%M%A%c!J0z?t$N%*%V%8%'%/%H$N%/%i%9HJVjCM$N%*%V%8%'%/%H$N%/%i%9HN4X78!K$rF~NO$H7F!$$=li$, **contravariance** JI$N>r7o$rK~$?7F$$$k$+$I$&$+$r8!::$9$kLdBj$K$D$$$F9M;!7F$$$k!%7+$7!$$3$NLdBj$O!$2f!9$d Abiteboul i,07CF$$$kLdBj$H0c$$!$%W%m%0%i%`$NFbMF$r2r@O$;$:$K2r$/$3$H$,$G$-$k!%$^$?!$[7], [8] $G$O!$%W%m%0%i%`Cf$NJQ?t$d<B9TJ8$JIN7?$r?dO@$9k?aN8xM}7O$rM?$($F$$$k$,!$7?8!::LdBj$r2r$/$?$a$N7W;;NL$K$D$$$FO[Hs$I5DO@$5lF$$$J$$!%

2. %a%=%C%I<B9T%b%G%k

2.1 9=J8

%G!<%?%Y!<%9%9%-!<%^$O!$<!$N 6 9`AH $\mathbf{S} = (C, \leq, Attr, Ad, Meth, Impl)$ G"$k!%

1. C $O%/%i%9L>$NM-8B=89g!%

2. $\leq$ $O%/%i%93,AX$rI=$9 C >e$NH>=g=x!' $c' \leq c$ NH$-!$ c O c' $N2<0L%/%i%9!J$^$?$O!$ c' $O c $N>e0L%/%i%9!K$G$"$k$H8@$&!%5DO@$N4JC1$N$?$a!$ $\leq$ $O?9$G$"$k!J9JoA!$$b$7 $c \leq c_1$ $+$D $c \leq c_2$ Ji$P!$ $c_1 \leq c_2$ $^$?$O $c_2 \leq c_1$!K$H2>Dj$9$k!% $\leq$ $N9b$5$r!$0[Jk $c_0, c_1, \ldots, c_n$ KBP7$F $c_0 \leq c_1 \leq \ldots \leq c_n$ $,@.$jN)$D:GBg$N n $HDj5A$9$k!%

3. $Attr$ $OB0@-L>$NM-8B=89g!%

4. $Ad : C \times Attr \to C$ $OB0@-@k8@$rI=$9ItJ,4X?t!% $Ad(c, a) = c'$ $O!V%/%i%9 c NG0U$N%*%V%8%'%/%H$NB0@- a NCMO!$%/%i%9 c' O=$N2<0L%/%i%9$N%*%V%8%'%/%HG"$k!W$3HrI=$9!J>\$7$/$O **2.2** $N%G!<%?%Y!<%9%9%-!<%^$N%;%^%s%F%#%/%9$NDj5A$r;2>H!K!%

5. $Meth$ $O%a%=%C%IL>$NM-8B=89g!%

6. $Impl : C \times Meth \rightarrow WFS$ $O%a%=%C%I$N<B9T%W%m%0%i%`$rI=$9ItJ,4X?t!%$3$3$G $WFS$ $O!$0J2<$GDj5A$9$k!$9=J8E*$K@5$7$$%W%m%0%i%`A4BN$N=89g$G$"$k!%G$0U $N $c \in C$ $H $m \in Meth$ KBP7$F!$ $Impl(c, m)$ $r!$ c $GDj5A$5l? m $N%a%=%C%I Dj5A$H8F$V!%

3F<B9TJ8$O!$<!$N 6 DN7A<0$N$$$:l+G"$k!%

1. $y := y'$,
2. $y := \mathrm{self}$,
3. $y := \mathrm{self}.a$,
4. $y := m(y')$,
5. $\mathrm{self}.a := y'$,
6. $\mathrm{return}(y')$.

$3$3$G!$ y, y' $OJQ?t!$ $a \in Attr$!$ $m \in Meth$!$ self $O%a%=%C%I$,8F$S=P$5l?%*%V%8%' %/%H!J<B0z?tHJ$k%*%V%8%'%/%H!K$rI=$9M=Ls8l$G$"$k!%3N$&$A!$ **2.2** $G=R$Ykh$& $K!$7A<0 5 $N<B9TJ8$@1,%G!<%?%Y!<%9$N99?7$r9T$&$3H,G-$k!%0J2<!$7A<0 5 $N <B9TJ8$r99?7A`:n$H8F$V!%

$s_1; s_2; \cdots; s_n\ (= \alpha)$ $r<B9TJ8$NM-8B7ONsH9$k!%$b$7!$ $1 \leq i \leq n$ $N<B9TJ8 s_i bCM,L$Dj5A$NJQ?t$r;2>H$;$:!$$+$D!!$J2!K:G8e$N<B9TJ8 s_n $,$ $\mathrm{return}(y)$ $N7A<0 G"kJiP!$ α $r9=J8E*$K@5$7$$%W%m%0%i%`$H8@$&!%

0lHL@-$r<:$&3HJ/!$0l;~JQ?t$r>JN,7F=q$/$3H,$"$k!%Nc$($P!$" y := self.a; $y := m(y')$;" $r!$0l;~JQ?t y $rN,$7$F" $y := m(\mathrm{self}.a)$;" $H=q$/!%

2.2 0UL#

%a%=%C%IDj5A$N7Q>5$rI=$9ItJ,4X?t $Impl^* : C \times Meth \rightarrow WFS$ $r<!$Nh&$KDj5A$9 $k!% $c \in C, m \in Meth$ H9$k!%$b$7!$ c $Impl(c, m)$ $,Dj5A$5lF$$$k c $N!J$\leq$$K4X9k!K:G >.$N>e0L%/%i%9$H9k!%9JoA!$$b$7 $Impl(c', m)$ $,Dj5A$5lF$$$F$+$D $c' \leq c$ Ji$P!$ $c \leq c''$!W$rK~$?9h$&$J%/%i%9G"$k!%$3NH$- $Impl^*(c, m) = Impl(c', m)$ $HDj5A$9$k!%$b7=Nh$&$J c' $,B8:_$7J1lP!$ $Impl^*(c, m)$ OLDj5AH9$k!%

F1MM$K!$B0@-@k8@$N7Q>5$rI=$9ItJ,4X?t $Ad^* : C \times Attr \to C$ $r<!$Nh&$KDj5A$9 $k!%$c \in C, a \in Attr$ H9$k!%$b$7 $Ad(c,a)$ $,Dj5A$5lF$$$k c $N:G>.$N>e0L%/%i%9 c' $,B8:_$9kJiP $Ad^*(c,a) = Ad(c',a)$ H7!$$5bJ1l$P $Ad^*(c,a)$ OLDj5A$H 9k!%

$\mathbf{S}$ $N%G!<%?%Y!<%9%$%s%9%?%s%9$O!$<!$N 2 9`AH $\mathbf{I} = (\nu, \mu)$ G"$k!%

1. ν O C $rDj5A0h$H9k4X?t$G!$\nu(c)$ $(c \in C)$ $O%*%V%8%'%/%H$NM-8B=89g!%$?$@ $7!$3F%/%i%94V$N%*%V%8%'%/%H=89g$O8_$$$KAG!J9JoA!$$1$7$F $c' \neq c$ $\nu(c) \cap \nu(c') = \phi$!KH9$k!%3F $o \in \nu(c)$ $r!!$J $\mathbf{I}$ K*1k!K%/%i%9 c $N%*%V%8%'%/ %H$H8F$V!%99$K!$ $O_{\mathbf{S},\mathbf{I}} = \bigcup_{c \in C} \nu(c)$ H7!$3F $o \in O_{\mathbf{S},\mathbf{I}}$ $r!$C1$K!J $\mathbf{I}$ K*1k!K%* %V%8%'%/%H$H8F$V!% $cl(o)$ Kh$j!$ $O_{\mathbf{S},\mathbf{I}}$ $NB0$9$k%/%i%9!$$9Jo$A!$ $o \in \nu(c)$ HJ$k c $rI=$9!%

2. μ $OM-8~%0%i%U$\mu = (V, E)$ G"$k!%$3$3$G!V $O%*%V%8%'%/%H$rI=$9D:E@$N=89g $O_{\mathbf{S},\mathbf{I}}$ G"$j!$E$ $O0J2<$N>r7o$rK~$?$9%i%Y%kIU$-M-8~JU$N=89g$G$"$k!%

   - $o \in \nu(c)$ H9$k!%$Ad^*(c,a) = c'$ Ji$P!$$Ag&$I0l$D$N $o' \in \nu(c'')(c'' \leq c')$ KBP7$F!$ $o \xrightarrow{a} o' \in E$!% $Ad^*(c,a)$ $,L$Dj5AJi$P!$ o $O%i%Y%k a rb$D=P <MJU$rb?$J$$!%

   $o \xrightarrow{a} o' \in E$ NH$-!$ o' $r%*%V%8%'%/%H o $NB0@- a NCMH8F$S!$ $o.a$ $GI=$9!%

0J2<GO!$ $\mathbf{I}$ $N2<$G$N $\mathbf{S}$ $N<B9T$r4JC1$K@bL@$9$k!J7A<0E*$JDj5A$O [1]!$[9] $^$?$O [10] $r;2>H!K!%%*%V%8%'%/%H o KBP7$F%a%=%C%I m $,8F$S=P5l$?$H$-!$ o $r!$$=$N 8F=P$7K*1k%;%k%U%*%V%8%'%/%H$H8@$$!$self $HN,5-$9$k!%6 <oN`$N3F<B9TJ8$KBP 7F!$<!$Nh&$J0UL#$rM?$($k!%

$y := y'$ $O!$ y' $NFbMF$r y $KBeF~$9$k!%

$y :=$ self $O!$self $rJQ?t y $KBeF~$9$k!%

$y :=$ self.a $O!$self $NB0@- a NCMr y $KBeF~$9$k!%

$y := m(y')$ $O!$JQ?t y' $KBeF~$5lF$$$k%*%V%8%'%/%HKBP9$k%a%=%C%I m $N8F=P 7rI=$7!$<!Nh$&$K<B9T5l$k!%$^$:!$ y' $KBeF~$5lF$$$kCM$r $o \in \nu(c)$ H9$k!%$b $7 $Impl^*(c,m)$ $,L$Dj5AJi$P7?%(%i!<$GDd;_9k!%b7 $Impl^*(c,m) = \alpha$ Ji$P!$ α K*$$$F o $r self $KB+G{$7!$ α $r<B9T$9$k!%JV$jCM$O y $KBeF~$9$k!%

Class employee
boss, supervisor : employee

Class manager
boss, supervisor : director

Class director
secretary : employee

?^ 2 Ad_1 $NDj5A

(director, get_secretary) :
return(self.secretary).

(employee, query1) :
y := get_secretary(self.supervisor);
return(y).

?^ 3 $Impl_1$ $NDj5A

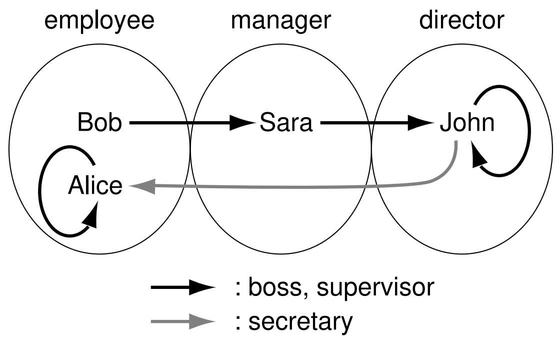
<B9TJ8 self.$a := y$ $r9M$($k!%self$NB0$9$k%/%i%9$r c H7$F$$$k;~$5$1$F$$$kCM $r o H9$k!% $Ad(c, a) = c'$ NH$-!$$b$7 o $\not\leq c'$ $rK~$?$9%/%i%9$N%*%V%8%'%/%HJi$P!$self $NB0@- a NCMr o H9$k!%$5bJ1l$P!$7?%(%i!<$GDd;_9k!%

return(y) $OJQ?t y $NFbMF$rJVjCMH9k3H$rI=$9!%

S CfNI$N%a%=%C%I$rIs$J%G!<%?%Y!<%9%$%s%9%?%s%9NbHG<B9T7F$b7?%(%i!<$,5/3i$J$$$H$-!$**S** $O7?@09g@-$rbD$H8@$&!%C"$7!$:G=i$N%a%=%C%I$N8F$S=P$7H7FO, $Impl^*(cl(o), m)$ $,Dj5A$5lF$$$kh&$J o KBP9$k m $N<B9T$N$_$r9M$($k!%$^$?!$**S** Cf$NIN%a%=%C%IrIsJ%G!<%?%Y!<%9%$%s%9%?%s%9$NbH$G<B9T$7FbI,$:Dd;_$9kH$-!$**S** $ODd;_@-$rK~$?$9$H8@$&!%

Nc **1:** %G!<%?%Y!<%9%9%-!<%^ **S** $= (C_1, \leq_1, Attr_1, Ad_1, Meth_1, Impl_1)$ $r9M$($k!%$3$3$G!$

- $C_1 = \{\text{director}, \text{manager}, \text{employee}\}$ G"$j!$director $\leq$ manager $\leq_1$ employee!%
- $Attr_1 = \{\text{boss}, \text{supervisor}, \text{secretary}\}$ G"$j!$ Ad_1 $O?^ 2$GDj5A5l$k!%
- $Meth_1 = \{\text{get\_secretary}, \text{query1}\}$ G"$j!$ $Impl_1$ $O?^ 3$GDj5A5l$k!%



?^ 4 $\mathbf{I}_1$ $N%G!<%?%Y!<%9%$%s%9%?%s%9

(employee, calc_supervisor) :
y := calc_supervisor(self.boss);
return(y).

(director, calc_supervisor) :
return(self).

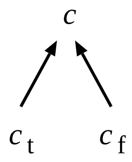
(director, get_secretary) :
return(self.secretary).

(employee, query2) :
self.supervisor := calc_supervisor(self);
y := get_secretary(self.supervisor);
return(y).

?^ 5 $Impl_1$ $NDj5A

?^ 4$O $\mathbf{S}_1$$N%G!<%?%Y!<%9%$%s%9%?%s%9 $\mathbf{I}_1 = (\nu_1, \mu_1)$ $r I=$7 $F$$ $k!% 3N?^K*$$ $F!$Bob!$Sara!$... $O%*%V%8%'%/%H$G$"$j!$Bob $\rightarrow$ Sara $O $\mu_1(\text{Bob}, \text{boss}) = \mu_1(\text{Bob}, \text{supervisor}) = \text{Sara}$ G"k3HrI=7F$$$k!%Bob $KBP 9k query1 $N<B9T$r9M$($k!$$\mu_1(\text{Bob}, \text{supervisor}) = \text{Sara} \in \nu_1(\text{manager})$ G"$j $Impl^*_1(\text{manager}, \text{get\_secretary})$ OLDj5AG"k+$i!$7?%(%i!<$,5/$3$k!%$7$?$,CF!$ $\mathbf{S}_1$$O7?@09g@-$r;}$?$J$$!%$$^1!$$\mathbf{S}_1$$;_@-$rK~$?$9$3HOMF0W$K<($;$k!%

$\mathbf{S}'_1 = (C_1, \leq_1, Attr_1, Ad_1, Meth'_1, Impl'_1)$ $r9M$($k!%$3$3$G!$$Meth'_1 =$ $\{\text{calc\_supervisor}, \text{get\_secretary}, \text{query2}\}$ G"$j!$$Impl'_1$$O?^ 5$G<($5lk!%3N$H $-!$$\mathbf{I}_1$$O $\mathbf{S}'_1$$N%$%s%9%?%s%9$Gb"$k!%Bob KBP9$k calc_supervisor $N<B9T$O@5>o$K =*N;$7!$John $,JV$5lk!%01J}!$Alice KBP9$k calc_supervisor $N<B9T$ODd;_7J$$!% calc_supervisor $N<B9T$,Dd;_9kH-!$>o$K%/%i%9 director $N%*%V%8%'%/%H$,JV5l



(a)

Class c_t

a_1, a_2, a', a''	:	c
a_f	:	c_f

(b)

$(c_t, \mathrm{nor}[a_1, a_2])$:
self.a' := self;
y := nor$'$(self.a_1);
y := nor$'$(self.a_2);
return(self.a').

(c_t, nor') :
self.a' := self.a_f;
return(self).

(c, nor') :
return(self).

$(c_t, \mathrm{if\_then}[a_1, m])$:
self.a'' := nor$[a_1, a_1]$(self);
self.a'' := nor$[a'', a'']$(self);
y := if_then$'[m]$(self.a'');
return(y).

$(c_t, \mathrm{if\_then}'[m])$:
y := m(self);
return(y).

$(c, \mathrm{if\_then}'[m])$:
return(self).

(c)

?^ 6 $\mathbf{S}_2$\$NDj5A

\$k!%<!\$K Bob \$KBP\$9\$k query2 \$N<B9T\$r9M\$(\$k!%?^ 5\$N (employee, query2) \$NBh 2 J8 \$h\$j!\$Bob.supervisor \$NCM\$O John $\in$(director) \$H\$J\$j!\$Bob \$KBP\$9\$k query2 \$N<B 9T\$O@5>o\$K=*N;\$9\$k!\$ $\mathbf{S}_1$ %7?@09g@-\$r;}\$D\$3\$H\$OMF0W\$K<(\$;\$k!% □

Nc **2:** 0J2<\$N\$h\$&\$J%G!<%?%Y!<%9%9%-!<%^ $\mathbf{S}_2 = (C_2, \leq_2, \mathit{Attr}_2, \mathit{Ad}_2, \mathit{Meth}_2, \mathit{Impl}_2)$ \$r 9M\$(\$k!%

- $C_2 = \{c, c_t, c_f\}$ \$G\$"\$j!\$ $c_t \leq_2 c, c_f \leq_2 c$ \$H\$9\$k!J?^ 6!Ja!K!K!%
- Ad_2 \$O?^ 6!Jb!K\$GDj5A\$5\$l\$k!%

$\mathbf{S}_2$$K$*$$$FO@M}CMI=8=$r<!$Nh&KDja$k!%$o$ r_tN%t%9%8%'%/%HH9$k!%
o $N3FB0@- $a \in \{a_1, a_2, a', a'', a_{\mathrm{f}}\}$ KD$$$F!$o.a = o$ NH$-??!$$=$&$G$J$$$H-56r
I=9bNH9k!%$o.a!$A$ $d_2(c_{\mathrm{t}}, a_{\mathrm{f}}) = c_{\mathrm{f}}$ $H$$$&@k8@!J?^ 6!Jb!K KKh$j r_{f} $=o.a$ $H
OJ$jF@$J$$$+$i!$$$o.a>o$K56$rI=$9!%

3NH-!$2 DN%a%=%C%I $\mathrm{nor}[a_1, a_2]$ $H $\mathrm{if\_then}[a_1, m]$ $r?^ 6!Jc!K$Nh&$KDj5A$9$k!%
$\mathrm{nor}[a_1, a_2]$ $O $o.a_1$ $H $o.a_2$ $N NOR $r7W;;$7!$7k2L$,??NH$-$O o $r!$56NH$-$O r_{f} $o.a$
$9!%$9YF$NO@M}1i;;;R$O NOR $rMQ$$$FI=$9$3H,G-kN$G!$$\mathrm{nor}[a_1,a_2]$ $rMQ$$$l
PG0U$NL?BjO@M}<0$r7W;;9k%a%=%C%I$r9=@.$9k3H,G-$k!%$$\mathrm{if_then}[a_1, m]$ $\mathrm{if\_then}[a$
$O if-then J8$NLOJo$r9T$$!$$o.a_1 = o$ NH$-$+D=NH$-$K8B$j!$$o$ KBP7$F m $r8F
$S=P$9!% □

3. 7?8!::LdBj$N7W;;NL

3.1 Dd;_@-$rK~$?$9%9%-!<%^

DjM} **1:** $\mathbf{S}$ $rDd;_@-$rK~$?$9%G!<%?%Y!<%9%9%-!<%^H9$k!%$3NH$- $\mathbf{S}$ $N7?8!::LdBj
$O!$%/%i%93,AX$N9b$5$r9b!91 $K8BDj$7$?>l9g$G$b7hDjITG=$HJk!% □

$3$3GO!$>ZL@$N35N,KD$$$FN_=RYk!J>ZL@$N>\:Y$OIUO? **A**;2>H!K %K\DjM}$N
>ZL@$r%A%e!<%j%s%05!3#$N<uM}LdBj$+$i$N5"Ce$Khj9T$&!%6qBNE*$K$O!$G$0U$N%A%e!<
%j%s%05!3# M H=lKBP9kF~NO x KBP7!$<!$N>r7o$rK~$?$9%9%$r9=@.9k3H$,$G$-$k!%$ $\mathbf{S}_{M,x}$ $r9=@.$9 $\mathbf{S}$
9k!%

– Dd;_@-$rK~$?$9!%

– %/%i%93,AX$N9b$5$, 1!%

– $M$$, x $r<uM}$9kH$-!$$+D=NH$-$N$\mathbf{S}_{M,x}$!$ $\mathbf{S}$?@09g@-$r;}$?$J$$!%

$\mathbf{S}_{M,x}$ $N%/%i%93,AX$r?^ 7!$B0@-@k8@$r?^ 8Nh$&$KDj5A9k!%$\mathbf{S}_{M,x}$ $O%/%i%93,AX
$N9b$5$, 1 G"$k!%%a%=%C%I TM $r?^ 9$Nh&$KDj5A$9$k!%%a%=%C%I test 0J30$N%a
%=%C%I$O!$$\mathbf{S}_{M,x}$ N9YF$N%/%i%9$KBP7FDj5A7F$*$/!%test O r_{f} KBP7FN
$_Dj5A$7F*$/!%

0J2<!$%G!<%?%Y!<%9$$%s%9%?%s%9 $\mathbf{I} = (\nu, \mu)$ $N2<$G!$$o \in \mathbf{S}_{M,x}, \mathbf{I}$ $O0z?t$H7F%a
%=%C%I m $r<B9T$9k3Hr $m(o)$ $H=q$/!%

$$\begin{tikzcd} & c & \\ c_{\mathrm{t}} \arrow[ur] & c'_{\mathrm{t}} \arrow[u] & c_{\mathrm{f}} \arrow[ul] \end{tikzcd}$$

?^ 7 $\mathbf{S}_{M,x}$$N%/%i%93,AX

Class c_{t}		
$a_{\Rightarrow}$	:	c
$a_1, \ldots, a_K$	:	c
$a'_1, \ldots, a'_K$	:	c
$a''_1, \ldots, a''_K$	:	c
$a'''_1, \ldots, a'''_K$	:	c
a_{cont}	:	c
$a_{\mathrm{yes}}, a'_{\mathrm{yes}}$	:	c
a_{f}	:	c_{f}
$a_{\mathrm{ws}}, a'_{\mathrm{ws}}$	:	c

Class c'_{t}		
a'_{yes}	:	c
a_{f}	:	c_{f}

Class c		
a'_{t}	:	c'_{t}

?^ 8 $\mathbf{S}_{M,x}$$NB0@-@k8@

%*%V%8%'%/%H $o \in \nu(c)$ $NB0@- a_{ws} $O!$%a%=%C%I m $NDj5ACf$K:F5"$,$"$k>l9g$G $b!$ m $N<B9T$,L58B%k!<%W$K4Y$i$J$$$3HrJ]>Z9k$?$a$KMQ$$$C5NkF %S $\mathbf{S}_{M,x}$ 5"$r4^$`3F%a%=%C%I m $NF0:n$r0J2<Nh$&$KDj5A9k!%

- $o \in \nu(c_{\mathrm{t}})$ KBP7$F m $,8F$S=P5l$?$H$-!$ $o.a_{\mathrm{ws}}$ NCM,??G"lP!$ $o.a_{\mathrm{ws}}$ $NCM $r56$H7?8e!$ $m(o)$ $N<B9T$rB3$1$k!%$=$&GJ1l$P!$ $m(o)$ $N<B9T$r3l0J >eB3$1$J$$!%

$O_{\mathbf{S}_{M,x},\mathbf{I}}$ $OM-8B=89g$G$"$kNG!$$3lKhj $\mathbf{S}_{M,x}$ $,d;_@-$rK~$?$9$3$H$,<($5lk!%$^$?!$ $m(o)$ $N<B9T$,=*N;9kD>A0KO a_{ws} NCMr??KLa7F*$/$3HG!$B>$N%a%=%C%I $bB0@- a_{ws} $rMxMQ$G$-$k!%

$3$3$G!$DjM} 1$N>ZL@$r9T$&A0$K!$%A%e!<%j%s%05!3#$NDj5Ar7F*$/!%

Dj5A **1:** 7hDj@-%A%e!<%j%s%05!3# M $O 3 ;zAH (Q, Σ, δ) $GI=$5lk!%$3$3$G!$

$(c_t$!$TM) :

y := get_ws(self);

y := init_ws(self);

y := step(self);

y := accept(self);

y := test(y);

return(self).

?^ 9 %a%=%C%I TM $NDj5A

- Q $O>uBV$NM-8B=89gG"$j!$=i4 q_0 >uBV$H q_{yes} >uBV q_{yes} $H$$$& 2 DNFCJL$J>u BV$r4^$`!%
- $\Sigma$$O%F!<%W5-9f$NM-8B=89g$G$"$j!$6uGr5-9f B !OH$5$$9f 2 DNFCJL $J5-9f$r4^$`!%
- $\delta$$O $(Q-\{q_{yes}\})\times\Sigma$$+$i $Q\times\Sigma\times\{\leftarrow,\rightarrow,-\}$ XN4X?tG"$k!%$\delta(q,\sigma) = (q',\sigma,d)$ Ji$P!$$\sigma$ $=\triangleright$$+$D $d = \rightarrow$$G$"$kH9$k!%$D$^$j!$%F!<%W%X%C%I$,%F!<%W$N:8 C<$+iMnAk3HO$J$$$bNH9k!%

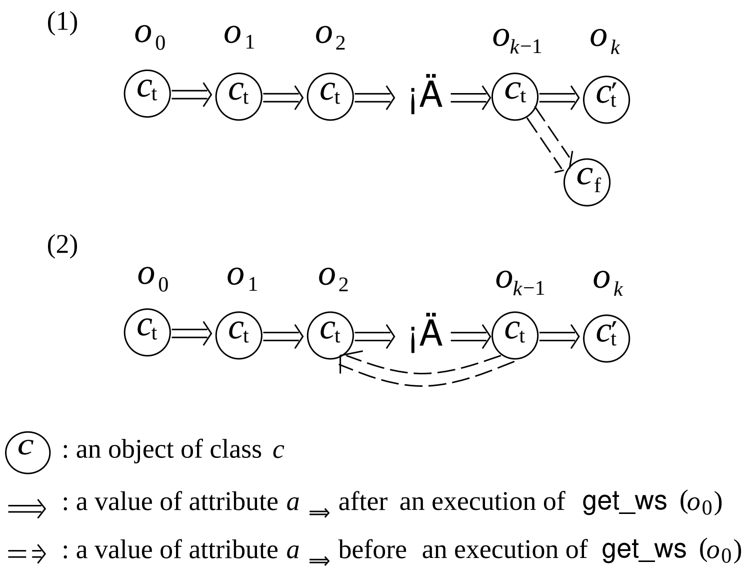
$\Box$

Dj5A **2:** $M$$N;~E@I=<($I$$OM-8BNs $\langle q_1,\sigma_1\rangle,\ldots,\langle q_k,\sigma_k\rangle$ $(k \geq 1)$ $GI=$5lk!%$3$3$G!$ $q_i \in Q\cup\{\perp\},\sigma_i\in\Sigma$ $(1 \leq i \leq k)$!$$+$D!$$\sigma_1 = \triangleright$$G$"$j!$$Ag&$I 1 DN q_i 1, Q $NMWAG$HJC$F$$$k!Ji $O%F!<%W%X%C%I$N0LCV$rI=$9!K!%;~E@I=<(I $N i HVL\$NMWAGBP $\langle q_i,\sigma_i\rangle$ $r $I[i]$ $H=q$/!%;~E@I=<(4V$NA+0\4X?t$ δ_M rDL>oNh$&$KDj5A9k!%$^$?!$$M$ $,F~NO x KBP7 j2sA+0\$7$?8e$N;~E@I=<($ I_j $=$I$9!% $\Box$

0J2<!$%a%=%C%I TM $N3F<B9TJ8$NF0:n$r@bL@$9$k!%

$o_0\in\nu(c_t)$ H9$k!%get_ws($o_0$) $N<B9T$Khj!$M?$(il$?%G!<%?%Y!<%9%$%s%9%?%s %9$+$i!$$M$$NLOJo$r9T$&$?$a$N<!$Nh&$J:n6HNN0h$rF@$k!%

- %G!<%?%Y!<%9%$%s%9%?%s%9$KhjDj$^$k$"$k k (≥ 1) KBP7$F o_i $\Rightarrow$ o_{i+1} $\in \nu(c_t)$ $(0 \leq i \leq k-2)$, $o_{k-1}.a_{\Rightarrow} = o_k \in \nu(c'_t)$!%



?^ 10 get_ws(o_0) <B9T8e$N%G!<%?%Y!<%9%$%s%9%?%s%9

b7!$%G!<%?%Y!<%9%$%s%9%?%s%9CKhCFj9=@.5l$k%*%V%8%'%/%HNs$,!$

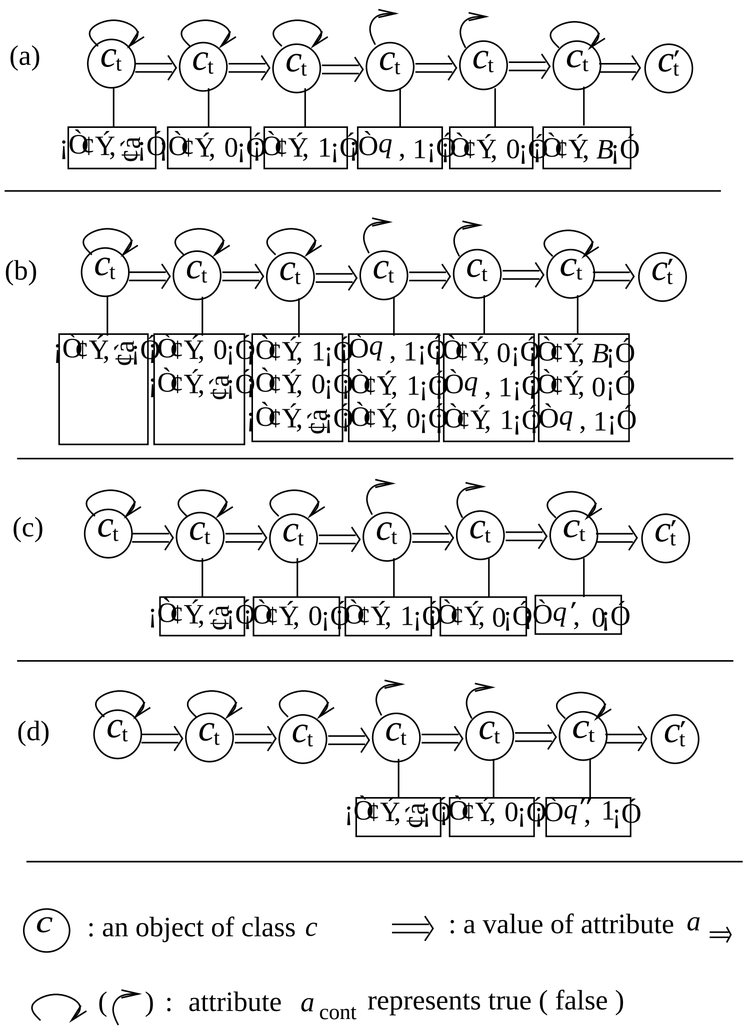
1. %/%i%9 c_t $N%*%V%8%'%/%H$,$$$/D+B3$$$?8e!$%/%i%9 c_f $N%*%V%8%'%/%H$HJk>l9g

2. JDO)rJ$9>l9g

$O!$ $o_{k-1}.a_{\Rightarrow}$ NCMr6/@)E*$K%/%i%9 c'_t $N%*%V%8%'%/%H$r;X9h$&$K=q-49(k3HG!$>e$N>r7o$rK~$?$9%*%V%8%'%/%HNs$rF@$k!J?^ 10!K!%$3$3$G!$ $(1 \leq i \leq k-1)$ $O%A%e!<%j%s%05!3#$N;~E@I=<($rI=$9NKMQ$$$ilk!% $o_i.a_1, \ldots, o_i.a_K$ $O;~E@I=<($NMWAG$r!J2?JI=8=$G!KI=$9!%$^$? o $N1&NY$NMWAG$r;X$9!%

%a%=%C%I init_ws $O!$ M $N=i4|;~E@I=<($r $o_i.a_1, \ldots, o_i.a_K$ $(0 \leq i \leq k-1)$ $K3JG<$9$k!%

%a%=%C%I step $O!$ M $NF0:n$NLOJo$r!J M $,Dd;_$9k+7J$$$+$K4X$oi:!K%G!<%?%Y!<%9%$%s%9%?%s%9$KhjDj$^$k$"$kM-8B%9%F%C%W?t!J8e=R!K$@$19T$&!%G!<%?%Y!<%9%$%s%9%?%s%9NNcr?^ 11!Ja!K$K<($9!% M $N;~E@ j $(0 \leq j)$ $N;~E@I=<($o_i.a_1, \ldots, o_i.a_K$ $(j \leq i \leq k-1)$ $K!J**2.2**$NNc 2$G<($7$? 2 ?JI=8=$G!K3JG<5l$k!% I_j $I_{j+1}[i]$ O $I_j[i-1], I_j[i], I_j[i+1]$ $$+$i7W;;$9k3H,G-kN$G!$$3li 3 DNCM$r0J2<$G=RYk%a%=%C%I c_1, c_2 copy$[a$ MQ$$$F3F%*%V%8%'%/%H$NB0@- $a_1, \ldots, a'_K, a''_1, \ldots, a''_K, a'''_1, \ldots, a'''_K$ $K%3%T!<$7F*$-!J?^



?^ 11 M $NLOJo$r9T$&:n6HNN0h

11!Jb!K K $**2.2**$NNc 2$G<($7$?%a%=%C%I nor $rMQ$$$k$I 7W;;$9$k!%copy$[a_2]$ $O ?^ 12$Nh&$KDj5A$5$l!$o Gt)$/$KBP7F8F$S=P$5l?H-$GL=$5lkO@M}CM$r $o.a_{\Rightarrow}.a_2$ $K%3%T!<$9$k!%$3lKhj!MN<!$N;~E@I=<($o_1, \ldots, o_i.a_K$ $(j+1 \leq i \leq k-1)$ $K5a$^$k!J?^ 11!Jc!K$C"$7!$$\delta(q,1)' = (q, 0)$!K%$M$N<!$N%9%F%C%W$NLO Jo$r9T$&$+I&$+$O!BOO_{\mathrm{cont}}$$Khj7hDj9k!%o $r;~E@I=<($N@hF,$NMWAG$,3JG<$5 lF$$$k%*%V%8%'%/%HH9$k!%$$_{\mathrm{cont}}$.$a$??$G$"$l$P!$M$NLOJo$r:F5"E*$KB3$1$k!%$= $&$GJ1lP!$M $NLOJo$r=*N;9k!%?^ 11NNcG$O!$M$NLOJo$r!Jc!K$+$i 2 %9%F%C %W9TC?8e!$Dd;_$9$k!J?^ 11!Jd!K!K%

$(c_{\mathrm{t}}, \mathrm{copy}[a_1, a_2])$:
$y := \mathrm{set\_f}[a_2](\mathrm{self}.a_{\Rightarrow})$;
$y := \mathrm{if\_then}[a_1, \mathrm{set\_t}[a_2]](\mathrm{self})$;
return(self).

$(c_{\mathrm{t}}, \mathrm{set\_f}[a_2])$:
self.a_2 := self.a_{f};
return(self).

$(c, \mathrm{set\_f}[a_2])$:
return(self).

$(c_{\mathrm{t}}, \mathrm{set\_t}[a_2])$:
$y := \mathrm{set\_t}'[a_2](\mathrm{self}.a_{\Rightarrow})$;
return(self).

$(c_{\mathrm{t}}, \mathrm{set\_t}'[a_2])$:
self.a_2 := self;
return(self).

$(c, \mathrm{set\_t}'[a_2])$:
return(self).

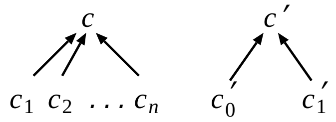
?^ 12 %a%=%C%I copy$[a_1, a_2]$ $NDj5A

%a%=%C%I accept $O!$$M$$NLOJo=*N;;~$N;~E@I=<($NCf$K<uM$>4BV$q_{\mathrm{yes}}$$1k+ I&$+$r!$B0@$_{\overline{\mathrm{yes}}}$$a, a'_{\mathrm{yes}}$$rMQ$$$FD4Yk!%accept $Q$$q_{\mathrm{yes}}$, 4^$^1k$H$$_{\overline{k}}$($\in \nu(c'_{\mathrm{t}})$) rJV7!$$=$&$G$J$$$H$$_k$ a_{f} ($\in \nu(c_{\mathrm{f}})$) rJV9!%

%a%=%C%I test $O%/%i%$_{\mathrm{f}}9KBP7FN_Dj5A$5$1F*$j!$accept $,JV$9%*%V%8%'%/ %H$r0z?t$H7F<B9T$5$1$k!J?^ 9!K!%$7$?$,CF!$$M$$NLOJo=*N;;~$N;~E@I=<($NCf$K <uM}>uBV$q_{\mathrm{yes}}$$,4^$^$1kH$-!$$+D=NH$-$N$_!$7?%(%i!<$,5/$3$k!%

$M$$, x $r<uM}$9kH2>Dj9k!%k!$$*$h$$_{\mathrm{cont}}$$GahDj$5$1$k $M$$N%9%F%C%W?t$,== J,Bg$-$J?t$HJk%G!<%?%Y!<%9%$%s%9%?%s%9$N2<GO!$$M$$NLOJo=*N;;~$N;~E@I=<($N Cf$K $q_{\mathrm{yes}}$$,4^$^$1!$$_{\mathrm{t}}$($c$TM) $NBh 5 J8$G%/%i%$_{\mathrm{t}}'$9$KB0$9$k%*%V%8%'%/%H$r0z?tH7$F test $,8F$S=P$5$1!$7?%(%i!<$,5/3k!%7?$,$C$F!?$$S_{M,x}$$O09g@-$r;}$?$J$$!%

01J}!$$S_{M,x}$$,7?@09g@-$r;}$?$J$$$H2>Dj9k!%Dj5Ahj!$7?%(%i!<$,5/3k2DG= @-$,$"$k%a%=%C%I$O test N_G"$k!%$_{\mathrm{t}}$($c$TM) $NBh 5 J8$G$O%/%i%$_{\mathrm{t}}'9KB0$9$k%*%V %8%'%/%H$^$?$O%/%i%$_{\mathrm{f}}9KB0$9$k%*%V%8%'%/%H$r0z?t$H7F test $,8F$S=P$5$1k,!$ Dj5Ahj!$$_{\mathrm{t}}'9KB0$9$k%*%V%8%'%/%H$r0z?t$H7F8F$S=P$5$1$?H-N_7?%(%i!<$,5/ 3k!%accept $,%/%i%$_{\mathrm{t}}'9N%*%V%8%'%/%HrJV9NO $M$$NLOJo=*N;;~$N;~E@I=<($NCf



?^ 13 $\mathbf{S}_{w,u}$$N%/%i%93,AX

Class $c_i (1 \leq i \leq n)$	
$a_{\rightarrow}$	: c

Class c	
$a_{\Rightarrow}$	: c'

Class c'_0 ! c'_1	
$a_{\Rightarrow}$	: c'

?^ 14 $\mathbf{S}_{w,u}$$NB0@-@k8@

$K $q_{\rm yes}$ $r4^$`H-N_G"k+$i!$$M$$O x $r<uM}$9$k!%

3.2 %a%=%C%IDj5ACf$K99?7A`:n$,$J$$%9%-!<%^

DjM} **2:** $\mathbf{S}$ $r%a%=%C%IDj5ACf$K99?7A`:n$,$J$$%G!<%?%Y!<%9%9%-!<%^H9$k!%$3NH $- $\mathbf{S}$ $N7?8!::LdBj$O!$%/%i%93,AX$N9b5r9b!91 $K8BDj$7$?>l9g$G$b7hDjITG=$HJk!% $\square$

$3$3GO!$>ZL@$N35N,KD$$$FN_=RYk!J>ZL@$N>\:Y$OIUO? **B**;2>H!K!%K\DjM}$N>ZL@$r Post $NBP1~LdBj$+iN5"CeKh$j9T$&!%6qBNE*KO!$Post $NBP1~LdBj$KBP9kF~NO $w = \langle w_1, \ldots, w_n \rangle, u = \langle u_1, \ldots, u_n \rangle$ KBP7!$<!$N>r7o$rK~$?$9%9%-!<%^ $\mathbf{S}_{w,u}$ $r9=@.$9$k!%

- 99?7A`:n$r4^$^$J$$!%
- %/%i%93,AX$N9b$5$, 1!%
- Post $NBP1~LdBj$N2r$,B8:_$9kH$-!$$+D=NH$-$N$_ $\mathbf{S}_{w,u}$ $O9g@-$r;}$?$J$$!%

w, u $*$h$S%"%k%U%!%Y%C%H $\Sigma = \{0, 1\}$ KBP7!$%9%-!<%^ $\mathbf{S}_{w,u}$ $N%/%i%93,AX$r?^ 13!$B0@-@k8@$r?^ 14Nh$&$KDj5A9k!%9JoA!$$\mathbf{S}_{w,u}$$N%/%i%93,AX$N9b$5$O 1 G"$k!%o,%/%i%9 c_i $(1 \leq i \leq n)$ $N%*%V%8%'%/%H$G$"$kH-!$$o$($i$)$r$w_i$$S $u_i$$rI=$7!$$o$,%/%i%9 $c'_0(c'_1)$ $N%*%V%8%'%/%H$G$"$kH-!$$o$O%"%k%U%!%Y%C%H 0!J1!K$rI=$9!%%a%=%C%I post $N

$(c_i, \mathrm{post})(1 \le i \le n)$:

$y := \mathrm{m_w}(\mathrm{self})$;

$y := \mathrm{isc}'(y)$;

$y := \mathrm{m_u}(\mathrm{self})$;

$y := \mathrm{isc}'(y)$;

$y := \mathrm{test}(\mathrm{self})$;

return(self).

?^ 15 %a%=%C%I post \$NDj5A

Dj5A\$r?^ 15\$K<(\$9!%test \$O\$I\$N%/%i%9\$KBP\$7\$F\$bDj5A\$;\$:!\$\$=\$NB>\$N%a%=%C%I\$O $\mathbf{S}_{w,u}$ \$N\$9\$Y\$F\$N%/%i%9\$KBP\$7\$FDj5A\$7\$F\$*\$/!%

$\mathbf{S}_{w,u}$ \$N%G!<%?%Y!<%9%\$%s%9%?%s%9 $\mathbf{I}$ \$H\$7\$F!\$0J2<\$N7A\$N\$b\$N\$r9M\$(\$k!J?^ 16!K!%

$$o_i.a_{\rightarrow} = o_{i+1}, o_i \in \nu(c_1) \cup \ldots \cup \nu(c_n) \ (1 \le i \le k),$$

$$o_{k+1} \in \nu(c), o_{k+1}.a_{\Rightarrow} = o'_1, o'_j.a_{\Rightarrow} = o'_{j+1},$$

$$o'_j \in \nu(c'_0) \cup \nu(c'_1) \ (1 \le j \le l), o'_{l+1} \in \nu(c')$$

\$3\$3\$G!\$ $o_1 \ldots o_k$ \$, Post \$NBP1~LdBj\$N2r\$N8uJd\$rI=\$7!\$ $o'_1 \ldots o'_l$ \$, Σ>e\$N7ONs\$rI=\$9!% %*%V%8%'%/%H o_i \$NI=\$98l\$r u_{o_i} !\$%*%V%8%'%/%H o'_j \$NI=\$9%"%k%U%!%Y%C%H\$r $w_{o'_j}$ \$H\$q \$/!%\$J\$*!\$\$3\$N7A\$KEv\$F\$O\$^\$i\$J\$\$!J%G!<%?%Y!<%9%\$%s%9%?%s%9\$KJDO)\$,B8:_\$9\$k!K >l9g\$OI,\$:L58B%k!<%W\$H\$J\$k\$h\$&\$K $\mathbf{S}_{w,u}$ \$N3F%a%=%C%I\$rDj5A\$7\$F\$*\$/.

0J2<!\$%a%=%C%I post \$N3F<B9TJ8\$K\$D\$\$\$F@bL@\$9\$k!%

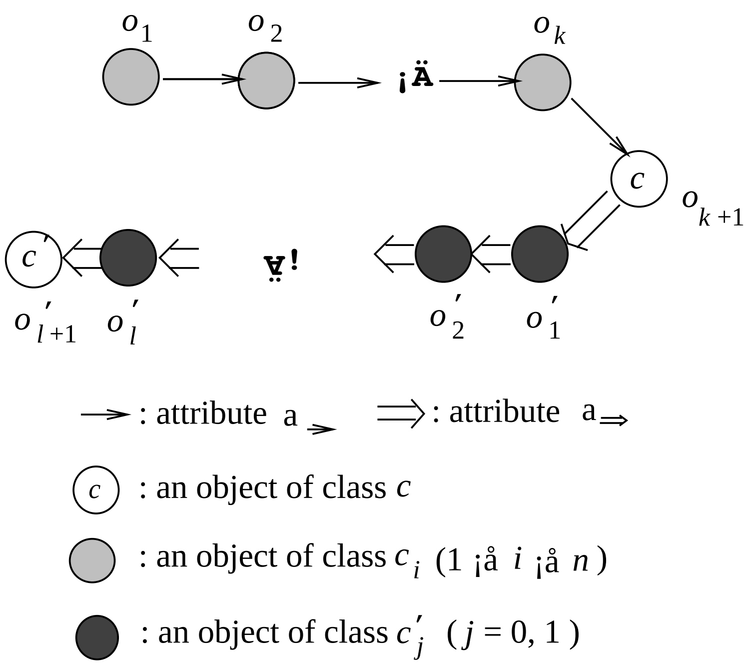
%a%=%C%I $\mathrm{m_w}$ \$O!\$ $w_{o_1} \ldots w_{o_k} = x_{l'} \ldots x_1$ \$+\$D $l' \le l$ \$, @.\$jN)\$D\$+\$I\$&\$+\$rD4\$Y\$k!% $\mathrm{m_w}$ \$NF0:n\$r<!\$N\$h\$&\$KDj5A\$9\$k!%

- \$"\$k $l'(\le l)$ \$KBP\$7\$F $w_{o_1} \ldots w_{o_k} = x_{l'} \ldots x_1$ \$, @.\$jN)\$D\$J\$i\$P!\$ $\mathrm{w}(\mathbf{m}_1)$ \$O $c'_{l'+1}$ \$rJV\$9!%

- \$=\$&\$G\$J\$1\$l\$P!\$ $\mathrm{w}(\mathbf{m}_1)$ \$ODd;_\$7\$J\$\$!%

\$7\$?\$,\$C\$F!\$ $w_{o_1} \ldots w_{o_k} = x_{l'} \ldots x_1 (l' \le l)$ \$, @.\$jN)\$D\$H\$-!\$\$+\$D\$=\$N\$H\$-\$N\$_!\$ $(cl(o_1), \mathrm{post})$ \$NBh 2 J8\$N%a%=%C%I isc' \$O $c'_{l'+1}$ \$r0z?t\$H\$7\$F<B9T\$5\$l\$k!%

isc' \$NF0:n\$r<!\$N\$h\$&\$KDj5A\$9\$k!%



?^ 16 $\mathbf{S}_{w,u}$$N%G!<%?%Y!<%9%$%s%9%?%s%9

- %/%i%9$N%*%V%8%'%/%H$r0z?tH7$F8F$S=P5l$?$H$-!$Dd;_9k!%
- $=$&GJ$$$H$-!$Dd;_7J$$!%

7?$,$C$F!$ $o_l = o'_{l+1}$ NH$-!$$+D=NH$-$N$_!$ (o'_{l+1}, c) $N<B9T$,Dd;_$7!$ $(cl(o_1), \mathrm{post})$ $NBh 3 J8$,<B9T5l$k!%$^$?!$%a%=%C%I jn5A$r w $HF1MM$K9T$&!%
7?$,$C$F, $w_{o_1} \ldots w_{o_k} = x_l \ldots x_1 = u_{o_1} \ldots u_{o_k}$$,@.$jN)$DH-!$$+D=NH$-$N$_!$ $(cl(o_1), \mathrm{post})$ $NBh 5 J8$N%a%=%C%I test $,8F$S=P5l!$7?%(%i!<$,5/3k!%

w, u $rF~NO$H9k Post $NBP1~LdBj$N2r$,B8:_$9kH2>Dj9k!%3NH-!$ $w_{o_1} \ldots w_{o_k} = u_{o_1} \ldots u_{o_k} = x_l \ldots x_1$$,@.$jN)$D $\mathbf{S}_{w,u}$$N%G!<%?%Y!<%9%$%s%9%?%s%9 $\mathbf{I}$ $,B8:_$7!$ $\mathbf{I}$ $N2<$G $\mathrm{post}(o_1)$ $r<B9T$9kH!$ $(cl(o_1), \mathrm{post})$ $NBh 5 J8$G test $,8F$S=P5l!$7?%(%i!<$,5/3k!%7?$,$C$F!$ $\mathbf{S}_{w,u}$ $?@09g@-$r;}$?$J$$!%

0lJ}!$ $\mathbf{S}_{w,u}$$,7?@09g@-$r;}$?$J$$$H2>Dj9k!%Dj5Ahj7?%(%i!<$,5/$3$k2DG=@-$,$"$kNO test N_G"k+$i!$ (c_i, post) $(1 \le i \le n)$ $NBh 5 J8$G test $,8F$S=P5lkh$&$J $\mathbf{S}_{w,u}$$N%G!<%?%Y!<%9%$%s%9%?%s%9$,B8:_9k!%7?$,$C$F!$ $w_{o_1} \ldots w_{o_k} = u_{o_1} \ldots u_{o_k}$ $rK~$?$9 $o_1, \ldots, o_k$$,B8:_$7!$ w, u $rF~NO$H9k Post $NBP1~LdBj$N2r$,B8:_$9$k!%

%G!<%?%Y!<%9%9%-!<%^ $\mathbf{S}$ $,Dd;_@-$rK~$?$9$+H]$+$rH=Dj$9$kLdBj$r!$ $\mathbf{S}$ KBP9$k

Dd;_@-H=DjLdBj$H8F$V_{w;u}!%SK*$$$F7?%(%i!<$,5/$3kN$O!$%a%=%C%I post $N<B9T$,

Dd;_9kH-!$$+D=NH$-$N$_$G$"$k!%7?$,$C$F!$0J2<$N7O$,F@il$k!%

7O **1:** **S** $r%a%=%C%IDj5ACf$K99?7A`:n$,$J$$%9%-!<%^H9$k!%$3NH$- **S** $NDd;_@-H=DjLdBj$O!$%/%i%93,AX$N9b5r9b!91 $K8BDj$7$?>l9g$G$b7hDjITG=$HJk!% □

4. $"$H$,$-

K\9FGO!$0J2<$N 2 DN99?7%9%-!<%^$NItJ,%/%i%9$KBP9k7?8!::LdBj$,7hDjITG=$G$"$k3H$r<($7$?!%

1. Dd;_@-$rK~$?$7!$$+$D%/%i%93,AX$N9b5,9b!91 G"$k%9%-!<%^!%
2. %a%=%C%IDj5ACf$K99?7A`:n$,J/!$$+$D%/%i%93,AX$N9b5,9b!91 G"$k%9%-!<%^!%

3lKh$j!$J88% [10] $GF3F~$5l?9YFNItJ,%/%i%9KBP9$k7?8!::LdBj$N7W;;NL$,5a$^$j!$

1. %/%i%93,AX$N9b$5$,0 NH$-
2. Dd;_@-$rK~$?$7!$$+$D%a%=%C%IDj5ACf$K99?7A`:n$,$J$$$H$-

$H$$$& 2 DN>l9g$r=|$$$F$O!$<jKIi($J$$$b7/$O7hDjITG=$HJk3H$,<($5l?!%

:#8e$N2]Bj$H7F$O!$7?8!::LdBj$,7hDj2DG=$HJk!$$h$j<BMQE*$JItJ,%/%i%9$rDs0F$7!$$=$N7W;;NL$r<($9$3H,9M$($ilk!%

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A. DjM} 1 $N>ZL@

0J2<!$self.a := self$r self.a := true!$self.a := self.$r self.a := false $HN,5-$9$k!% TM Cf$N%a%=%C%I test, get_ws, init_ws, step, accept $NDj5A$r$=$l$>$l?^ 17–21$K<($9!% Dj5ACf!$2<@~$rIU7?J8$O%^%/%mI=5-$G$"$j!$%A%e!<%j%s%05!3# M$H$=$lXNF~NO x

$(c_{\mathrm{f}}, \mathrm{test})$:
return(self).

?^ 17 %a%=%C%I test $NDj5A

$(c_{\mathrm{t}}, \mathrm{get\_ws})$:
self.a_{ws} := true;
y := get_ws$'$(self);
return(self).

$(c, \mathrm{get\_ws})$:
return(self).

$(c_{\mathrm{t}}, \mathrm{get\_ws}')$:
y := self if self.a_{ws} = true
and y := self.a'_{t} otherwise;
y' := if_then[a_{ws}, get_ws$''$](self);
return(y).

$(c_{\mathrm{t}}, \mathrm{get\_ws}'')$:
self.a_{ws} := false;
y := get_ws$'$(self.$a_{\Rightarrow}$);
self.$a_{\Rightarrow}$:= y;
self.a_{ws} := true;
self.a'_{ws} := true;
set $a_1, \ldots, a_K$ to $\langle \perp, B \rangle$;
return(self).

$(c, \mathrm{get\_ws}')$:
return(self.a'_{t}).

$(c, \mathrm{get\_ws}'')$:
return(self).

?^ 18 %a%=%C%I get_ws $NDj5A

$,6qBNE*$KM?$($il?H-$K!$DL>o$N<B9TJ8$N7ONs$KE83+$9k3H,G-$k!%

JdBj **1:** $\mathbf{S}_{M,x}$ NG0U$N%G!<%?%Y!<%9%$%s%9%?%s%9 $\mathbf{I}$ $N2<$G!$ $\mathrm{get\_ws}(o_0 \in \mathcal{O}_{\mathbf{S}_{M,x},\mathbf{I}})$
$N<B9T$,I,$:Dd;_$9$k!%

[>ZL@] $o_0 \in \nu(c'_{\mathrm{t}}) \cup \nu(c_{\mathrm{f}}) \cup \nu(c)$ NH$-!$ $(c, \mathrm{get\_ws})$ $,8F$S=P5lkN$G!$L@i+$KDd;_$9$k!%

$o_0 \in \nu(c_{\mathrm{t}})$ NH$-$O!$ $(c_{\mathrm{t}}, \mathrm{get\_ws})$ $NBh 1 J8$G $o_0.a_{\mathrm{ws}}$ $r??$H7?8e!$ o_0 KBP7$F get_ws$'$ $r8F$S=P$9. get_ws$'$ $+$i get_ws$''$ $r2p$7$F get_ws$'$ $,:F5"E*$K8F$S=P$5lk!%

get_ws$'$ $N i 2sL\$N8F=P7K$*$1$k0z?t$N o_i CMH9k!% get_ws$'(o_{i-1})$ GO!$ $(c_{\mathrm{t}}, \mathrm{get\_ws}')$ $NBh 2 J8$Khj!$ $o_{i-1}.a_{\mathrm{ws}}$ $,??$G$"$1$P!$ o_{i-1} KBP7$F get_ws$''$ $r8F$S=P$9.

$(c_{\mathrm{t}}, \mathrm{init\_ws})$: $\underline{\text{set } a_1, \ldots, a_K \text{ to } \langle q_0,\ \triangleright\rangle;}$ $y := \mathrm{init\_ws1}(\mathrm{self}.a_{\Rightarrow});$ return(self).	$(c, \mathrm{init\_ws})$: return(self).
$(c_{\mathrm{t}}, \mathrm{init\_ws1})$: $\underline{\text{set } a_1, \ldots, a_K \text{ to } \langle \perp, x_1\rangle;}$ $y := \mathrm{init\_ws2}(\mathrm{self}.a_{\Rightarrow});$ return(self).	$(c, \mathrm{init\_ws1})$: return(self).
$\vdots$	
$(c_{\mathrm{t}}, \mathrm{init\_ws}n)$: $\underline{\text{set } a_1, \ldots, a_K \text{ to } \langle \perp, x_n\rangle;}$ return(self).	$(c, \mathrm{init\_ws}n)$: return(self).

?^ 19 %a%=%C%I init_ws $NDj5A

get_ws$''(o_{i-1})$ $O $(c_{\mathrm{t}}, \mathrm{get\_ws}'')$ $NBh 1 J8$G$_i a_1.a_{\mathrm{ws}}$$NCM$r56$H7?8e!$Bh 2 J8$G $o_{i-1}.a_{\Rightarrow} = o_i$$KBP7F get_ws$'$$r:F5"E*$K8F$S=P$9!%$J1\!\!\in\!\! K$o_i \in \nu(c'_{\mathrm{t}}) \cup \nu(c_{\mathrm{f}}) \cup \nu(c)$!$$^ $?$O!$J2!K$o_i \in \nu(c_{\mathrm{t}})$ $+$D $o_i.a_{\mathrm{ws}}$$,56G"kH$-!$get$'$_ws$N:F5"8F=P$7$O=*N;$9$k!% $o_i \in \nu(c_{\mathrm{t}})$ $+$D $o_i.a_{\mathrm{ws}}$$,??G"kH$-!$get$'$_ws$N:F5"8F=P$7$OB39T$9$k!%get$'$_ws$N:F 5"8F=P7,9Tol$F$$$k4VOo_{i-1}.a_{\mathrm{ws}}$$NCM$,?7$?$K??$HJk3HOJ$$$N$G!$get_ws$'$ $N:F5"8F=P$7$,1 2s9T$olkKh$K $a_{\mathrm{ws}}$$K?G"$k%*%V%8%'%/%H$N?t$,1 D:$D8:CF $$$/!%I Cf$KB8:_$9$k%*%V%8%'%/%H$N?t$OM-8B$G$"$kNG!$I,$:M-8B2s$N get_ws$'$ 5"8F=P7G$(c_{\mathrm{t}}, \mathrm{get_ws}')$ $NBh 2 J8$N>r7o$,@.$jN)$?$J$/$J$j!$get_ws$N:F5"8F=P$7$, =*N;$9$k!%

7?$,$C$F!$get_ws$(o_0)$$N<B9T$OI,$:Dd;_9k!% □

JdBj 1$HF1MM$N>ZL@K!Kh$j!$$\mathbf{S}_{M,x}$$NG$0U$N%G!<%?%Y!<%9%$%s%9%?%s%9$N2<$G!$ $\mathbf{S}_{M,x}$Cf$N:F5"E*$KDj5A5l$?%a%=%C%I (step, delta, accept JI) $N<B9T$,I,$:Dd;_$9 k3H,>ZL@5l$k!%$7$?$,CF!$<!$NJdBj$,@.$jN)$D!%

JdBj **2:** $\mathbf{S}_{M,x}$$ODd;_@-$rK~$?$9!% □

(c_t, step) :
$y := \mathrm{if\_then}[a_{\mathrm{cont}}, \mathrm{step}'](\mathrm{self})$;
return(self).

(c, step) :
return(self).

(c_t, step') :
$y := \mathrm{if\_then}[a_{\mathrm{ws}}, \mathrm{step}''](\mathrm{self})$;
return(self).

(c, step') :
return(self).

(c_t, step'') :
self.a_{ws} := false;
$y := \mathrm{delta}(\mathrm{self})$;
$y := \mathrm{step}(\mathrm{self}.a_{\Rightarrow})$;
self.a_{ws} := true;
return(self).

(c, step'') :
return(self).

(c_t, delta) :
$y := \mathrm{if\_then}[a'_{\mathrm{ws}}, \mathrm{delta}'](\mathrm{self})$;
return(self).

(c, delta) :
return(self).

(c_t, delta') :
self.a'_{ws} := false;
for each i $(1 \leq i \leq K)$
  self.a'_i := self.a_i;
  $y := \mathrm{copy}[a'_i, a''_i](\mathrm{self})$;
  $y := \mathrm{copy}[a''_i, a'''_i](\mathrm{self})$;
Calculate $\langle q, \sigma \rangle$ from
  $a'_1, \ldots, a'_K, a''_1, \ldots, a''_K, a'''_1, \ldots, a'''_K$
  and assign the result to $a_1, \ldots, a_K$;
$y := \mathrm{delta}(\mathrm{self}.a_{\Rightarrow})$;
self.a'_{ws} := true;
return(self).

(c, delta') :
return(self).

?^ 20 %a%=%C%I step $NDj5A

$(c_{\mathrm{t}}, \mathrm{accept})$:
self.a'_{yes} := false;
y := accept$'$(self) :
return(y).

(c, accept) :
return(self).

$(c_{\mathrm{t}}, \mathrm{accept}')$:
y := if_then[a_{ws}, accept$''$](self);
return(y).

$(c'_{\mathrm{t}}, \mathrm{accept}')$:
return(self.a'_{yes}).

(c, accept') :
return(self).

$(c_{\mathrm{t}}, \mathrm{accept}'')$:
self.a_{ws} := false;
self.a_{yes} := true if q_{yes} is stored in self,
and self.a_{yes} := false otherwise;
Calculate self.$a_{\mathrm{yes}} \vee$ self.a'_{yes} and
assign the result to self.a_{yes};
y := copy[$a_{\mathrm{yes}}, a'_{\mathrm{yes}}$](self);
y := accept$'$(self.$a_{\Rightarrow}$);
return(y).

(c, accept'') :
return(self).

?^ 21 %a%=%C%I accept $NDj5A

%/%i%9 c_{t} $N%*%V%8%'%/%H o $O%A%e!<%j%s%05!3#$N;~E@I=<($NMWAG$rI=9N$K MQ$$$ilk!%0J2<!$$o$ $N<g$JB0@-$N0UL#$K$D$$$F4JC1$K=R$YF*$/!% $o.a_1, \ldots, o.a_K$ $O;~E@I=<($NMWAG$r!J2 ?JI=8=$G!KI=$9!% $o.a_{\Rightarrow}$ $N1&NY$NMWAG$r;X$9!%B0@- $a'_1, \ldots, a'_K, a''_1, \ldots, a''_K, a'''_1, \ldots, a'''_K$ $O%A%e!<%j%s%05!3#$N 1 F0:n8e$N;~E@I=<($r7W;; 9k$?$a$N:n6HNN0h$G!$>\:Y$O8e=R9k!% $a_{\mathrm{yes}}, a'_{\mathrm{yes}}$ $O%A%e!<%j%s%05!3#$,<uM}>uBV$K F~$C$?$+I&$+$rD4Yk$?$a$NB0@-$G$"$k!% a_{cont} $O%A%e!<%j%s%05!3#$NLOJo$r2? %9%F%C%W9T$&$+$r7hDj9k$?$a$KMQ$$$ilk!%

JdBj **3:** $\mathbf{I} = (\nu, \mu)$ $r $\mathbf{S}_{M,x}$ NG0U$N%G!<%?%Y!<%9$%s%9%?%s%9H7!$ $o_0 \in \nu(c_{\mathrm{t}})$ rG 0U$N%*%V%8%'%/%H$H9k!%3NH-!$$\mathbf{I}$ $N2<$G$N o_0.getNewBD $N<B9T8e$K$*$$$F!$$"$k k $(k \geq 1)$ $,B8:_$7$F!$0J2<$N>r7o!JC1!K$,@.$jN)$D!%

!JC1!K

!JC1–1!K $o_i.a_{\Rightarrow} = o_{i+1} \in \nu(c_{\mathrm{t}})$ $(0 \leq i \leq k-2), o_{k-1}.a_{\Rightarrow} = o_k \in \nu(c'_{\mathrm{t}})$!%

!JC1–2!K $o_i.a_{\mathrm{ws}} = o_i, o_i.a'_{\mathrm{ws}} = o_i$ $(0 \le i \le k-1)$.

!JC1–3!K $o_i.a_1, \ldots, o_i.a_K$ $(0 \le i \le k-1)$ $, $\langle \perp, B \rangle$ $rI=$9!%

[>ZL@] get_ws(o_0) $N<B9T=*N;;~$^GK$(c_t$, get_ws$''$) $NBh 2 J8$+$i get_ws, 8F$S=P 5l$?2s?t k KBP7$F!$JdBj$N>r7o!JC1!K$,@.$jN)$D3H$r<($9!#$^$:!$(c_t$, get_ws) $N Bh 2 J8$Khj o_0 KBP7$F get_ws$', 8F$S=P$5lk!%get_ws$'(o_0)$ GO!$(c_t$, get_ws) $NBh 1 J8$Khj $o_0.a_{\mathrm{ws}}$ $O??$G$"$kNG, (c_t$, get_ws$'$) $NBh 2 J8$N>r7o$,@.$jN)$A!$ o_0 KBP7$F get_ws$''$, 8F$S=P5l$k!%get_ws$''(o_0)$ GO!$(c_t$, get_ws$''$) $NBh 2 J8$Khj $o_0.a_{\Rightarrow} = o_1$ KBP7$F get_ws$', 8F$S=P$5lk!%7?$,$C$F!$ $k \ge 1$ $,@.$jN)$D!%

get_ws$'(o_i)$ $(1 \le i \le k-1)$ K*$$$F$O!$ $o_i.a_{\mathrm{ws}}$ NCMO??G"kN$G!$(c_t$, get_ws$'$) $NBh 1 J8$*hSBh 3 J8Kh$j JV$5lk!%7?$,$C$F!$(c_t$, get_ws$''$) $NBh 2 J8$*$h $SBh 3 J8$Khj $o_{i-1}.a_{\Rightarrow} = o_i \in \nu(c_t)$ HJ$k!%get_ws$(o_k)$ GO!$JdBj 1$N!J1!K!$J2!K $N$$$:l+$,@.N)$9$k!%J1!K$N>l9g$O $(c'_t$, get_ws$)$ $NDj5A$h$jL@$i$+$K!$J2!K$N>l9g$O $(c_t$, get_ws$'$) $NBh 1 J8!$Bh 3 J8hj!$$$$:lN>l9g$b%/%i%$%"%s%H$,JV$5 lk!J$=$l$>$lK\J8Cf$N?^ 10$N!J1!K!$J2!K;2>H!K!%$7$?$,CF!$ $o_{k-1}.a_{\Rightarrow} \in \nu(c'_t)$ HJ $k!%0J>e$h$j!$JC1–1!K$,@.$jN)$D!%

$^$?!$(c_t$, get_ws$''$) $NBh 4 J8!$Bh 5 J8!$Bh 6 J8$Khj!$JC1–2!K!$JC1–3!K$,@.$jN) $D!% $\square$

JdBj **4:** $"$k k $(k \ge 1)$ KBP7$F>r7o!JC1!K$rK~$?$9%G!<%?%Y!<%9%$%s%9%?%s%9 $\mathbf{I} = (\nu, \mu)$ $r9M$($k!%$3NH$-!$ $\mathbf{I}$ $N2<$G$N init_ws$(o_0)$ $N<B9T8e$K$*$$$F!$0J2<$N>r7o !JC2!K$,@.$jN)$D!%

!JC2!K

!JC2–1!K $o_i.a_{\Rightarrow} = o_{i+1} \in \nu(c_t)$ $(0 \le i \le k-2), o_{k-1}.a_{\Rightarrow} = o_k \in \nu(c'_t)$!%

!JC2–2!K $o_i.a_{\mathrm{ws}} = o_i, o_i.a'_{\mathrm{ws}} = o_i$ $(0 \le i \le k-1)$!%

!JC2–3!K $o_i.a_1, \ldots, o_i.a_K$ $(0 \le i \le k-1)$ $, M $N=i4|;~E@I=<($NMWAG $H[I]$ $rI=$9!%

$\square$

[>ZL@] init_ws, init_ws$i$ $(1 \le i \le n)$ $NDj5A$h$j!$ $o_i.a_{\Rightarrow}, o_i.a_{\mathrm{ws}}, o_i.a'_{\mathrm{ws}}$ $(0 \le i \le k-1)$ NCMO=q-49(il$J$$$N$G!$JC2–1!K!$JC2–2!K$,@.$jN)$D!%

init_ws(o_0) GO!$o_0.a_1, \ldots, o_0.a_K$ NCMr $\langle q_1, \rhd \rangle$ $K@_Dj$7$?8e!$K BP7F

init_ws1 $r8F$S=P$9!%$|x| = n < k$ NH$-!$init_ws$i$ $(1 \le i \le n)$ GO!$ $(c_t$, init_ws$i)$

$NBh 2 J8$Khj $o_i.a_1, \ldots, o_i.a_K$ NCM, $\langle \perp, x \rangle$ $K@_Dj$5lk!%$o_i.a_1, \ldots, o_i.a_K$ $(n+1 \le$

$i \le k-1)$ NCMO=q-49(il$J$$$N$G!$JdBj 3!JC1–3!Khj3liNB0@-CM$O $\langle \perp, B \rangle$

$rI=$9!%F1MM$K!$$n \ge k$ NH$-$O!$$o_i.a_1, \ldots, o_i.a_K$ $(1 \le i \le k-1)$ NCM, $\langle \perp, x \rangle$ $K

@_Dj5l$k!%$$$$:lN>l9g$b!$$o_i.a_1, \ldots, o_i.a_k$ $(0 \le i \le k-1)$ K M $N=i4|;~E@I=<($NMWAG $J_0[i+1]$ $,3JG<$5lk!%7?$,$C$F!$JC2–3!K$,@.$jN)$D!% □

JdBj **5:** $"$k k $(k \ge 1)$ KBP7$F0J2<$N>r7o!JC3!K$rK~$?$9%G!<%?%Y!<%9%$%s%9%?%s

%9 $\mathbf{I} = (\nu, \mu)$ $r9M$($k!%

!JC3!K

!JC3–1!K$o_i.a_{\Rightarrow} = o_{i+1} \in \nu(c_t)$ $(0 \le i \le k-2), o_{k-1}.a_{\Rightarrow} = o_k \in \nu(c'_t)$!%

!JC3–2!K$o_i.a'_{\text{ws}} = o_i$ $(0 \le i \le k-1)$!%

!JC3–3!K$"$k j $(0 \le j \le k-1)$ $,B8:_$7$F!$$o_i.a_1, \ldots, o_i.a_K$ $(j \le i \le k-1)$

$, M $N;~E@I=<($NMWAG $J_j[i-j+1]$ $rI=$9!%

3NH-!$$\mathbf{I}$ $N2<$G$N delta$(j)$ $N<B9T8e$K$*$$$F!$0J2<$N>r7o!JC3$'$!K$,@.$jN)$D!%

!JC3$'$!K

!JC3$'$–1!K$o_i.a_{\Rightarrow} = o_{i+1} \in \nu(c_t)$ $(0 \le i \le k-2), o_{k-1}.a_{\Rightarrow} = o_k \in \nu(c'_t)$!%

!JC3$'$–2!K$o_i.a'_{\text{ws}} = o_i$ $(0 \le i \le k-1)$!%

!JC3$'$–3!K$o_i.a_1, \ldots, o_i.a_K$ $(j+1 \le i \le k-1)$ $, M $N;~E@I=<($NMWAG $J_{j+1}[i-j]$

$rI=$9!%

□

[>ZL@] Dj5Ahj $o_i.a_{\Rightarrow}$ $(0 \le i \le k-1)$ NCMO=q-49(il$J$$$N$G!$JC3–1!Khj

!JC3$'$–1!K$,@.$jN)$D!%

copy$[a_1, a_2]$ $OK\J8Cf$N?^ 12Nh$&$KDj5A5l!$%V%k%$%9%k%*%V%8%'%/%H o $K

BP7F8F$S=P$5l?H-Gb=5l$kO@M}CM$r $o.a_2$ $K%3%T!<$9$k!%(delta$'$) $N

Bh 2 J8$*$h$SBh 3 J8!$Bh 4 J8$N copy J8$H!JC3–3!Khj!$$o_i.a'_1, \ldots, o_i.a'_K$ $(j \le i \le k-1)$

KO $J_j[i-j+1]$ NCM,!$$o_i.a''_1, \ldots, o_i.a''_K$ $(j+1 \le i \le k-1)$ KO $J_j[i-j]$ NCM,!$

$o_i.a'''_1, \ldots, o_i.a'''_K$ $(j+2 \le i \le k-1)$ KO $I_j[i-j-1]$ NCM,$=$1$>$13JG<$5$1$k!%
$3$1$i 3 DNB0@-NCM+$i<!$N;~E@I=<($NMWAG $I_{j+1}[i-j]$ NCM,7W;;G-kN$G!$
(c_t, delta') $NBh 5 J8$Khj3NCM$r5a$a$k!%$3$3$G$O (c_t, delta') $NBh 5 J8$O **2.2** $NNc 2
$G<($7$?%a%=%C%I nor $rMQ$$$F<B8=G-$k!%$K$D$$$FO=1>$l o_j, o_{j+1} a''_1 NCfK
$\triangleright$ $r4^$`NG!$$N>19g$O<!$N;~E@I=<($NMWAG$r $\langle \perp, B \rangle$ H7$N>19g$O d' H d'
N_$+$i<!NCMr5aakh&$KDj5A$9$k!%

(c_t, delta') $NBh 6 J8$G delta $r:F5"E*$K8F$S=P$9$3$HKhjNMWAG $I_{j+1}[i-j]$
$, $o_i.a_1, \ldots, o_i.a_K$ $(j+1 \le i \le k-1)$ $K5a$^$k!%$7$?$,CF!!$3C3!K$,@.$jN)$D!%

$^$?!$ (c_t, delta') $NBh 7 J8$Khj!!$JC2!K$,@.$jN)$D!% $\square$

JdBj **6:** $"$k k $(k \ge 1)$ KBP7$F>r7o!JC2!K$rK~$?$9%G!<%?%Y!<%9%$%s%9%?%s%9 $\mathbf{I} = (\nu, \mu)$ $r9M$($k!%$3NH$-!$$\mathbf{I}$ $N2<$G$N $\mathrm{step}(o_0)$ $N<B9T8e$K$*$$$F!$0J2<$N>r7o!JC4!K
$,@.$jN)$D!%

!JC4!K

!JC4–1!K $o_i.a_\Rightarrow = o_{i+1} \in \nu(c_t)$ $(0 \le i \le k-2), o_{k-1}.a_\Rightarrow = o_k \in \nu(c'_t)$!%

!JC4–2!K $o_i.a_{\mathrm{ws}} = o_i, o_i.a'_{\mathrm{ws}} = o_i$ $(0 \le i \le k-1)$!%

!JC4–3!K $o_i.a_1, \ldots, o_i.a_K$ $(j' \le i \le k-1)$ $, M $N;~E@I=<($N3FMWAG $I_{j'}[i-j'+1]$
$rI=$9!%$3$3$G!$ $j' = \max\{j \mid \bigwedge_{i=0}^{j} o_i.a_{\mathrm{cont}} = o_i\}$ G"$k!%

[>ZL@] Dj5Ahj $o_i.a_\Rightarrow$ $(0 \le i \le k-1)$ NCMO=q-49(il$J$$$N$G!$!JC2–1!Khj
!JC4–1!K$,@.$jN)$D!%

o_i $(0 \le i \le k-1)$ KBP7$F step $,8F$S=P5l$?$H$-!$$o_i.a_{\mathrm{cont}}$ $,??$G$"$l$P o_i $KBP
7F step $,8F$S=P5l!$$5iK!$$ $\mathrm{step}'(o_i)$ GO $o_i.a_{\mathrm{ws}}$ $,??$G$"$l$P o_i KBP7$F step''
$,8F$S=P5l$k!% $\mathrm{step}''(o_i)$ GO (c_t, step'') $NBh 2 J8$Khj o_j KBP7$F%a%=%C%I delta
$,8F$S=P5l$k!%$\mathbf{I}$ $O!JC2!K$rK~$?$9NG!$$ $\mathrm{delta}(o_0)$ $NA0$N%G!<%?%Y!<%9%$%s%9%?
%s%9$O!JC3!K$rK~$?$9!%JdBj 5hj!$$ $\mathrm{delta}(o_i)$ $N<B9T$G M $NLOJo$, 1 %9%F%C%W9T$o
$l!$<B9T8e$N%G!<%?%Y!<%9%$%s%9%?%s%9$O!JC3!K$rK~$?$9!%!JC3–3!K$O!J C3!K$K$*
$$$F $j+1$ $r j HCV-49$($?>19gG"k+$i!JC3!K$O!JC3!K$r4^0U$9kN$G $\mathrm{delta}(o_i)$
<B9T8e$N%G!<%?%Y!<%9%$%s%9%?%s%9$O!JC3!K$rK~$?$9!%$=$N8e!$$ $\mathrm{step}''(o_i)$ $NBh 3 J8
Kh$j!$$ $o_i.a_\Rightarrow$ KBP7$F step $,:F5"E*$K8F$S=P$5lk!%

0J>e$N5DO@$h$j!$**I** $N2<$G step(o_0) $r<B9T$7$?$H$-!$step $N0z?t$HJk%*%V%8%'%/%H$NB0@- a_{cnt} NCM,??G"$k8B$j M $NLOJo$,B3$1$ilk!%7?$,$C$F!JC4–3!K$,@.$jN)$D!%

$^$?!$$(c_t, \mathrm{step}'')$ $NBh 4 J8$h$j!JC4–2!K$,@.$jN)$D!% $\square$

JdBj **7:** $"$k k $(k \geq 1)$ KBP7$F>r7o!JC4!K$rK~$?$9%G!<%?%Y!<%9%$%s%9%?%s%9 $\mathbf{I} = (\nu, \mu)$ $r9M$($k!%$3NH$-!$**I** $N2<$G$N accept$(o_0)$ $N<B9T8e$K$*$$$F!$0J2<$N>r7o!JC5!K$,@.$jN)$D!%

!JC5!K

B0@- $a_1, \cdots, a_K$ NCMNCf$K a_{yes} $r4^$`%*%V%8%'%/%H o_i $(0 \leq i \leq k-1)$ $,B8

:_9kH- accept(o_0) O o_k rJV7!$$=$&$G$J$$$H$- $o_k.a_{\mathrm{f}}$ rJV9!%

[>ZL@] accept(o_0) GO!$$(c_t, \mathrm{accept})$ $NBh 1 J8$G $o_0.a'_{\mathrm{yes}}$ NCMr56H7$?8e!$Bh 2 J8$G o_0 KBP7$F accept$'$ $r8F$S=P$9!%

accept$'(o_i)$ $(0 \leq i \leq k-1)$ GO $o_i.a_{\mathrm{ws}}$$,??G"lP o_i KBP7$F accept$''$ $,8F$S=P5l$k!%

accept$''(o_i)$ $(0 \leq i \leq k-1)$ GO!$$(c_t, \mathrm{accept}'')$ $NBh 2 J8$Khj!$ $o_i.a_1, \ldots, o_i.a_K$ NCfK $a_{\mathrm{yes}}$$,4^$^$lkH$- $o_i.a_{\mathrm{yes}}$ NCMr??H7!$$=$&$G$J$$$H-56H9k!%$=$7$F!$Bh 3 J8$G $o_i.a_{\mathrm{yes}}$ $H $o_i.a'_{\mathrm{yes}}$ $NO@M}OB$r $o_i.a_{\mathrm{yes}}$ $K3JG<$7!$Bh 4 J8$G$=$NCM$r $o_{i-1}.a'_{\mathrm{yes}}$ $K%3%T!<$9$k!%

(c_t, accept'') $NBh 5 J8$G accept$'$ $r:F5"E*$K8F$S=P$9$3$HKh$j!$ $o_i.a_K$ NCfK a_{yes} $r4^$`%*%V%8%'%/%H o_i $(0 \leq i \leq k-1)$ $,B8:_$9kH$- $o_k.a'_{\mathrm{yes}}$ $O??!J$9Jo$A $o_k.a'_{\mathrm{yes}} = o_k$!K$HJj!$$=$&$G$J$$$H$- $o_k.a'_{\mathrm{yes}}$ $O56!J$9Jo$A $o_k.a'_{\mathrm{yes}} = o_k.a_{\mathrm{f}}$!K$HJk!%

I $N2<$G accept(o_0) $r<B9T$7$?$H$-!$$(c_t, \mathrm{accept}')$ $N return J8$Khj $o_k.a'_{\mathrm{yes}}$ NCM,JV5lkN$G!JC5!K$,@.$jN)$D!% $\square$

JdBj **8:** $M$$, x $r<uM}$9kH$-!$$+D=NH$-$N$_$O $S_{M,x}$ $,@09g@-$r;}$?$J$$!% $\square$

[>ZL@] $M$$, x $r<uM}$9kH2>Dj9k!%JdBj 3$GDj5A$5lk $k$$*hS JdBj 6$GDj5A$5lk I' $,==J,Bg$-$J?t$HJk%G!<%?%Y!<%9%$%s%9%?%s%9$N2<GO!$ M $NLOJo=*N;;~$N;~E@I=<($ a_{yes} $r4^$`NG!$JdBj 7$h$j (c_t, TM) $NBh 5 J8$G%/%i%9 c_t $KB0$9$k%*%V

$(c_1, \mathrm{m_w})$:
$y := \mathrm{m_w}(\mathrm{self}.a_{\rightarrow})$;
if w_{1,d_1} is 0
then $y := \mathrm{is0}(y)$;
else $y := \mathrm{is1}(y)$;
$\vdots$
if $w_{1,1}$ is 0
then $y := \mathrm{is0}(y)$;
else $y := \mathrm{is1}(y)$;
return(y).

$\cdots$

$(c_n, \mathrm{m_w})$:
$y := \mathrm{m_w}(\mathrm{self}.a_{\rightarrow})$;
if w_{n,d_n} is 0
then $y := \mathrm{is0}(y)$;
else $y := \mathrm{is1}(y)$;
$\vdots$
if $w_{n,1}$ is 0
then $y := \mathrm{is0}(y)$;
else $y := \mathrm{is1}(y)$;
return(y).

$(c, \mathrm{m_w})$:
return(self.$a_{\Rightarrow}$).

$(c', \mathrm{m_w})$:
return(self).

?^ 22 %a%=%C%I $\mathrm{m_w}$$NDj5A

%8%'%/%H$r0z?t$H7F test $,8F$S=P5l!$7?%(%i!<$,5/3k!%7?$,$C$F!$$S_{M,x}$
@09g@-$r;}$?$J$$!%

01J}!$$S_{M,x}$$,7?@09g@-$r;}$?$J$$$H2>Dj9k!$$S_{M,x}$$NDj5Ahj!$7?%(%i!<$,5/$3
$k2DG=@-$,$"$k%a%=%C%I$O test N_G"$k!%JdBj 7,$T(M)$!Nh 5 J8GO%/%i
%9 $c_t$$KB0$9$k%*%V%8%'%/%H$^$?$O%/%i%9 $c_f$$KB0$9$k%*%V%8%'%/%H$r0z?t$H7F test $,
8F$S=P$5lk$,!$Dj5Ahj$c_t$$KB0$9$k%*%V%8%'%/%H$r0z?t$H7F8F$S=P$5l?H-
N_7?%(%i!<$,5/$3$k!%%a%=%C%I accept $,$c_t$$N%*%V%8%'%/%HrJV9NO M $N
LOJo=*N;;~$N;~E@I=<($NC$f_{yes}$$Krq_4^$'$H$-$N$_$G$"$k$+$i!$$M$ $O x $r<uM}$9$k!%□

JdBj 2$HJdBj 8$h$j!$DjM} 1$,@.$jN)$D!%

B. DjM} 2$N>ZL@

$\Sigma = \{0,1\}$ H7!$Post $NBP1~LdBj$KBP9kF~NO $w = \langle w_1, \ldots, w_n \rangle, u = \langle u_1, \ldots, u_n \rangle$
$r!$

$$w_1 = w_{1,1}w_{1,2}\ldots w_{1,d_1} \;\; (w_{1,i} \in \Sigma \;\; (1 \leq i \leq d_1))$$

$$\vdots$$

$(c_1, \mathrm{m_u})$:
$y := \mathrm{m_u}(\mathrm{self}.a_{\to})$;
$\underline{\text{if } u_{1,e_1} \text{ is } 0}$
$\underline{\text{then } y := \mathrm{is0}(y);}$
$\underline{\text{else } y := \mathrm{is1}(y);}$
$\vdots$
$\underline{\text{if } u_{1,1} \text{ is } 0}$
$\underline{\text{then } y := \mathrm{is0}(y);}$
$\underline{\text{else } y := \mathrm{is1}(y);}$
$\mathrm{return}(y)$.

$\ldots$

$(c_n, \mathrm{m_u})$:
$y := \mathrm{m_u}(\mathrm{self}.a_{\to})$;
$\underline{\text{if } u_{n,e_n} \text{ is } 0}$
$\underline{\text{then } y := \mathrm{is0}(y);}$
$\underline{\text{else } y := \mathrm{is1}(y);}$
$\vdots$
$\underline{\text{if } u_{n,1} \text{ is } 0}$
$\underline{\text{then } y := \mathrm{is0}(y);}$
$\underline{\text{else } y := \mathrm{is1}(y);}$
$\mathrm{return}(y)$.

$(c, \mathrm{m_u})$:
$\mathrm{return}(\mathrm{self}.a_{\Rightarrow})$.

$(c', \mathrm{m_u})$:
$\mathrm{return}(\mathrm{self})$.

?^ 23 %a%=%C%I $\mathrm{m_u}$ $NDj5A

$$w_n = w_{n,1} w_{n,2} \ldots w_{n,d_n} \ (w_{n,i} \in \Sigma \ (1 \le i \le d_n))$$

$$u_1 = u_{1,1} u_{1,2} \ldots u_{1,e_1} \ (u_{1,i} \in \Sigma \ (1 \le i \le e_1))$$

$$\vdots$$

$$u_n = u_{n,1} u_{n,2} \ldots u_{n,e_n} \ (u_{n,i} \in \Sigma \ (1 \le i \le e_n))$$

H9$k!%K\J8Cf$N?^ 15$GDj5A$5lk%a%=%C%I post Cf$N3F%a%=%C%I $r?^ 22–?^ 25$N$h $&$K9=@.9k!%%a%=%C%I test OI$N%/%i%9$KBP7F$bDj5A$7$J$$!%

%G!<%?%Y!<%9%$%s%9%?%s%9Cf$KJDO)$,B8:_$7$J$$>l9g$N%S%=%C%I $GC5:w 5lF@kN$O%/%i%9 c_i $(1 \le i \le n)$ $KB0$9$k%*%V%8%'%/%H$NB0@-hS%/%i%9 c, c_0', c_1' $KB0$9$k%*%V%8%'%/%H$NB0@-$_$G$"$k$+$i!$I H7$F!$

!JB-1!K

$$o_i.a_{\to} = o_{i+1}, o_i \in \nu(c_1) \cup \ldots \cup \nu(c_n) \ (1 \le i \le k),$$

$$o_{k+1} \in \nu(c), o_{k+1}.a_{\Rightarrow} = o_1',$$

$$o_j'.a_{\Rightarrow} = o_{j+1}', o_j' \in \nu(c_0') \cup \nu(c_1') \ (1 \le j \le l),$$

$$o_{l+1}' \in \nu(c')$$

$(c'_0, \mathrm{is0})$:
return(self.$a_{\Rightarrow}$).

$(c'_1, \mathrm{is1})$:
return(self.$a_{\Rightarrow}$).

$(c', \mathrm{is0})$:
loop forever;

$(c', \mathrm{is1})$:
loop forever;

$(c, \mathrm{is0})$:
return(self).

$(c, \mathrm{is1})$:
return(self).

?^ 24 %a%=%C%I is0 $*$h$S is1 $NDj5A

(c'_0, isc') :
loop forever;

(c'_1, isc') :
loop forever;

(c', isc') :
return(self).

(c, isc') :
return(self).

?^ 25 %a%=%C%I isc' $NDj5A

$N7A$NbN$r9M$(1P==J,G"$k (K\J8Cf$N?^ 16;2>H)!%0J2<!$%*%V%8%'%/%H o_i N9YF$N%a%=%C%I$N<B9T7k2L$r w_{o_i}, u_{o_i} !$%*%V%8%'%/%H o_j $NI=$9%"%k%U%!%Y%C%H$r e_j H7F-!$I $N2<$G$N $\mathrm{post}(o_1)$ $N<B9T$K$D$$$F9M$($k!%

JdBj **9:** $"$k l' $(l' \le l)$ KBP7$F $w_{o_1} \ldots w_{o_k} = x_{l'} \ldots x_1$$,@.$jN)$DJi$P!$$\mathrm{w}(m_1)$ $N<B9T$,Dd;_7F $o'_{l'+1}$ $,JV$5lk!%$=$&GJ$$$H$-$\mathrm{w}(m_1)$ $N<B9T$ODd;_7J$$!%

[>ZL@] >e$NJdBj$,@.$jN)$D3H$r k $K4X$9$k5"G<K!$Khj>ZL@9k!%0lHL@-$r<:$&3HJ/ $o_1 \in \nu(c_1)$ $H2>Dj$9$k!%

[4pDlCJ3,] $k=1$ H9$k!%$\mathrm{w}(m_1)$ $NBh1J8$*hS $\mathrm{w}(c_1)$ $NBh1J8$Khj (m_w) $NBh1J8$N:8JU yNCM$O u_{o_1} HJ$j!$Bh2J80J9_$G $w = w_1 = x_{d_1} \ldots x_1$ $+$D $d_1 \le l$ $,@.$jN)D+I&$+$r!$%a%=%C%I is0, is1 $rMQ$$$FD4Yk!%$3$3$G $\mathrm{is0}(\mathrm{is1})$ $Q(c'_0)$ $\mathrm{w}(c'_1)$ $r0z?t$H7F8F$S=P$5l?H-$ $a_{\Rightarrow}$ JV7!$$=$&$G$J$$$H$-Dd;_$7$J$$!%7?$,$C$F!$ $w_{o_1} = x_{d_1} \ldots x_1$$,@.$jN)$DH-!$$\mathrm{w}(m_1)$ $N<B9T$O o'_{d_1+1} rJV7!$$=$&$G$J$$$H$-Dd;_$7$J$$!%

[5"G<CJ3,] $k=s$ $(s \ge 1)$ NH$-@.$jN)DH2>Dj9k!%

$k = s + 1$ NH$-!$ $\mathrm{m_w}(o_1)$ GO $(c_1, \mathrm{m_w})$ $NBh 1 J8$Khj$ o_2 KBP7$F $\mathrm{m_w}$ $,8F$S

=P5l$k!%5"G<K!$N2>Djhj!$$"$k $r(r \leq l)$ KBP7$F $w_{o_2} \ldots w_{o_{s+1}} = x_r \ldots x_1$ $,@.

$jN)$DH-!$$+D=NH$-$N$ $\mathrm{m_w}(o_2)$ $N<B9T$,Dd;_$7 o'_{r+1} G,JV5l$k!%$=$N8e!$

$(c_1, \mathrm{m_w})$ $NBh 2 J80J9_$G $w_{o_1} = x_{r+d_1} \ldots x_{r+1}$ $+$D $r + d_1 \leq l$ $,@.$jN)D+I&$+$r

%a%=%C%I $\mathrm{is0}, \mathrm{is1}$ $rMQ$$$FD4Yk!%

7?$,$C$F!$ $\mathrm{m_w}(o_1)$ $N<B9T$O $w_{o_1} \ldots w_{o_{s+1}} = x_{r+d_1} \ldots x_1$ $,@.$jN)DH$- o'_{r+d_1+1}

rJV7!$$=$&$G$J$$$H$-Dd;_$7$J$$!% □

JdBj 9hj!$ $w_{o_1} \ldots w_{o_k} = x_{l'} \ldots x_1$ $(l' \leq l)$ $,@.$jN)DH$-!$$+D=NH$-$N$_!$

$(cl(o_1), \mathrm{post})$ $NBh 2 J8$N%a%=%C%I isc' $o'_{l'+1}$ $r0z?t$H7F<B9T5l$k!%

JdBj **10:** $o_{l'+1} = o'_{l'+1}$ NH$-!$$+D=NH$-$N$_ $(o'_{l'+1}, \mathrm{isc})$ $N<B9T$ODd;_9k!%

[>ZL@] $o_{l'+1} \neq o'_{l'+1}$ NH$-!$ $o_{l'+1}$ $NB0$9$k%/%i%9$K=>CF (c_0, isc') $^$?$O (c_1, isc')

$N$$$:l+$,<B9T$5lk$,!$Dj5Ahj$$$:lN $(o'_{l'+1})$ $b9g$b$N<B9T$ODd;_7J$$!%

01J}!$ $o_{l'+1} = o'_{l'+1}$ NH$-$O (c_1, isc') $,<B9T$5$l!$ $(o'_{l'+1}, \mathrm{isc})$ $N<B9T$ODd;_9k!% □

JdBj 9!$JdBj 10$h$j $w_{o_1} \ldots w_{o_k} = x_l \ldots x_1$ NH$-!$$+D=NH$-$N$_!$ $(cl(o_1), \mathrm{post})$

$NBh 3 J8$,<B9T5l$k!%$^$?!$ $(cl(o_1), \mathrm{post})$ $NBh 3 J8!$Bh 4 J8KD$$$F$b!$$=l>$lJdBj

9!$JdBj 10$HF1MM$NJdBj$,@.$jN)$D!%7?$,$C$F $w_{o_1} \ldots w_{o_k} = x_l \ldots x_1 = u_{o_1} \ldots u_{o_k}$

$,@.$jN)DH$-!$$+D=NH$-$N$_!$ (o_1, post) $NBh 5 J8$N%a%=%C%I test $,8F$S=P

5l!$7?%(%i!<$,5/3k!%

<!$K!$%G!<%?%Y!<%9%$%s%9%?%s%9Cf$KJDO)$,B8:_$9$k>l9g$K$D$$$F $S_{w,u}$ 9M$($k!% $\mathbf{S}$

$NJDO)$r4^$`%G!<%?%Y!<%9%$%s%9%?%s%9H7FO!$

1. %*%V%8%'%/%H o $+$iB0@-$ a $r 1 2s0J>e$?IC$F:F$S o $KE~C#$9kh$&$JJDO)$,

   B8:_9k

2. %*%V%8%'%/%H o' $+$iB0@-$ a $r 1 2s0J>e$?IC$F:F$S o' $KE~C#$9kh$&$JJDO)$,

   B8:_9k

$H$$$& 2 DN>l9g$r9M$(lP==J,G"k,!$ 1 !K$N>l9g$O $(c_i, \mathrm{m_w})$ $(1 \leq i \leq n)$ $NBh 1 J8

$N $\mathrm{m_w}$ $N8F=P$7$,=*N;$;$:!$ $\mathrm{m_w}$ $N<B9T$,Dd;_7J$$!% 2 !K$N>l9g$O $(c_i, \mathrm{m_w})$ $(1 \leq i \leq n)$

Cf$N $\mathrm{is0}, \mathrm{is1}$ $N<B9T$,L58B%k!<%WHJk+!$$^$?$O post' CfN isc $,L58B%k!<%W

HJ$k!%$7$?$,CF!$$$$:lN>l9g$b7?%(%i!<$O5/3i$J$$!%

w, u \$rF~NO\$H\$9\$k Post \$NBP1~LdBj\$N2r\$, B8:_\$9\$k\$H2>Dj\$9\$k\$H!!\$J B-1 !K\$GI=\$;\$k $w_{o_1} \dots w_{o_k} = u_{o_1} \dots u_{o_k} = x_l \dots x_1$ \$, @.\$jN)\$D $\mathbf{S}_{w,u}$ \$N%G!<%?%Y!<%9%\$%s%9%?%s%9 **I** \$, B8:_\$7!\$ **I** \$N2<\$G post$_1(c)$ \$r<B9T\$9\$k\$H!\$ (c_l) post$_l(c)$ \$NBh 5 J8\$G test \$, 8F\$S=P\$5\$l 7?%(%i!<\$, 5/\$3\$k!%\$7\$?\$, \$C\$F!\$ $\mathbf{S}_{w,u}$ \$O 7?@09g@-\$r;}\$?\$J\$\$!%

0lJ}!\$ $\mathbf{S}_{w,u}$ \$, 7?@09g@-\$r;}\$?\$J\$\$\$H2>Dj\$9\$k\$H!\$Dj5A\$h\$j7?%(%i!<\$, 5/\$3\$k2DG=@- \$, \$"\$k\$N\$O%a%=%C%I test \$N\$_\$G\$"\$k\$+\$i!\$ pid$_i(c)$ $(1 \le i \le n)$ \$NBh 5 J8\$G test \$, 8F\$S =P\$5\$l\$k\$h\$&\$J $\mathbf{S}_{w,u}$ \$N%G!<%?%Y!<%9%\$%s%9%?%s%9\$, B8:_\$7!\$ $w_{o_1} \dots w_{o_k} = u_{o_1} \dots u_{o_k}$ \$rK~\$?\$9 $o_1, \dots, o_k$ \$, B8:_\$9\$k!%\$7\$?\$, \$C\$F!\$ w, u \$rF~NO\$H\$9\$k Post \$NBP1~LdBj\$N2r \$, B8:_\$9\$k!%

0J>e\$h\$j!\$DjM} 2\$, @.\$jN)\$D!%