O@　J8

%b%8%e!<%k7?%K%e!<%i%k%M%C%HKh$kIJ;l%?%0IU$1

GO　@D†　O$　JuNH††　0f:486　6Q†　;T@n　F;65††

Part of Speech Tagging with Min-Max Modular Neural Networks

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$"$i$^$7　%K%e!<%i%k%M%C%H$rMQ$$$?IJ;l%?%0IU$1%7%9%F%`$O$9$G$KGO$i$K$h$jDs0F$5$l$F$-$?!%%7%9%F%`$O!$?tK|%*!<%@!<$NB?IJ;l8l$r;}$D>.5,LO%?%98l%3!<%Q%9$rMQ$$$F3X=,9k3HKhCF!$IJ;l%?%0IU$1$N<gMW<jK!$H5lF-$?1#$l%^%k%3%U%b%G%khjOk$+$K9b$$@:EYGL3X=,%G!<%?$r%?%0IU$1$9$k3H$,$G$-$?!%%7$+$7J,$i!$MQ$$$?#3AX%Q!<%;%W%H%m%sO=$N<}B+@-$NLdBj$+$i!$$3Nh$&$J>.5,LO%G!<%?$N3X=,$K$*$$$F$b<}B+$,CY$/3X=,@:EY$,Dc$+$C$?!%$=N?$a!$3X=,2s?t$d3X=,%G!<%?$rA}d7Fb!$$=$l0J>e@:EY8~>e$r?^kNOFq7$$!%K\8&5fGO!$$3$NLdBj$r2r7h9k$?$a$K!$IJ;l%?%0IU$1%7%9%F%`$K!$O$$i$,Ds0F$7$?%b%8%e!<%k7?%K%e!<%i%k%M%C%H$rMQ$$$?!%?7$7$$%7%9%F%`$O!$J#;($+$DBg5,LO$JIJ;l%?%0IU$1LdBj$rJ#?tNh$j4JC1$G>.5,LO$JLdBj$KJ,3d7F2r$/$?$a!$<}B+@-$NLdBj$,J/!$IJ;l%?%0IU$1LdBjrh$jB.$/hj9b@:EY$G3X=,$9k3H,G-$?!%$=$N7k2L!$F1$83X=,%G!<%?$rMQ$$$J$,$i3X=,@:EY$r>e$2k3$H!$$5iKOh$jBg5,LO$J%G!<%?$rMQ$$$F3X=,9k3H$,2DG=$HJj!$IJ;l%?%0IU$1N5iJ$k@:EY8~>e$,2DG=HJC?!%

%-!<%o!<%I　IJ;l%?%0IU$1!$%?%$8l%3!<%Q%9!$%b%8%e!<%k7?%K%e!<%i%k%M%C%H!$JBNs3X=,!$2a3X=,

1. $^$($,$-

B?IJ;l8l$N[#Kf@-$rJ8L.KhCF2r>C9k3H!Jh?;l%?%0IU$1!K$O9=J82r@O$d5!3#K]Lu$H$$$C$?<+A3$8$l=hM}$K7g$+$;$J$$4pK\5;=QG"$k!%$=$N5;=Q$O!$$?$($P9g!$1#$l%^%k%3%U%b%G%khjMZ$+$K9b$$@:EY$GIJ;l2;@<9g@.$NA0=hM}!$OCR $d2;@<G'<1$N8e=hM}!$$iK?%0IU1,G-$?!%$F>pJs8!:wJIXNI}9-$$1~MQ$b9M$(il$k!$$3l^$+$7J,$i!$%?%0IU$1%7%9%F%`$KMQ$$$?#3AX%Q!<$G?tB?$/$NIJ;l%?%0IU$1%7%9%F%`[1]!A[13] $,Ds0F$5lF$-$?$,!$$=li$N%7%9%F%`$G9b$$@:EY$r=P$9$?$aKOBgNL!J1Q8l$N>l9g!$I4K|%*!<%@!K$N3X=,%G!<%?$,I,MW$,$"$k!%$7$+$7J,$i!$<B:]!$1Q8l$dF|K\8lJI$r=|$$$??tB?$/$N8@8l$K4X$7FO!$%3!<%Q%9$,F@BNb^$@@0HwCJ3,$K$"$kN,8=>u$G!$M=$aBgNL$N3X=,%G!<%?$rF@$kN,:FqG$"$k!%$=$N$?$a$K!$I.<TiO!$1#$l%^%k%3%U%b%G%kJI$NE}7W<jK!$hjb%G!<%?$,%Q!<%9%M%9LdBj$K6/$$$H;Wol$k%K%e!<%i%k%M%C%H$rMQ$$$k3HKhCF!$>/$J$$3X=,%G!<%?$rMQ$$$F$b==J,<BMQE*$JIJ;l%?%0IU1,2DG=$J%7%9%F%`$rDs0F$7$F$?[14]!A[17]!%Ds0F$7$?%7%9%F%`$O!$?tK|%*!<%@!<$NB?IJ;l8l$r4^$`>.5,LO%?%$8l%3!<%Q%9$r3X=,$KMQ$$$F!$9g!$1#$l%^%k%3%U%b%G%k$h$jMZ$+$K9b$$@:EY$GIJ;l%?%0IU$1$,$G$-$?!%$7$+$7$J$,$i!$%?%0IU$1%7%9%F%`$KMQ$$$?#3AX%Q!<%;%W%H%m%s7?%K%e!<%i%k%M%C%H$O!$3X=,>e$N<}B+@-LdBj$,$"$j!$?tK|%*!<%@!<5,LO$N3X=,%G!<%?KBP7Fb96%0J$N3X=,@:EY$KC#9kNOMF0WGOJ/!$$=$N@:EY$K$O>e8B$,$"$k!%$^$?!$$3$N3X=,$K$bAjEv;~4V$,$+$+C?!%$^$?!$G|Bg$J3X=,;~4Vr+1F3X=,@:EY$r>e$2k3Hr;n$_$?H7Fb2a3X=,KJ$k62$lb"$j!$I,$:$7$b%?%0IU$1@:EY$N8~>e$KDJ$,$kHO8BiJ$$!%$=$7$F!$EvA3J,$i!$3X=,%G!<%?$rA}$d$;$PA}d9$[$I3X=,$N<}B+$,Fq7/Jk!%=>CF!$3X=,2s?t$d3X=,%G!<%?$rA}$d7Fb"$k?e=`0J>e$N@:EY8~>e$r?^$k$N$,:$Fq$H;W$o$l$k!%K\8&5f$G$O!$$3$N$h$&$JLdBj$r2r7h$9$k$?$a$K!$IJ;l%?%0IU$1%7%9%F%`$KO$$i$,Ds0F$7$? Min-Max %b%8%e!<%k7?%K%e!<%i%k%M%C%H!JN,7F M³ %M%C%H%o!<%/$H8F$V!K[18]!A[20] $rF3F~$7$?!%M³%M%C%H%o!<%/$OJ#;($+$DBg5,LO$J3X=,LdBj$rJ#?tNh$j4JC1$G>.5,LO$JLdBj$KJ,3d7F2r$/$?$a!$<}B+@-$NLdBj$,J/!$IJ

† M9@/>JDL?.Am9g8&5f=j$1$$$OsJ>pJsDL?.M;9g8&5f%;%s%?!<!$5~ET I\
Keihanna Human Info-Communication Research Center, Communications Research Laboratory, Ministry of Posts and Telecommunications, 2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0289 Japan
†† M}2=3X8&5f=jG>2J3XAm9g8&5f%;%s%?!<!$OB8w;T
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;l%?%0IU$1LdBj$rhjB.$/$h$j9b@:EY$G3X=,G2K7$FJ#;($JLdBj$r4JC1$JItJ,LdBj$KJ,3d$7!$J,3d
$^$?!$<}B+@-$NLdBj$,$J$$$?$a!$8D!9$N%b%8%e!<%k$N$?LdBj$r$=$l$>$lFHN)$N%b%8%e!<%k$G2r$$$?8e!$
Cf4VAX$N%f%K%C%H?t$r6KC<$K>/$J$/$9k3H,G-k}9g7F:G=*7k2L$r=P$9$+$G$"$k!%K\>OGOLdBj
3X=,@:EY$r>e$2Fb2a3X=,$,5/$3jK$/$$$H9M$($N$13d$HE}9gKD$$$F$=$N4pK\E*$JItJ,$K$D$$$F=R$Y
$k!%=>$C$F!$F1$83X=,%G!<%?$rMQ$$$J$,$i3X=,@:EY$r>\:Y$O[18]!A[20]$r;2>H$5l?$$!%
>e2k3H!$$^$?$OhjBg5,LO$J%G!<%?$r3X=,9k

3. 1 LdBj$NJ,3d

HKhj!L3X=,%G!<%?XNIJ;l%?%0IU1N5iJk$N@a$G$O!$G!2?K7$FJ#;($GBg5,LO$J!$K 8D$N%/
@:EY8~>e$,2DG=$HJC$?!%i%9$N$"$k%/%i%9J,$1LdBj!J0J9_!$$3lr K-class Ld

K\O@J8O^$:!$IJ;l%?%0IU$1LdBj$NDj<02=$HM^3 Bj$H8F$V!K$r>.5,LO$J two-class LdBj$XJ,3d7F$$$/
%H%o!<%/$N4pK\$G$"$kLdBj$NJ,3d$HE}9gKD$$$F=RKD$$$F=RYk!%$3$3$G T $r K-class LdBj$N3X=,
$k!%<!$K M^3%M%C%H%o!<%/Kh$kIJ;l%?%0IU$1KD$$$%C%HH9$k!%B($A!$
$F=R$Y$k!%:G8e$K7W;;5!<B83$N7k2L$K$D$$$F=R$Y!$M^3

$$T = \{(X_l, Y_l)\}_{l=1}^{L} \qquad (5)$$

%M%C%H%o!<%/$rMQ$$$k3HKh$j3X=,@-G=$H0lHL2=G=
NO$NN>LL$K$*$$$F=>MhhjM%l?IJ;l%?%0IU$1%7%9%F
%`$N9=C[$,2DG=G"k3Hr<($9!%

C"$7!$ $X \in R^n$ $OF~NO%Y%/%H%k!$ $Y \in R^K$ $OL\I8=P
NO!$ L $O3X=,%G!<%?$N?tG"$k!%

0lHLE*$K!$ K-class LdBj$O K 8D$N two-class LdBj$K
J,3dG-$k!%$=NH$-!$8D!9$N two-class LdBj$KBP1~
9k3X=,%;%C%H$O0J2<$Nh&KJ$k!%

$$T_i = \{(X_l, y_l^{(i)})\}_{l=1}^{L} \qquad (6)$$

C"$7!$ $i = 1, \cdots, K$!$ $y_l^{(i)} \in R^1$ $O0J2<$Nh&$KDj5A$5
lkL\I8=PNOG"$k!%

$$y_l^{(i)} = \begin{cases} 1 - \epsilon & X_l \text{ \$,\%/\%i\%9 } C_i \text{ \$KB0\$9>l9g} \\ \epsilon & X_l \text{ \$,\%/\%i\%9 } \bar{C}_i \text{ \$KB0\$9>l9g} \end{cases} \qquad (7)$$

C"$7!$ ϵ $OHy>.$N@5?t$G!$ $\bar{C}_i$ O C_i 0J30N9YF$N%/
%i%9$rI=$9!%=>CF!$<0 (6) $O%/%i%9 C_i K9$k%G!<
%?H=$&$G$J$$$G!<%?$r6hJ,$1$9$kLdBj$KBP1~$9$k3X
=,%;%C%HG"$k!%0J2<!$6qBNE*$J%/%i%9J,$1LdBj$NDj
5AK3Nh$&$J3X=,%;%C%H$rMQ$$$k3HH9$k!%

0lHLE*KO!$(6) <0$GDj5A5l$? two-class LdBj$O$^
$05,LO$,Bg$-$/J#;(G"k?$a!$$=lr9K C
9k%G!<%?$H8D!9$NB>$N%/%i%9$KB0$9$k%G!<%?$r6hJ,
$1$9$kLdBj$KJ,3d9k!%6qBNE*KO!$$^$:!$3X=,%;%C
%H T K"$kA4F~NO%Y%/%H%k X_l ($l = 1, \cdots, L$) $r%/%i
%9$4$H$K6hJ,$1$9$k!%$=$N7k2L!$ K 8D$NF~NO%Y%/%H%k
$K4X$9$k%5%V%;%C%H

$$\chi_i = \{X_l^{(i)}\}_{l=1}^{L_i}, \quad i = 1, \cdots, K \qquad (8)$$

$,7A@.$5lk!%$3$3$G!$ L_i O=$N i HVL\$N%5%V%;%C%H
K"$kF~NO%Y%/%H%k$N?t$G!$ $\sum_{i=1}^{K} L_i = L$ G"$k!%$=
7F!$(6) <0$GDj5A5l$? two-class LdBj$r0J2<$K<($9
$K - 1$ 8DNh$j>.5,LO$J two-class LdBj$KJ,3d$9$k!%

(left column)

$,4{$KMQ0U5l$F$$$kbN$H2>Dj$9$k!JC"$7!$ v $OEP
O?5l$?C18l$NAm?t$G!$ γ $OIJ;l$N?tG"$k!K!%=>$C
$F!$IJ;l%?%0IU$1LdBj$O!G0U$NJ8 $W = w_1 w_2 \cdots w_s$
!J $w_i \in V$, $i = 1, \cdots, s$!K$,M?$(il$?;~!$0J2<$N
<jB3$- φ KhCFIJ;lNs $T = \tau_1 \tau_2 \cdots \tau_s$!J $\tau_i \in \Gamma$,
$i = 1, \cdots, s$!K$r8+$D1k3HG"$k!%

$$\varphi : W^t \to \tau_t, \; t = 1, \cdots, s \qquad (3)$$

C"$7!$ t $OIJ;l$rDjah$&$H9kL\I8C18l$N%$%s%G%C%/
%9$rI=$7!$ W^t $OL\I8C18l w_t $rCf?4$H7?!$:81&$=$l
$>$l (l, r) 8D$NC18l$G9=@.5l$kC18lNs$G$"$k!%B($A!$

$$W^t = w_{t-l} \cdots w_t \cdots w_{t+r} \qquad (4)$$

C"$7!$ $t - l \geqq 1$, $t + r \leqq s$!%=>CF!$IJ;l%?%0IU$1$O
IJ;l$r%/%i%9$KCV-49($?%/%i%9J,$1LdBjH7FH$i
$($k3H$,$G$-!$%K%e!<%i%k%M%C%H$G<h$j07$&$3H,
G-$k!%

3. M^3 %M%C%H%o!<%/Kh$kLdBj$N2r$-J}

M^3 %M%C%H%o!<%/$GLdBj$r2r$/4pK\E*$J9M$(J}$O!$ $K - 1$ 8DNh$j>.5,LO$J two-class LdBj$KJ,3d$9$k!%

(left column, earlier section)

2. IJ;l%?%0IU$1LdBj

$3$3GO!$C18l$N<hj&$kIJ;l$,%j%9%H%"%C%W5l
$F$$$k<-=q

$$V = \{w^1, w^2, \cdots, w^v\} \qquad (1)$$

$HIJ;l%;%C%H

$$\Gamma = \{\tau^1, \tau^2, \cdots, \tau^\gamma\} \qquad (2)$$

$$T_{ij} = \{(X_l^{(i)}, 1-\epsilon)\}_{l=1}^{L_i} \cup \{(X_l^{(j)}, \epsilon)\}_{l=1}^{L_j} \qquad (9)$$

C"$7!$ $j = 1, \cdots, K\ (j \neq i)$!$ $X_l^{(i)} \in \chi_i$ $H $X_l^{(j)} \in \chi_j$ O=1>$1%/%i%9 C_i $H%/%i%9 C_j $KB0$9$kF~NO%Y%/%H%k$G$"$k!%=>CF!$<0 (9) $GDj5A$5$1$? two-class LdBj$O%/%i%9 C_i $H C_j $r6hJ,$1$9$kbNG"$j!$%/%i%9$N?t K $,Bg$-$1$1PBg-$$$[$I<0 (6) $N two-class LdBj$h$j>.5,LO$KJk!%3Nh&$K!$<0 (5) $N K-class LdBj$O4JC1$K<0 (9) Nh$&$J two-class LdBj$KJ,3d$9k3H,G-$k!%

>e$K=R$Y$?$h$&$K K-class LdBj$O $K \times (K-1)$ 8D$NAjBPE*$K>.5,LO$J two-class LdBj$KJ,3d9k3H$,$G$-$k!%7+$7!$$3$N $K \times (K-1)$ 8D$N two-class LdBj$NCfKb!$$^$@J#;($9$.$kLdBj$,B8:_$9k3H,M(il$k!%$=1i$N two-class LdBj$O0J2<$K<($9h&$K==J,>.5,LO$G%7%s%W%k$JLdBj$^$GJ,3d$9k3H,G-$k!%

$^$:!$<0 (8) $GDj5A$5$1$?F~NO%;%C%H χ_i $r0J2<$Nh&$J $N_i (1 \leqq N_i \leqq L_i)$ 8D$N%5%V%;%C%H χ_{ij} $KJ,3d$7$?$H2>Dj7h$&!%

$$\chi_{ij} = \{X_l^{(ij)}\}_{l=1}^{L_i^{(j)}}, \quad j = 1, \cdots, N_i \qquad (10)$$

C"$7!$ $L_i^{(j)}$ $O%5%V%;%C%H χ_{ij} K"$kF~NO%Y%/%H%k$N?t$G!$ $\bigcup_{j=1}^{N_i} \chi_{ij} = \chi_i$. 3N$J,3dKOM#0l@-$,$J$$$?$a!$K\O@J8GO!$L5:n0YE*$JJ,3d$r9T$&H9$k!%$3Nh$&$J F~NO%;%C%H$rMQ$$$1$P<0 (9) $GDj5A$5$1$k two-class LdBj$r0J2<$K<($9 $N_i \times N_j$ 8DNh$j>.5,LO$G%7%s%W%k$J two-class LdBj$K:FJ,3d9k3H$,$G$-$k!%

$$T_{ij}^{(u,v)} = \{(X_l^{(iu)}, 1-\epsilon)\}_{l=1}^{L_i^{(u)}} \cup \{(X_l^{(jv)}, \epsilon)\}_{l=1}^{L_j^{(v)}} \qquad (11)$$

C"$7!$ $u = 1, \cdots, N_i$ $v = 1, \cdots, N_j$!$ $X_l^{(iu)} \in \chi_{iu}$ $H $X_l^{(jv)} \in \chi_{jv}$ O=1>$1%/%i%9 C_i $H%/%i%9 C_j $KB0$9$kF~NO%Y%/%H%k$G$"$k!%

=>CF!$2>$K<0 (9) $GDj5A$5$1$k two-class LdBj$,$9YF<0 (11) $^$G:FJ,3d$5$1$?$JiP!$ K-class LdBj$O $\sum_{i=1}^{K} \sum_{j=1\ (j \neq i)}^{K} N_i \times N_j$ 8D$N two-calss LdBj$KJ,3d$5$1k3HKJk!%b73X=,%;%C%H$,Fs$D$N0[$J$kMWAG$7$+$J$$!JB($A!$ $L_i^{(u)} = 1$, $L_j^{(v)} = 1$!Kh&$KJ,3d$5$1$?Ji$P!$<0 (11) $O0J2<$Nh&KJ$k!%

$$T_{ij}^{(u,v)} = \{(X_l^{(iu)}, 1-\epsilon) \cup (X_l^{(jv)}, \epsilon)\} \qquad (12)$$

$3$1$O$$$&$^$GbJ$/@~7AJ,N%2DG=$JLdBjHJ$k!%

3.2 LdBj$NE}9g

J,3d$5$1$?LdBj$r8D!9$N%b%8%e!<%k$G3X=,7?8e!$LdBj$r2r$/$?aK$=$1iN%b%8%e!<%k$r:FE}9g$7J1$1$PJi$J$$!%3N@aGO!$%b%8%e!<%k$rINh&$KE}9g$9k+KD$$$F=RYk!%J<3Nh&$JE}9g$KhC$F=PMh>e$,C?%M%C%H%o!<%/$,LdBj$r@5$7$/2r$/$3H,G-k+KD$$$F$O [19], [20] $r;2>H$5$1$?$$!%

%b%8%e!<%k$NE}9g$K$O MIN!$MAX!$INV $H$$$&;0DN%f%K%C%H$rMQ$$$?!%$3$3$G!$ T_{ij} $H $T_{ij}^{(u,v)}$ $rMQ$$$F$=$1$>$13X=,%;%C%H T_{ij} [<0 (9)] $H $T_{ij}^{(u,v)}$ [<0 (11)] $r3X=,$9$k%b%8%e!<%k$rI=$9!%$=7F!$ M $K \times K$ $N%^%H%j%/%9 $\mathcal{M}$ $N (i,j) HVL\$NMWAGH7!$ M_{ij} $r $\mathcal{M}$ $NMWAG (i,j) $KBP1~$9$k $N_i \times N_j$ $N%^%H%j%/%9 $\mathcal{M}_{ij}$ $N (u,v) HVL\$NMWAGH9$k!%$K$-class LdBj T [<0 (5)] $r $K \times (K-1)$ 8D$N two-class LdBj T_{ij} [<0 (9)] $KJ,3d$7$F2r$/>l9g!$$^$:!$%^%H%j%/%9 $\mathcal{M}$ N=1>1N9TK"$k%b%8%e!<%k$r!$J#?t$NF~NO$+$i:G>.CM$rA*$S=P$9 MIN %f%K%C%H$rMQ$$$FE}9g9k!%B($A!$

$$\mathrm{MIN}_i = \min(\mathrm{M}_{i1}, \cdots, \mathrm{M}_{ij}, \cdots, \mathrm{M}_{iK}), \quad i = 1, \cdots, K\ (i \neq j) \qquad (13)$$

$3$3GOJX59>e MIN %f%K%C%H$N5-9f$r$=$N$^$^$=$N%f%K%C%H$N=PNO$rI=9bNH$7!$%b%8%e!<%k$N5-9f$r$=$N$^$^%b%8%e!<%k$N=PNO$rI=9bNH7F$$$k!%$=$7$F!$$3$N K 8D$N MIN %f%K%C%H$N=PNO$+$i:G=*E*$J2r$r0J2<Nh$&$KF@$k!%

$$C = \arg\max_i \{\mathrm{MIN}_i\}, \quad i = 1, \cdots, K \qquad (14)$$

C"$7!$ C $OF~NO%G!<%?$NB0$9$k%/%i%9G"$k!%

5,LONBg-$J two-class LdBj T_{ij} $,B8:_$9$k>l9g!$$h$j>.5,LO$JLdBj $T_{ij}^{(u,v)}$ XN:FJ,3d$,9T$o1k!%$=$N>l9g!$ $T_{ij}^{(u,v)}$ $r3X=,$9$k%b%8%e!<%k $\mathrm{M}_{ij}^{(u,v)}$ $O0J2<$Nh&$KE}9g$5$1$k!%$^$:%^%H%j%/%9 $\mathcal{M}_{ij}$ N=1>1N9TK"$k N_j 8D$N%b%8%e!<%k$r MIN %f%K%C%H$GE}9g9k!%B($A!$

$$\mathrm{MIN}_{ij}^{(u)} = \min(\mathrm{M}_{ij}^{(u1)}, \cdots, \mathrm{M}_{ij}^{(uN_j)}), \quad u = 1, \cdots, N_i \qquad (15)$$

$=$7$F!$$=$N N_i 8D$N MIN %f%K%C%H$r!$J#?t$NF~NO$+$i:GBgCM$rA*$S=P$9 MAX %f%K%C%H$rMQ$$$F99$KE}9g$7$F%b%8%e!<%k M_{ij} $r7A@.$9$k!%B($A!$

$$\mathrm{M}_{ij} = \max(\mathrm{MIN}_{ij}^{(1)}, \mathrm{MIN}_{ij}^{(2)}, \cdots, \mathrm{MIN}_{ij}^{(N_i)}) \quad (16)$$

3Nh&$$KE}9g5l$?%b%8%e!<%k$O M_{ij} =N^$^<0 (13) KAH_9~$^lk!%

%/%i%9J,1H$$$&4QE@$+$i$O two-class LdBj$H T_{ij} $H T_{ji} $OF10l$G$"$k!%N><T4V$NM#0l$N0c$$$O$=$lir3X=,9k%b%8%e!<%k$NL\I8=PNO$G$"$k!%B($A!$A0<T$NL\I8=PNO$, $1-\epsilon$ [(7) <0;2>H] Ji!$8e<T$NL\I8=PNO$O ϵ G"$k!%=>CF!MO M_{ij} $H!$F~NONCMrH?E>9k%f%K%C%H INV $rMQ$$$k3HKhCF9=@.G-$k!%

0J>e!$%b%8%e!<%k$NE}9g$N;EJ}$K$D$$$F4JC1$K=R$Y$?!%6qBNE*$J%M%C%H%o!<%/NNcO<!>O$GIJ;l%?%0IU$1$H$$$&6qBNE*$J2]Bj$rMQ$$$F@bL@9k!%

4. M^3 %M%C%H%o!<%/Kh$kIJ;l%?%0IU$1

4.1 %?%$%8l$NIJ;l%?%0IU$1

%?%$%8l$OF|K\8l$d1Q8l$H0cCFC18l$N8l7AJQ2=$,$J$$!%9JoA!$C18l$,J8CfNI3K$"$CFb!$$^$?!$$INh$&$JLr3d$GMQ$$$ilF$$$F$b!$$=$N8lWC$N=P8=7AOJQoiJ$$!%$^$?!$0l$D$NC18l!JJ8;zNs!K$,!$F0;l$HA0CV;l!$$"$k$$$OF0;l$HI{;l$H$$$C$?$h$&$KJ#?t$NIJ;l$r;}$D>l9g$b?tB?$/$"$k!%$3li$NE@$+$i!$F|K\8l$d1Q8l$JIN8@8lHHfY$F!$%?%$8l$NIJ;l%?%0IU1OFq$7$$$H;Wol$k!J>\:Y$K$D$$$F$O [21] $r;2>H!K!%0lJ}!$IJ;l$N[#KfN(!J;HMQ$9$k%3!<%Q%9Cf$NB?IJ;l8l$NHfN(!K$K$*$$$F$O!$1Q8l!JBrown %3!<%Q%9$N>l9g [22]!K!$F|K\8l!J5~Bg%3!<%Q%9$N>l9g [23]!K!$$=7FCf9q8l!J@62ZBg3X%3!<%Q%9$N>l9g [24]!K$,!$$=l>$l!$35%!$56%!$ 42%G"kNKBP7!$%?%$8l!JK\O@J8$GMQ$$$?%3!<%Q%9!JCm 1!K$N>l9g!K$O6O$+ 19%$G$"$k!%$?$@$7!$K\O@J8$KMQ$$$?%3!<%Q%9$O5,LO$,>.$5$$$?$a!$$3$N?t;z$,%?%$8lA4BN$NFC@-$r@5$7$/H?1G$7$F$$$k$+$I$&$+ODj+GO$J$$!%$$$:lK$;$h!$K\O@J8$K<(7?%?%0IU$1@:EY$NCM$OB?IJ;l8l$N$_$rBP>]H7$F$$$k$?$a!$>e5-[#KfN($K$O1F6A$5lJ$$!%

4.2 IJ;l%?%0IU$1LdBj$NJ,3d

K\O@J8$KMQ$$$?%?%$8l%3!<%Q%9$O 10,452 J8$+$i9=@.5l$F$$$k!%$=$l$rL5:n0Y$K 8,322 J8$H 2,130 J8$KJ,1F$=$l$>$l3X=,$H%F%9%H$K;H$&!%3X=,J8$K$*$$$F$O 124,331 8D$NC18l!J$=$N$&$A!$22,311 8D$,B?IJ;l8l!K$r!$%F%9%HJ8K*$$$F$O 34,544 8D$NC18l!J$=$N$&$A!$6,717 8D$,B?IJ;l8l!K$rM-$9$k!%%M%C%H%o!<%/$N3X=,KO3X=,J8$NB?IJ;l8l$N$_$rMQ$$$k3HH7$?!%%?%$8lKO 47 <oN`$NIJ;l$,Dj5A$5$l$F$$$k$, [21], [25]!$MQ$$$?%3!<%Q%9$K%?%0IU$1$5$l$F$$$kIJ;l$O<B:] 38 <oN`7+$J$$!%=>CF!$IJ;l$r%/%i%9H7FHi(lP!$$3$NIJ;l%?%0IU$1LdBj$O 38-class $N%/%i%9J,$1LdBjHJ$k!JCm 2!K!%$=l>$l3X=,J8$K8=lk 22,311 8D$NB?IJ;l8l$H%F%9%HJ8$K8=$l$k 6,716 8D$NB?IJ;l8l$N%/%i%9J,I[$rI= 1$K<($9!%

I= 1 3F%/%i%9$KB0$9$k%G!<%?$NJ,I[
Table 1 Distribution of data belonging to each class

%/%i%9	%G!<%?$N?t		%/%i%9	%G!<%?$N?t	
	3X=,	%F%9%H		3X=,	%F%9%H
C_1	3,041	962	C_{20}	4	0
C_2	72	13	C_{21}	76	17
C_3	1,444	385	C_{22}	4	7
C_4	2,400	701	C_{23}	9	2
C_5	1,582	399	C_{24}	57	15
C_6	3,008	1,011	C_{25}	32	11
C_7	12	0	C_{26}	90	34
C_8	3,197	1,008	C_{27}	30	5
C_9	1,537	475	C_{28}	6	1
C_{10}	481	176	C_{29}	88	23
C_{11}	705	233	C_{30}	2	1
C_{12}	787	226	C_{31}	177	58
C_{13}	601	108	C_{32}	6	0
C_{14}	124	38	C_{33}	8	0
C_{15}	906	328	C_{34}	17	1
C_{16}	90	30	C_{35}	20	3
C_{17}	213	49	C_{36}	2	0
C_{18}	875	214	C_{37}	131	37
C_{19}	476	145	C_{38}	1	0

I= 2 3F%/%i%9$N3X=,%G!<%?$,J,3d5l$?%5%V%;%C%H$N?t
Table 2 Number of subsets of training data in each class

	%5%V%;%C%H$N?t		%5%V%;%C%H$N?t
N_1	10	N_9	5
N_3	5	N_{11}	2
N_4	8	N_{12}	2
N_5	5	N_{13}	2
N_6	10	N_{15}	3
N_8	10	N_{18}	3

3.1 @a$K=>$($P!$$3$N 38-class LdBj$r$^$:0l0UE*$K<0 (9) $KDj5A$5l? $K \times (K-1) = 38 \times 37$ 8D$N two-class LdBj!$ T_{ij} $(i, j = 1, \cdots, K,\ j \neq i)$!$$KJ,3d5l$k!%$7$+$7!$I= 1$+$iJ,$+kh$&$K!$$bCH$b

!JCm 1!K'K\O@J8$GMQ$$$?%?%$8l%3!<%Q%9 ORCHID(Open linguistic Resources CHanelled toward InterDisciplinary research) $O 1996 G/$K3+;O5l$?M9@/>JDL?.Am9g8&5f=j!JCRL!K$H%?%$9qN)EE;R!&7W;;5!5;=Q%;%s%?!<!JNECTEC!K$N6&F18&5f%W%m%8%'%/%H [21] $N@.2L$G$"$k!%

!JCm 2!K'MQ$$$?%3!<%Q%9K*$$$F$O%?%0IU$1$5$l$?IJ;l$N<oN`$O 38 8D$7$+$J$$$,!$K\%7%9%F%`$N0lHL2=G=NO$r9MN8$7$F!$K\8&5f$G$OF~NO$N9=@.KO8=J88% [21] $K<($5lF$$$k 47 <oN`N9YF$NIJ;l$KBP1~G-kh$&$K7F$$$k!J4.3.1 @a$r;2>H!K!%

>.5J two-class LdBj!$$T_{30,38}$!K$N3X=,%G!<%?$O6O$+ 2+1 = 3 8DG"kNKBP7!$$bCHbBg-$J two-class LdBj!J$T_{6,8}$!K$N3X=,%G!<%?$O $3,008 + 3,197 = 6,205$ 8Db"$k!%$3Nh$&$JLdBjO^$@Bg$-9.k?$a!$3X=,%G!<%??t$, 481!JI= 1$NKC_{10}r1[$($k 12 $N%/%i%9$N%G!<%?r=l>$1 300!r1[$($J$$ h&$KL5:n0Y$KJ,3d9k!%$=$N7k2L!$$=li$N%/%i%9$r4^$` two-class LdBj $T_{i,j}$ $O<0 (11) $KDj5A$5l? $N_i \times N_j$ 8D$N two-class LdBj!$ $T_{ij}^{(u,v)}$ $(u = 1, \cdots, N_i,$ $v = 1, \cdots, N_j)$!$$K:FJ,3d5l$k!%$3$3$G!$$N$O 3.1 @a$N$HF1MM!$$=l>$l%/%i%9 C_i $H%/%i%9 C_j $KB0$9$k3X=,%G!<%?$,J,3d5l$?%5%V%;%C%H$N?tG"$k!%$=NCM, 1 hjBg$-$$$bNrI= 2$K<($9!JCM$, 1 NbNO$=$N%/%i%9$N%G!<%?$,J,3d5l$F$$$J$$$3Hr0UL#9k!K!%=>CF!Nc($P two-class LdBj $T_{1,2}$ $O $N_1 \times N_2 = 10 \times 1 = 10$ 8D$NItJ,LdBj$KJ,3d5l!$$T_{1,3}$ $O $N_1 \times N_3 = 10 \times 5 = 50$ 8D$NItJ,LdBj$KJ,3d5l$k!%0lJ}!$$TNh$&$J two-class LdBjO3$l0J>eJ,3d$5lJ$$!%B($A!$$N_2 = 1$, $N_7 = 1$!JN_2 $H N_7 $OI= 2$K<(5l$F$$$J$$$3HKCm0U5l$?$$!K!%

3.2 @a$G=R$Y$?$h$&$K two-class LdBj$H T_{ji} $OF1 0l$G$"$k$?$a!$38-class $NIJ;l%?%0IU$1LdBj$O

$$\sum_{i=1}^{38} \sum_{j=i+1}^{38} N_i \times N_j = 3,893 \tag{17}$$

8D$N>.$5$J two-class LdBj$KJ,3d5l$?!%$=liN&$A!$$bCH$b5,LO$NBg$-$J two-class LdBj$O $T_{10,19}$ $G!$3X=,%G!<%?$N?t$O 481+476=957 G"C?!J<B:]!$$C_{10}$ $H C_{19} O=$N3X=,%G!<%?$,J,3d5l$F$$$J$$%/%i%9NCfKbCHbBg$-$JFsDN%/%i%9G"$k!K!%

4.3 IJ;l%?%0IU$1MQ$N M^3 %M%C%H%o!<%/

4.3.1 9= @.

M^3 %M%C%H%o!<%/$O!$?^ 1$K<($9h&$KA0=R$7$? 3,893 8D$N two-class ItJ,LdBj$r3X=,$7$?%b%8%e!<%k$rE}9g7F9=@.5l$k!%8D!9$N%b%8%e!<%k M_{ij} $O!$=$NBP1~$9$kLdBj T_{ij} $,:FJ,3d$5l?>l9g!JNc$($P T_{13}=2$r;2>H!K!$99$K?^ 2$Nh&$K9=@.$5lk!%?^$K<($5lF$$$kNcGO!$LdBj T_{13} $r99$K $N_1 \times N_3 = 10 \times 5 = 50$ 8D$NItJ,LdBj$KJ,3d7F$$$k$?$a!$ M_{13} $O 50 8D$N%b%8%e!<%k $M_{13}^{(u,v)}$ $(u = 1, \cdots, 10,\ v = 1, \cdots, 5)$ $+$i9=@.5l$k!%$=7F!$$M_{ji}$ $(j > i)$ $O M_{ij} $H INV %f%K%C%H$+$i9=@.$5lk!%

4.3.2 F~ =P NO

M^3 %M%C%H%o!<%/$NF~NO%Y%/%H%k X!J3X=,CJ3,GO X_l[<0 (5)]!K$OL\I8C18l w_t $rCf?4$H7?:81&$=$l$>$l (l, r) 8D$NC18l$+$i9=@.$5lkC18l[s0W(4)] $+$i F/@.5l$?>pJs$G9=@.5lkbNG!$0J2<$Nh&$KI=$9!%

$$X = (x_{t-l}, \cdots, x_t, \cdots, x_{t+r}) \tag{18}$$

6qBNE*$K!$C18l w $,F~NO$N0LCV p $(p = t-l, \cdots, t+r)$ $KM?$(il$?;~!$$X$ $N9=@.ItJ,$G$"$k x_p $O0J2<$Nh&$J%Y%/%H%k$G$"$k!%

$$x_p = (e_{w1}, e_{w2}, \cdots, e_{w\gamma}) \tag{19}$$

C"$7!$%Y%/%H%k<!85 γ!J47!K$OIJ;l$N?tG"$k!%=>$C$F!$F~NO%Y%/%H%k X $N<!85$O $\gamma \times (l + 1 + r)$ KJ$k!%$b$7C18l w $,3X=,%G!<%?$K=P8=9kJi$P!$3FMWAG e_{wi} $O0J2<$Nh&$KF@$ilk!%

$$e_{wi} = \mathrm{Prob}(\tau^i | w) \tag{20}$$

C"$7!$$\mathrm{Prob}(\tau^i|w)$ $OC18l w $NIJ;l$ τ^i G"$k3NN($G!$3X=,%G!<%?$+$i0J2<$Nh&$K?dDj$5lk!%

$$\mathrm{Prob}(\tau^i|w) = \frac{|\tau^i, w|}{|w|} \tag{21}$$

$3$3$G!$$|\tau^i, w|$ $OA43X=,%G!<%?$rDL$8!$$w$ $,IJ;l τ^i $r<h$k2s?t$G!$$|w|$ $O w $,=P8=$9$k2s?t$G$"$k!%0lJ}!$$b$7C18l w $,3X=,%G!<%?$K=P8=7J$$$JiP!$3FMWAG e_{wi} $O0J2<$Nh&$KF@$ilk!%

$$e_{wi} = \begin{cases} \frac{1}{\gamma_w} & \tau^i \text{ \$, } w \text{ \$N<h\$j\$\&\$kIJ;l\$N>l9g} \\ 0 & \text{\$=\$NB>} \end{cases} \tag{22}$$

$3$3$G!$$\gamma_w$ $OC18l w $,;}$A$&$kIJ;l$N?t$G$"$k[4]!%

=PNO%Y%/%H%k Y $O0J2<$Nh&$KDj5A$5lk!%

$$Y = (y_1, y_2, \cdots, y_{38}) \tag{23}$$

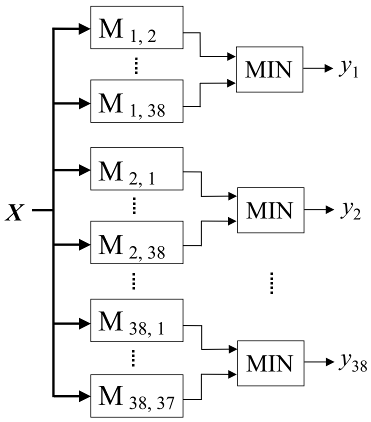
C"$7!$$Y$ $O0J2<$Nh&$K%G%3!<%I$5lkbNH9$k!%

$$\tau(w_t) = \begin{cases} \tau^i & y_i \geq 0.5 \text{ \$+\$D } y_j < 0.5 \text{!J} j \neq i \text{!K\$N>l9g} \\ & \\ \text{Unknown} & \text{\$=\$NB>} \end{cases} \tag{24}$$

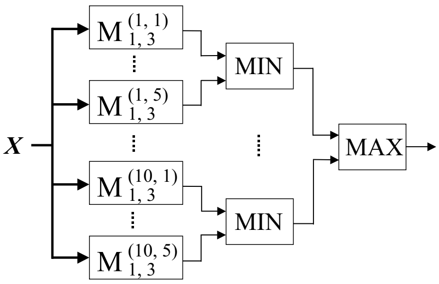
---

[3] !JCm 3!K'3NFsDN?t;z!J481 $H 300!K$O<}B+@-$H%b%8%e!<%k?t!J$D$^$j!$?M%a%?!<?t!K$N%H%l!<%I%*%U$r9MN8$7FE,EvK7haF$h$$$bNG$"$k!%$8%e!<%k?t$,B?$/$Fbh$$$+$i<}B+$r%9%T!<%I%"%C%W7?1lP5Jrhj>.5/9lPh$/!$5U$N>l9g$O$=$NCMrBg-$/$9lP$h$$!%

[4] !JCm 4!K'K\O@J8$G<B83$KMQ$$$?3X=,MQ$*$hSF%9%HMQ$N%3!<%Q%9$O!$?M$KhC$F%?%0IU$1r5l?bNG"$j!$$$$ofkL$CN8l!J<-=q$KB8:_7J$$8l!K$OB8:_$7$J$$!%7+$7<B:]!$C18l w $,L$CN8l$N>l9g$K$O3FMWAG e_{wi} $r $\frac{1}{\gamma}$ $K@_Dj$9lPL$CN8l$X$NBP1~$b2DG=KJ$k!%



?^1 M^3 %M%C%H%o!<%/$N9=@.
Fig. 1 Construction of the M^3 Network



?^2 %b%8%e!<%k $M_{1,3}$ $N9=@.
Fig. 2 Construction of module $M_{1,3}$

$3$3$G $\tau(w)$ $OC18l w XN%?%0IU$17k2L$rI=$9!%

3l$^$GDs0F7?%7%9%F%`[16] GO!$IJ;l%?%0IU$1 @:EY$r8~>e$5$;$k$?$a$KF~NO$ND9$5 (l,r) $K?–=L@–$r ;}$?$;$?!%$7$+$7!$?–=L@–$KE,9k!V>.$5$$$%M%C%H%o!< %/$+$iBg$–$$%M%C%H%o!<%/XN!WA2?J7?3X=,$r:NMQ$7 $?$?$a!$:G=i$N%+!<%M%k$H7?%M%C%H%o!<%/$N3X=,$, 6KC<KCY+C?!%K\8&5fGO!$3X=,$N9bB.2=$r?^$k$? aK$O M^3 %M%C%H%o!<%/$K3Nh&$J?–=L@–$rF3F~$7 $J$$$3HH7?!%$^$?!$J8$N3FC18l$r:8$+$i1&$X=g$K %?%0IU$1$7$F$$$/H–!$:8B&$NC18lODMK%?%0IU$1 :Q$_$H9M$(ilk?$a!$=>Mh$N%7%9%F%`$G$O!$$=li $NC18l$K4X9kF~NO$r9=@.$9kH$–!$$=l^GN%?%0 IU$17k2L$b%U%#!<%I%P%C%/7FMQ$$$?!%K\8&5fGO!$ 4JC1N?aK:81&$NC18l$r6hJL$;$:A0$K=R$Y$?J}K!$G $=$liNF~NO$r9=@.$9k3HK7?!%99$K!$=>Mh$N<5!K' M^3 K!$G$O!$F~NO $[k$0 (19)] $N9=@.$K$O!$3X=,%G!<%?$+ $iF@$ilk%$%s%U%)%a!<%7%g%s%2%$%s!JIG!K$r=E$_$H

7FMQ$$$?$,!$3X=,LdBj$,J,3d$5l?>l9g!$3X=,%G!< %?$N?t$,6KC<$K>/$J$$$?$a!$$=l>lN%b%8%e!<%k$K BP1~$9$k IG r5$7$/F@k3H,G–$J$$!%$=$N$?$a!$ M^3 %M%C%H%o!<%/GO IG $rMQ$$$J$$$3HK7?!%

5. <B 83 7k 2L

7W;;5!<B83KO 4.2 @a$K=R$Y$?%G!<%?$rMQ$$$?!% M^3 %M%C%H%o!<%/$KM?$($kC18lNs$ND9$5 (l,r) $r (3,3) $K@_Dj$7$?!%$=lKBP1~7FF~NOAX$N%f%K%C%H?t$O $(l+1+r)\times\gamma = 7\times 47 = 329$ G"C?!%C"$7!$$\gamma$ $O IJ;l$N<oN`G"$k!%M^3 %M%C%H%o!<%/$r9=@.9k8D!9 $N%b%8%e!<%k$O4pK\E*$KF~NOAX!]Cf4VAX!]=PNOAX$K 266 − 2 − 1 8D$N%f%K%C%H$r;}$D;0AX%Q!<%;%W%H%m%s $G9=@.$5lk!%9YFN%b%8%e!<%k$O0J2<$Nh&$KDj 5A$5lk8m:9 $E_{ACT}(k)$ $,L\I8CM0J2<$KJk$^$GA43X =,%G!<%?rDL8$F7+$jJV$73X=,$r9T$&!%

$$E_{ACT}(k) = \frac{\sum_{b=1}^{P} |D^{(b)} - O^{(b)}(k)|}{P} \qquad (25)$$

C"$7!$$k$ $O3X=,$N2s?t!$$D^{(b)}$ $O b HVL\$N3X=,%G!<%?$K BP$9$kM}A[$N=PNO!$$O^{(b)}(k)$ $O b HVL\$N3X=,%G!<%?$K BP$9$k<B:]$N=PNO!$$P$ $O3X=,%G!<%?$NAm?tG"$k!%%b %8%e!<%k$O!$2,000 2s3X=,$7Fb8m:9$,L\I8CM$^$G8: >/$7$J$$>l9g!$<}B+$7$J$$$H8+J5lk!%$=$NH–!$ Cf4VAX$N%f%K%C%H?t$r 2 $+$i 4 99KO 6 $^$GA}d7$F :FEY3X=,$r9T$&!%

0lJ}!$Hf3S<B83$KMQ$$$?=>Mh$N%7%9%F%`$O$=$l$>$l F~NOAX$K $[47\times(l+1+r)]$ !$Cf4VAX$K $\frac{[47\times(l+1+r)]}{2}$ !$=P NOAX$K 38 8D$N%f%K%C%H$r;}$D;0AX%Q!<%;%W%H%m%s$G9= @.$5$l$k!%C"$7!$%7%9%F%`$KM?$($kC18lNs$ND9$5 (l,r) $O0J2<$Nh&$K?–=L@–$rbDbNH9$k!%3X=,CJ3,$K $*$$$F$O!$$(l,r)$ $r $(1,1)\to(2,1)\to(2,2)\to(3,2)\to(3,3)$ Nh$&$KCJ3,E*$KA}2C$5$;!$>.$5$$$%M%C%H%o!<%/ $+$iBg$–$$%M%C%H%o!<%/$XA2?JE*$K3X=,$r9T$J$&!%0l J}!$%?%0IU1K$*$$$F$O!$5UKI,MWK1~8F (l,r) $r $(3,3)\to(3,2)\to(2,2)\to(2,1)\to(1,1)\to(1,0)\to(0,0)$ Nh$&$KCJ3,E*$K=L>.$7$F$$$/!%C"$7!$%?%0IU$1 K*$$$F$O!$Cf4VAX$N%f%K%C%H?t$r:GBgN^$^!JB($A!$ $(l,r)=(3,3)$ $KBP1~$7$?$b$N!K$K8GDj7?!%$^$?!$F~ NO$ND9$5 (l,r) $r:GBg $[9$JoA!$(3,3)]$ N^$^$K8GDj 7? 3 AX%Q!<%;%W%H%m%s$bHf3S<B83$KMQ$$$?!%

M^3 %M%C%H%o!<%/$rMQ$$$k>l9g!$J#;($JLdBj$r$$$/iG$b%7%s %W%k$JLdBj$KJ,3d$9k3H,G–k?$a!$87L)$J0UL#$G$O<}B+@–$NLdBj $OB8:_$7$J$$!%$3$3$G8@$&<}B+@–LdBj$O3X=,2s?t$HCf4VAX%f%K%C%H?t$K hC$F@_1?$?aK@8$8$kbNG"$k!%

I= 3　M^3 %M%C%H%o!<%/Kh$kIJ;l%?%0IU$1@:EY*
Table 3　Tagging accuracy of M^3 networks

%1!<%9	L\I88m:9	Cf4VAX$N%f%K%C%H?t	<}B+7?%b%8%e!<%k?t	<}B+7J$+$C$?%b%8%e!<%k?t	@:EY (%) 3X=,	%F%9%H
1	0.005	2	3,841	52	98.4	92.6
2	0.005	2, 4	3,882	11	98.5	93.0
3	0.005	2, 4, 6	3,890	3	99.5	93.4
4	0.002	2	3,738	155	98.7	93.0
5	0.002	2, 4	3,797	96	99.3	93.1
6	0.002	2, 4, 6	3,852	41	99.8	94.2

* IJ;l$K[#Kf@-$N$"$kC18lN_$rB,DjBP>]$H7?!%

I= 3$O M^3 %M%C%H%o!<%/$Khk%?%0IU$1@:EY$rO;DN%1!<%9$KJ,$1$F<($9!%K\O@J8$G$$$&@:EY$OIJ;l$K[#Kf@-N"$kC18l$N$_$rBP>]KB,Dj5l?bNG"$k!%%1!<%9 1 $O!$3X=,;~$NL\I88m:9$, 0.005 $G!$3F%b%8%e!<%k$NCf4VAX$N%f%K%C%H?t$O 2!J%G%U%)%k%H!K$N>l9gNbNG$"$k!%$=$N>l9g!$3X=,$K$*$$$F$O 3,841 8D$N%b%8%e!<%k$,<}B+$G$-!$;DjN 52 8D$N%b%8%e!<%k$,<}B+G-J+C?!%%?%0IU1K$*$$$F$O!$3X=,%G!<%?XN@:EY!J3X=,@:EY!K$O 98.4%$G!$%F%9%H%G!<%?$X$N@:EY!J%?%0IU$1@:EY!K$O 92.6%$G$"$C$?!%%1!<%9 2 $O!$%1!<%9 1 $N3X=,$r9TC?>e$G!$<}B+7J$+$C$?%b%8%e!<%k$r$=$NCf4VAX$N%f%K%C%H?t$r 4 $^$GA}d7$F:FEY3X=,$r9TC?>l9gNbNG$"$k!%$=$N>l9g!$<}B+$7J+C?%b%8%e!<%k$, 11 $^$G8:C?!%3X=,@:EY$O 98.5%$G!$%?%0IU$1@:EY$O 93.0%$G$"$C$?!%F1MM$K!$%1!<%9 3 $O!$%1!<%9 2 $N3X=,$r9TC?>e$G!$<}B+7J$+$C$?%b%8%e!<%k$rCf4VAX$N%f%K%C%H?t$r 6 $KA}$d7F:FEY3X=,$r9T$C$?>l9g$NbNG"$k!%$=7F!$%1!<%9 4-6 $OL\I88m:9$r 0.002 $^$G8:i7F=l>$l%1!<%9 1-3 $HF1MM$J3X=,$r9T$C$?>l9g$K$D$$$FNbNG$"$k!%

3NI=$O!$M^3 %M%C%H%o!<%/OI,MWK1~8F3X=,@:EY$r>e$2k3H,G-kH$$$&3H$r<($9HHbK!$M^3 %M%C%H%o!<%/$N%?%0IU$1@:EY$b3X=,@:EY$N8~>e$K$HfNc$7$F>e$,CF9T$/$3Hr<(7F$$$k!%D^$j!$:#2s$N<B83$K$*$$$F$O!$M^3 %M%C%H%o!<%/$K2a3X=,$NLdBj$,5/$3iJ$+$C$?!%<B:]!$M^3 %M%C%H%o!<%/$K2a3X=,$,5/3jK/$$$860x$O8D!9$N%b%8%e!<%k$NCf4VAX$N%f%K%C%H?t$,6KC<$K>/$J$$$3HK$"$k$H9M$(il$k!%0lJ}!$3 AX%Q!<%;%W%H%m%s$N>l9g!$I= 4$K<($7$?$h$&$K!$3X=,@:EY$,>e$,$kKD$l!$%?%0IU$1@:EY$,$+$(CFDc2<7F7^C?!%D^$j!$2a3X=,LdBj$,5/$3C?$H9M$(il$k!!JCm 6!K

I= 4　3 AX%Q!<%;%W%H%m%sKh$kIJ;l%?%0IU$1@:EY*
Table 4　Tagging accuracy of three-layer Perceptrons

%1!<%9	L\I88m:9	@:EY (%) 3X=,	%F%9%H
1	0.005	95.8	93.0
2	0.004	97.0	92.8
3	0.003	97.4	92.6

* IJ;l$K[#Kf@-$N$"$kC18lN_$rB,DjBP>]$H7?!%

I= 5　3F<jK!Kh$kIJ;l%?%0IU$1@:EY*
Table 5　Tagging accuracy of various methods

<jK!	@:EY (%)
%Y!<%9%i%$%s%b%G%k	83.6
1#$l%^%k%3%U%b%G%k	89.1
3 AX%Q!<%;%W%H%m%s	93.0
?-=L@-%Q!<%;%W%H%m%s	94.4
M^3 %M%C%H%o!<%/	94.2

* IJ;l$K[#Kf@-$N$"$kC18lN_$rB,DjBP>]$H7?!%

I= 5$O0[$J$k%K%e!<%i%k%M%C%H$KhkIJ;l%?%0IU$1@:EY$r<($9!%C"$7!$%Y!<%9%i%$%s%b%G%kHO!$J8L.>pJs$r;Ho:3X=,%3!<%Q%9$+$iF@il$?8D!9$NC18l$,<h$kIJ;l$NIQEY>pJs$N$_$rMQ$$$F%?%0IU1r9TJ&bNG"$k!%3 AX%Q!<%;%W%H%m%s$HM^3 %M%C%H%o!<%/Kh$k%?%0IU$17k2LO=l>$lI= 3$HI= 4NCfGbCHb@:EY$N9b$$$bNrMQ$$$F$$$k!%3NI=$+$i!$%K%e!<%i%k%M%C%H<jK!A4HL$,E}7W<jK!hj%?%0IU$1@:EY$,9b$$$3H,J,$+$k!%$=$7$F!$%K%e!<%i%k%M%C%H<jK!NCfG$O!$M^3 %M%C%H%o!<%/$O 3 AX%Q!<%;%W%H%m%s$h$j 1%0J>e@:EY$,9b$/!$?-=L@-%Q!<%;%W%H%m%sHOF1DxEY$N@:EY$rM-$9!%

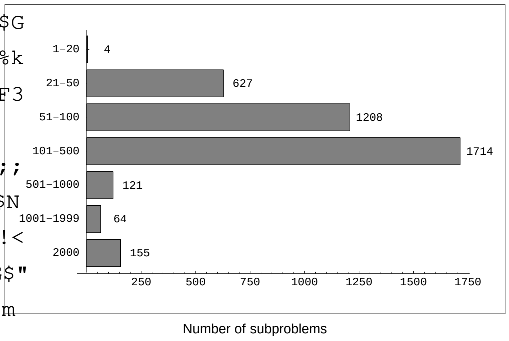
M^3 %M%C%H%o!<%/$N:GBg$NFCD'$O!$Bg5,LO$GJ#;($J LdBj$r>.5,LO$G%7%s%W%k$JLdBj$KJ,3d$7!$J,3d5l$?

!JCm 6!K' $3$3GO $(l, r) = (3, 3)$ $N8GDjD9$NbN$rMQ$$$?!%?-=L@-%Q!<%;%W%H%m%s$O!$L\I88m:9$, 0.004 $^$G2<$,$k$H!$A26a3X=,K*1k%+!<%M%k%M%C%H%o!<%/$N3X=,$,<}B+G-J+C?$?$a!$Hf3S$KMQ$$$k3H$,$G$-$J$+$C$?!%

I= 6 0[Jk%K%e!<%i%k%M%C%H<jK!$N3X=,$K$+$+$k7W;;NL
Table 6 Computational complexity of different neural-network based methods

<jK!	%G!<%??t	3X=,2s?t	%Q%i%a!<%??t
3 AX%Q!<%;%W%H%m%s	22,311	79	60,371
?-=L@-%Q!<%;%W%H%m%s	22,311	1,055/30/24/10/14	12,620/21,244/32,078/45,120/60,371
M^3 %M%C%H%o!<%/	957/699/699	2,000	660/1,320/1,980

LdBjr=l>$lFHN)$J%b%8%e!<%k$G3X=,$9k3H,$G $-$k$H$$$&E@H5lk!%B($A!$$=l>lN%b%8%e!<%k $rJBNsE*$K3X=,9k3H$,2DG=$G$"$k!%JBNs7W;;$rF3 F~$9lP!$$M^3$%M%C%H%o!<%/$N3X=,;~4VObCH$b3X =,$NCY$$%b%8%e!<%k$N3X=,;~4V$KJk!%;HMQ9k7W;; 5!$NB.EY$r9M$($J1l$P!$3X=,$N;~4V$r7hDj9k$N $O%G!<%?$N?t!$3X=,2s?t!$5Z$S3X=,$9Y-%Q%i%a%?!< !J%K%e!<%m%s4V$N7k9g=E$_!K$N?t$H$$$&;0DNMWAGG" $k!%I= 6$O 3 AX%Q!<%;%W%H%m%s!$?-=L@-%Q!<%;%W%H%m %s!$5Z$S M^3%M%C%H%o!<%/KD$$$FN3$N;0MWAG$r<($9!%%Q!<%;%W%H%m%s$N>l9g!$LdBj$r0l3g$G3X=,$7$F$$ k?$a!$3X=,9k%G!<%?$N?t$O3X=,%G!<%?$NAm?t$K$J $k!%0lJ}!$$M^3$%M%C%H%o!<%/$O!$LdBj$rJ,3d7F3X=,$7 $F$$$k$?$a!$%G!<%?$N?t$OJ,3d$5l?LdBjNCfGbC Hb%G!<%??t$NB?$$$bNrMQ$$$k!%C"$7!$I= 3$N%1!<%9 6 Kb<(7F$$$kh&$K!$$M^3$%M%C%H%o!<%/$N3X=,$O 3 %i%&%s%I$G9TC?NG!$I=$KO=l>lN%i%&%s%I$K $*$$$FbCHb%G!<%??t$NB?$$$bNrA*sG<(7F$$ $k!%?-=L@-%Q!<%;%W%H%m%s$N3X=,$O>.$5$$%M%C%H%o!< %/$+$iBg$-$$%M%C%H%o!<%/XN 5 CJ3,$NA2?J7?3X=,$G $"$k$?$a!$$+$+$C$?3X=,2s?t$HBP1~9k%Q%i%a%?!<$r $=$l$>$l<(7F$$$k!%$3$3$G!$7W;;NL$r!J%G!<%??t × 3X=,2s?t × %Q%i%a%?!<?t!K$G7W;;$9kJ$i!$%Q!<%;%W %H%m%s!$?-=L@-%Q!<%;%W%H%m%s!$5Z$S M^3%M%C%H%o!< %/$N7W;;NLO=l>$l 1.06×10^{11}!$ 3.57×10^{11}!$$= 7F!5.88×10^9 KJ$k!%B($A!$$M^3$%M%C%H%o!<%/$O JBNs7W;;$rMQ$$$k3HKhCF=>Mh<jK!hj3X=,$, 60 G\0J>eB.$/JC$?!%C"$7!$<B83$KMQ$$$?%Q!<%;%W%H%m %s$H?-=L@-%Q!<%;%W%H%m%s$N=PNOAXKOA0$K=R$Y$?DL $j!$47 8D$N%f%K%C%H$r@_Dj7?$,!$$3$3$G8x@5$5$rJ] D?aK%Q%i%a%?!<$N7W;;$G$O M^3%M%C%H%o!<%/$HF1 MM=PNOAX$N%f%K%C%H?t$r 38 H7$?!%$=7F!$$3$3$GCm 0U5l$?$$$N$O!$$M^3$%M%C%H%o!<%/$N7W;;NL$N7W;;$K MQ$$$?;0MWAGO9YF:GBg$N%1!<%9$rMQ$$$F$$$k3H G"$k!%MQ$$$F$$$k;0MWAG$OI,$:7b0lDN3X=,%1!< %9$KBP1~$7$F$$$ko1GO$J$$$?$a!$<B:]$N7W;;NL$O bC$H>/$J$+$C$?$H;Wol$k!%



?^ 3 3X=,2s?tKh$k%b%8%e!<%k$NJ,I[
Fig. 3 Distribution of trained modules according to the number of epochs in learning

0lJ}!$<B:]!$JBNs7W;;$rMQ$$$J$$$/Fb M^3%M%C%H %o!<%/$N3X=,;~4V$,G|BgKJko1GOJ$$!$$=$N7W ;;NL$O=>Mh<jK!$HF1DxEY$NbNG"$k!%?^ 3$OJ,3d$5 l? 3,893 8D$NItJ,LdBj$r8m:9 0.002 0J2<$^$G3X=,$9 kH$-!JI= 3$N%1!<%9 4!K$N3X=,2s?t$NJ,I[$r<($7$F$$ $k!%$3$N?^$r8+lPJ,$+$kh&$K!$$[HsIN%b%8%e!< %k$O 500 2s0JFb$N3X=,$G<}B+$7$F$$$k!%$=$7$F!$$=$N 3X=,$,=*C?CJ3,$G<}B+$7$J$$%b%8%e!<%k$N?t$O6O$+ Am?t$N 4%7+$J$$/!!$JBNs7W;;$G$J$$>l9g!K%1!<%9 5 $H 6 $N3X=,$K$*$1$k7W;;NL$,%1!<%9 4 KHfYL5;kG-$k $[$I>.$5$$!%0J>eN3Hr9M$($F!$$3$3$G6a;wE*$K8D!9 $N%b%8%e!<%k$NJ?6Q3X=,2s?t$r 250!$%Q%i%a%?!<$N?t $r 660!$$=7F!$J?6Q3X=,%G!<%?$N?t$r:GBg$H:G>.$N Cf4V!'B($A!$$\frac{957+1}{2} = 479$!J4.2 @a$r;2>H!KH9$k!%$= $&$9kH!$Am7W;;NL$O6a;wE*$K0J2<$Nh&$K7W;;$G$- $k!'%b%8%e!<%k?t × %Q%i%a%?!<?t × J?6Q%G!<%??t × J? 6Q3X=,2s?t $= 3,893 \times 660 \times 479 \times 250 = 3.08 \times 10^{11}$!% 3N?t;z$O=>Mh<jK!hj>.5/!$L5;k7?%1!<%9 5 $H 6 $N7W;;NL$rB-7F$b=>Mh<jK!$HF1DxEYNbNH8@$($k!%

6. 7k $S

K\O@J8$O!$J#;($GBg5,LO$JLdBj$r4JC1$G>.5,LO$JLd Bj$KJ,3d7F07$&%b%8%e!<%k7?%K%e!<%i%k%M%C%H$rMQ $$$?IJ;l%?%0IU$1%7%9%F%`$K$D$$$F=RY?!%?7%7%9%F

%`$OJBNs7W;;$,2DG=N?$a=>Mh<jK!$HF1DxEY$N%?%0IU
$1@:EY$rM-7J$,$i=>Mh<jK!hj 60 G\0J>e$bB.$/3X
=,$r9T$&3H$,$G$-$?!%$=$7$F!$8D!9$N%b%8%e!<%k$O
>.5,LO$G4JC1$J two-class LdBj$@$1$r3X=,$9lP$h$$
$?$a<}B+@-$NLdBj$,J/3X=,@:EY$r$$$/iG$b>e$2$k
3H$,$G$-$k$@$1GJ$/!$Cf4VAX$N%f%K%C%H?t$r6KC<
$K>/$J$/@_Dj$G$-$k$?$a!$2a3X=,$NLdBj$b5/$3jK$/
$$!%=>CF!$?7$7$$<jK!$rMQ$$$k3HKhCF!$IJ;l
%?%0IU1N5iJk@:EY8~>e$r!$3X=,@:EY$r>e$2k3
HKhCFb!$3X=,%G!<%?$rA}d9$3$HKhCF$b?^
k3H,2DG=HJC?!%:#8e$O!$K\%7%9%F%`$rIJ;l<o
N`$, 63 $GB?IJ;l8l$,==?tK|8D$r4^$`hjBg5,LO$JCf
9q8l%3!<%Q%9$XE,1~$7$F$$$/M=DjG"$k!%

J8 8%

[1] R. Garside, G. Leech, and G. Sampson, The Computational Analysis of English: A Corpus-Based Approach, London: Longman, 1987.

[2] D. Hindle, "Acquiring disambiguation rules from text," Proc. ACL'89, Vancouver BC, pp. 118-125, 1989.

[3] E. Brill, "Transformation-based error-driven learning and natural language processing: a case study in part-of-speech tagging," Computational Linguistics, Vol. 21, No. 4, pp. 543-565, 1994.

[4] K. Church, "A stochastic parts program and noun phrase parser for unrestricted text," Proc. 2nd ACL Applied NLP, Austin, Texas, pp. 136-143, 1988.

[5] S. DeRose, "Grammatical category disambiguation by statistical optimization," Computational Linguistics, Vol. 14, No. 1, pp. 31-39, 1988.

[6] D. Cutting, J. Kupiec, J. Pederson, and P. Sibun, "A practical part of speech tagger," Proc. 3rd ACL Applied NLP, Trento, Italy, pp. 133-140, 1992.

[7] E. Charnik, c. Hendrickson, N. Jacobson, and M. Perkowitz, "Equations for part-of-speech tagging," Proc. 11th National Conference on Artificial Intelligence, AAAI Press/MIT Press, Menlo Park, pp. 784-789, 1993.

[8] E. Charniak, Statistical Language Learning, The MIT Press, 1993.

[9] R. Weischedel, et al., "Coping with ambiguity and unknown words through probabilistic models," Computational Linguistics, Vol. 19, No. 2, pp. 359-382, 1993.

[10] B. Merialdo, "Tagging English text with a probabilistic model," Computational Linguistics, Vol. 20, No. 2, pp.155-171, 1994.

[11] H. Schütze and Y. Singer, "Part-of-speech tagging using a variable memory markov model," Proc. ACL'94, Las Cruces, New Mexico, pp. 181-187, 1994.

[12] M. Nakamura, K. Maruyama, T. Kawabata, and K. Shikano, "Neural network approach to word category prediction for English texts," Proc. COLING'90, Helsinki University, pp. 213-218, 1990.

[13] H. Schmid, "Part-of-speech tagging with neural networks," Proc. COLING'94, Kyoto, pp. 172-176, 1994.

[14] Q. Ma and H. Isahara, "A multi-neuro tagger using variable lengths of contexts," Proc. COLING-ACL'98, Montreal, pp. 802-806, 1998.

[15] GO!$0f:486!$ "D9$52DJQJ8L.$rMQ$$$?%^%k%A%K%e!<%m%?%,!<!$" <+A38@8l=hM}!$Vol. 6, No. 1. pp. 29-42, 1999.

[16] GO!$Fb85!$B<ED!$0f:486!'"IJ;l<+F0%?%0$E$1%7%9%F%`!]?-=L@-F~NO%K%e!<%m%?%,!<!$" ?M9)CNG=3X2q;o!$Vol. 14, No. 6, pp. 1116-1124, 1999!%

[17] Q. Ma, K. Uchimoto, M. Murata, and H. Isahara, "Hybrid neuro and rule-based part of speech taggers," Proc. COLING'2000, Saarbrücken, pp. 509-515, 2000.

[18] B. L. Lu and M. Ito, "Task decomposition based on class relations: a modular neural network architecture for pattern classification,", Biological and Artificial Computation: From Neuroscience to Technology, Lecture Notes in Computer Science, J. Mira, R. Moreno-Diaz and J. Cabestany, Eds., vol. 1240, Springer, pp. 330-339, 1997.

[19] B. L. Lu and M. Ito, "Task decomposition and module combination based on class relations: a modular neural network for pattern classification," IEEE Trans. Neural Networks, Vol. 10, No. 5, pp. 1244-1256, 1999.

[20] B. L. Lu and M. Ichikawa, "Emergnec of learning: an approach to coping with NP-complete problems in learning," Proc. of IJCNN'2000, Como, Italy, Vol. IV, pp. 159-164, 2000.

[21] V. Sornlertlamvanich, N. Takahashi, and H. Isahara, "Building a Thai Part-Of-Speech Tagged Corpus (ORCHID)," The Journal of the Acoustical Society of Japan (E), Vol.20, No.3, pp 189-198, 1999.

[22] J. Kupiec, "Robust part-of-speech tagging using a hidden Makov model," Computer Speech and Language, Vol. 6, pp. 225-242, 1992

[23] B<ED!$Fb;3!$Fb85!$GO!$0f:486!$"7hDj%j%9%H!$MQNc%Y!<%9<jK!$rMQ$$$?%3!<%Q%98m$j8!=P!&8m$jD{@5!$" <+A38@8l=hM}8&5f2q 2000-NL-136!$pp. 49-56!$2000!%

[24] B. L. Lu, Q. Ma, M. Ichikawa, and H. Isahara, "Massively parallel learning of part-of-speech disambiguation," RIKEN Review, no. 30, pp. 40-49, 2000.

[25] T. Charoenporn, V. Sornlertlamvanich, and H. Isahara, "Building a large Thai text corpus - part of speech tagged corpus: ORCHID," Proc. NLPRS'97, Phuket, Thailand, pp. 509-512, 1997.

[26] W. Daelemans and A. Van den Bosch, "Generalisation performance of backpropagation learning on a syllabification task," In M. Drossaers & A. Nijholt (Eds.), TWLT3: Connectionism and Natural Language Processing. Enschede: Twente University, pp. 27-38, 1992.

[27] J. Quinlan, C4.5: Programs for Machine Learning, San Mateo, CA: Morgan Kaufmann, 1993.

!JJ?@. x G/ xx 7n xx F|<uIU!K

GO @D !J@50w!K

1983 G/KL5~9R6u9RE7Bg3X<+F0@)8f3XIt B46H!%1987 G/C^GHBg3XBg3X1!M}9)3X8&5f 2J=$;N2]Dx=$N;!%1990 G/F1Bg3X1!9)3X8& 5f2JGn;N2]Dx=$N;!%9)3XGn;N!%1990 ∼ 93 G/3t<02q<R>.LnB,4o6PL3!%1993 G/M9@/>J DL?.Am9g8&5f=jF~=j!$<gG$8&5f41!%?M9)?@ 7P2sO)LV%b%G%k!$CN<1I=8=!$<+A38@8l=hM}$N8&5f$K=>;v!%F|K\ ?@7P2sO)3X2q!$<+A38@8l=hM}3X2q!$EE;R>pJsDL?.3X2q3F2q0w!%

O$!!JuNH !J@50w!K

1982 G/Cf9q@DEg2=9)3X1!!&7WB,@)8fB4!% 1982 G/!] 1986 G/@DEg2=9)3X1!=u<j!%1989 G/@>KL9)6HBg3XBg3X1!%3%s%T%e!<%?%5%$%(%s%93X2J=$;N2]DxN;!%1994 G/5~BgBg3X1!Gn ;N2]DxN;!%Gn;N!J9)3X!K!%1994 G/!] 1999 G/M}8&%P%$%*!&%_%a%F%#%C%/%3%s%H%m!<%k 8&5f%;%s%?!<%U%m%s%F%#%"8&5f0w!%1999 G/M}8&G>2J3XAm9g8& 5f%;%s%?!<8&5f0w!%G>7?%3%s%T%e!<%?!$?@7P2sO)LV%b%G%k!$%Q %?%s!<G′<1!$<+A38@8l=hM}!$:GE,2=$N8&5f$K=>;v!%F|K\?@7P2s O)3X2q!$IEEE Computer Society 3F2q0w!%

0f:486 6Q

1978 G/5~ETBg3X9)3XItEE5$9)3XBhFs3X 2JB46H!%1980 G/F1Bg3X1!=$;N2]Dx=$N;!%Gn ;N!J9)3X!K!%F1G/DL>&;:6H>JEE;R5;=QAm9g 8&5f=jF~=j!%1995 G/M9@/>JDL?.Am9g8&5f=j 4X@>;Y=jCNE*5!G=8&5f<<<<D9!%8=:_!$F18& 5f=j$1$$$OsJ>pJsDL?.M;9g8&5f%;%s%?!< 46@->pJs=hM}8&5f<<<<D9!%<+A38@8l=hM}!$5!3#K]Lu$N8&5f$K=> ;v!%8@8l=hM}3X2q!$>pJs=hM}3X2q!$?M9)CNG=3X2q!$F|K\G′CN2J 3X2q!$ACL 3F2q0w!%

;T@n!!F;65

C^GHBg3XBg3X1!9)3X8&5f2J=P?H!J9)3XGn ;N!K!%1986 G/!] 1997 G/EEAm8&!$D6J,;RIt$K $F?@7P6=J35!9=!$8w7WB,!$G>7?%3%s%T%e!< %?$N4pAC8&5fJI$r<B;\!%1997 G/!]8=:_!$ M}8&!$G>2J3XAm9g8&5f%;%s%?!<!$G>AO@.%G %P%$%98&5f%A!<%`$K$F!$EE5$@8M}3X$+$i>p Js=hM}M}O@!$%A%C%W3+H/$^$G$r 1 $D$N8&5f<<$G9T$&$H$$$&M_D% $j$J%]%j%7!<$G%A!<%`%j!<%@!<$H7F6PL3!%

?^!$I=$NBjL>%j%9%H

?^#1 M^3 %M%C%H%o!<%/$N9=@.
Fig. 1 Construction of the M^3 Network

?^#2 %b%8%e!<%k $M_{1,3}$ $N9=@.
Fig. 2 Construction of module $M_{1,3}$

?^#3 3X=,2s?tKh$k%b%8%e!<%k$NJ,I[
Fig. 3 Distribution of trained modules according to the number of epochs in learning

I=#1 3F%/%i%9$KB0$9$k%G!<%?$NJ,I[
Table 1 Distribution of data belonging to each class

I=#2 3F%/%i%9$N3X=,%G!<%?$,J,3d5l$?%5%V%;%C%H$N?t
Table 2 Number of subsets of training data in each class

I=#3 M^3 %M%C%H%o!<%/Kh$kIJ;l%?%0IU$1@:EY
Table 3 Tagging accuracy of M^3 networks

I=#4 3 AX%Q!<%;%W%H%m%sKh$kIJ;l%?%0IU$1@:EY
Table 4 Tagging accuracy of three-layer Perceptrons

I=#5 3F<jK!Kh$kIJ;l%?%0IU$1@:EY
Table 5 Tagging accuracy of various methods

I=#6 0[Jk%K%e!<%i%k%M%C%H<jK!$N3X=,$K$+$+$k7W;;NL
Table 6 Computational complexity of different neural-network based methods