

Bayesian and Neural Networks for Motion Picture Recommendation

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+ % * (% , # - % . & / # 0 % , % ' * # 1 2 & * 3 *
4 5 6 3 * % ' 7 # 8 ' % 9 & * * % ' # : & ' / 3 % # 4 ; # 4 . 6 < ' & =
> < " # ? @ # # @ BBC

Abstract

1 2 3 * # (2 & * 3 * # < DD . 3 & * # E < F 2 3 , & # . & < ' , 3 , / # (& F 2 , 3 G) & * # (% # < # 5 < (< * & (# % 9 # E % 6 3 & * # 5 & * F ' 3 ! & 5 #
! " # F % . . < ! % ' < (3 6 & # 1 % F 3 < . 1 # < , 5 # F % , (& , (# < ((' 3 !)) (& * # 3 , # % ' 5 & ' # (% # F ' & < (& # < # E 3 J & 5 # ' & F % E E & , 5 & ' #
* * * (& E # 9 % ' # E % 6 3 & * ; # + < " & * 3 < , # , & (K % ' L * A # (K % # 6 & * 3 % , * # % 9 # , &) ' < . # , & (K % ' L * A # 5 & F 3 * 3 % , # (' & & * A #
< , 5 # * 3 E D . & # ') . & # F . < * * 3 9 3 & * * < ' & # F % E D < ' & 5 ; # M (# 3 * # 5 & (& ' E 3 , & 5 # (2 < (# + < " & * 3 < , # < , 5 # , &) ' < .
, & (K % ' L * # %) (D & ' 9 % ' E # (2 & # ' & E < 3 , 3 , / # (& F 2 , 3 G) & * ; # + % (2 # (& F 2 , 3 G) & * # < F 2 3 & 6 & 5 # ' & E < ' L < ! . " #
2 3 / 2 # (% D N ? B # D ' & F 3 * 3 % , A # < , # 3 E D % ' (< , (# E & (' 3 F # % 9 # ' & F % E E & , 5 < (3 % , # G) < . 3 (' ; # 4 , # < ((& E D (# (% #
F % , (' < * (# ' & F % E E & , 5 < (3 % , # G) < . 3 (" # 9 % ' # F % , (& , (N % , . " # < , 5 # F % . . < ! % ' < (3 6 & N % , . " # 5 < (< * & (* # < * #
F % E D < ' & 5 # K 3 (2 # < # 5 < (< * & (# 5 & * F ' 3 ! & 5 # ! " # ! % (2 # F % , (& , (# < , 5 # F % . . < ! % ' < (3 6 & # < ((' 3 !) (& * # " 3 & . 5 * #
3 , F % , F .) * 3 6 & # ' & *) . (* ; # M , *) 9 9 3 F 3 & , (# F % , (& , (# 3 , 9 % ' E < (3 % , # 3 , # (2 & # F) ' ' & , (# 5 < (< * & (* # E < " # ! & # (2 & #
' & < * % , # 9 % ' # (2 3 * ;

Machine Learning Concepts

><F23, &#.&<' , 3, /#3*#<#<D35. ''#/'%K3, /#93&.5#K3(23, #F%ED)(&'#*F3&, F&;

Definition: “A computer program is said to **learn** from experience E with respect to some class of tasks T and performance measure P , if its performance at tasks in T , as measured by P , improves with experience E ” (Mitchell, 1997).

Definition: A **dataset** is a group of data. It is basically an n -by- m matrix with n rows and m columns. The rows are called **instances**. Instances are basically different occurrences of a situation. The columns are called **attributes**. Attributes are certain details that were recorded during every instance.

V3/) ' &#?#3*#K2<(#<#/&, &'3F#5<(<*&(#E<''#.%L#.3L&;

Figure 17#Sample Dataset

Student	Graduation Year	Major	GPA
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Decision Trees

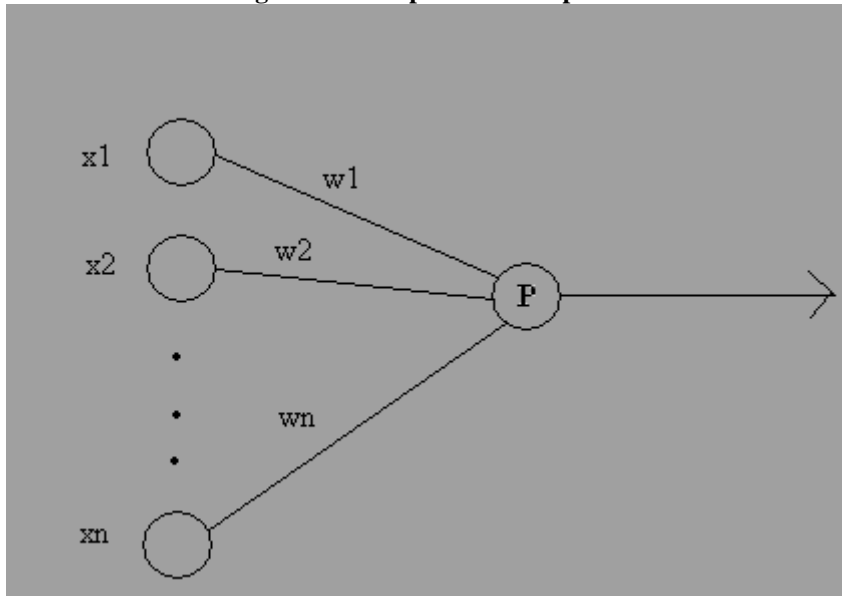
4, %(2&'#F.<***393&'#K23F2#!)3.5*#)D%, #').&#F.<***393&'*#3*#%, &#K3(2#5&F3*3%, #'&'&*&#;##
` &F3*3%, #'&'&*&#<'3F<..'#(<L&#<#.%%L#<(#E).(3D.&#<((('3!))&'&#<, 5#! '&<L#(2&E#3, (%#*#D<'<(&#
D<'3, /*#D' &53F(3, /#5399&'&, (#6<.)&'9%#(2&#(<' /&#<((('3!))&'&#<'&5#%, #2&#D<'3, /#%9#(2&'#
6<'3<! .&#;#Z&K#! '<, F2&'&#<'&#E<5	%'# , &K#D<'3, /*#<, 5#<#<#&'&#*).(#<, #&, (3'&#('*#E<5&#&#
K23F2#(2&#F.<***393&'#<, F23, /#<(#&<F2#D%3, (#5&D&, 53, /#%, #K2<#(2<.)&#%9#<#D<'(3F).<'#
<((('3!))&'*#;#><, ''#<./%'3(2E*#2<6&#!&&, #E<5&#&#)*3, /#5&F3*3%, #'&'&*&#(2&#E*#(#!<'3F#<E%, /#
(2&E#!&3, /#(2&#M` ^#<./%'3(2E#Ha)3, <, A#?RR^!;#O%K&6&#A#5&F3*3%, #'&'&*, 3(3<..'#2<5#<#
D'#! .&E#3, #%6&'93(3, /#5<(<A#3, #2<(#'<, 5%E#%FF)'&, F&'#K%).5#F'&(&# , &K#! '<, F2&'#(%#
'&'&#<, 5#K%).5#(2&'&9%'&#&#<5#(%#<#E%'&#F%ED.&J#('&#A#%, &#(2<(#F%).5#D' &53F(#9<.*&#
) (F%E*#5)&#(%#*#E, *(<, F&'#K2*#&#(<' /&#<((('3!))&'<.)&#K%).5#!ᔗ&'&, (#2<, #
) (2&'#3, *(<, F&'#K3(2*#3E3.<'#6<.)&'9%#3*#<((('3!))&'*#<#&'&#*).(A# , &K#<./%'3(2E*#K&'&#&
E<5&#&#)*3, /#D') , 3, /#8') , 3, /#K%).5#&#E%6&#&#<'<, F2&'#%9#(2&#('&#'#3(3ED' %6&5#(2&#
)6&#<.#<FF)'<F' #%9#(2&#('&#&#bJ<ED.&'#%9#5&F3*3%, #'&'&#&#<./%'3(2E*#3, F.)5&#- \; [Ha)3, <, A#
?RR^!#K23F2#!)3.(#)D%, #M` ^#! ''#<553, /#D') , 3, /A#<#K&#.#<#<.%K3, /# ,)E&'3F#<((('3!))&#
6<.)&'&#;

Neural Networks

4'(393F3<.#, &)'<.#, &(K%'L*#<'&#<, %(2&'#('D&#%9#E<F23, &#&#<' , 3, /#(&F2, 3G)&#M(#K<*#
3, *D3'&5#! ''#(2&# , &)'% , *#3, *35&#<#2)E<, #!'<3, #K23F2#F% , , &F(#%#&<F2#(2&'&#<, 5#/&, &'<(&
) (D)(*#!<'&5#%, *#(3E).3#9' %E#%(2&'# , &)'% , *;#M, #<'(393F3<.#, &)'<.#, &(K%'L*#D&'F&D(' , *#
<'&#)*&5#3, *(&#<5#%9# , &)'% , *;#4#D&'F&D(' , #(<L&'#3, #E<, ''#3, D)(*#<, 5#<***3/ , *#%E&#
F% , *(<, (#F<..&5#(%#&<F2#%, &A#F<..&5#<#K&3/2(:##12&#K&3/2(#&D'&'&#&, (*#(2ED%'< , F&#%9#(2&#
3, D)(#%#(2&#D&'F&D(' , ;#M, #2&#E<F23, &#&#<' , 3, /#F<*#&#(2, D)(*#<'&#(2ᔗ&'&, (#6<.)&'9#
(2&#<((('3!))&'&'#%9#<, #3, *(<, F&#D&'F&D(' , #2&, #<55*#<..#%9#(2, D)(*#E).(3D.3&5#! ''#
(2&3'K&3/2(*;#M(#2&, #<DD.3&#&#<#(2'&'2%.5#(%#(23*#6<.)&#M9#3(3*#<!%6&#BA#(2&#D&'F&D(' , #K3..#
) (D)(#<#?;#M9#(2<.)*# , %(#<!%6&#BA#(2&, #2&#D&'F&D(' , #K3..#%) (D)(#<#V?;#V%'#&J<ED.&A#
V3/)'&#*#<#53<'<E#%9#<#D&'F&D(' , ;#

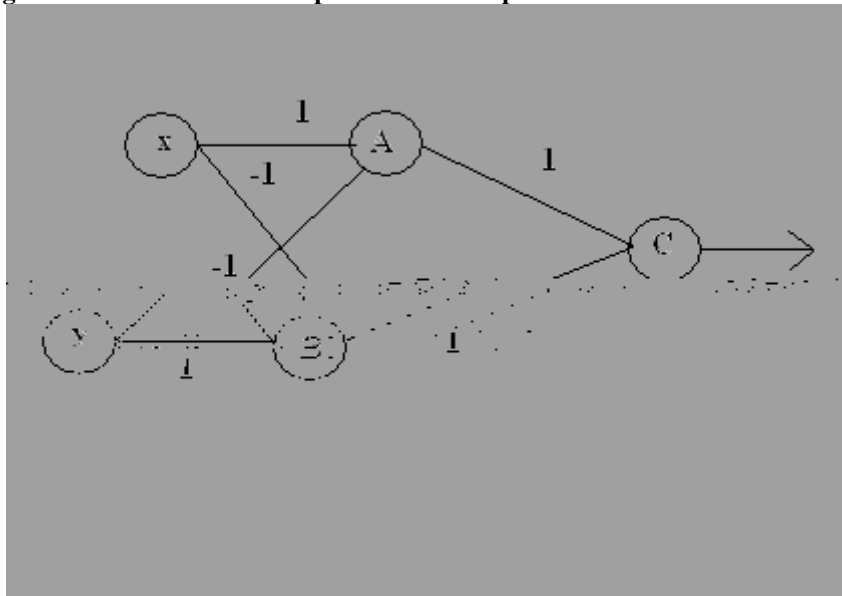
Formula: c36&, #3, D)(*#J?A#J_#d #J, A#<#D&'F&D(' , #K3..#<***3/ , #K&3/2(*#K?A#K_#d #K, #(%#
&<F2#%9#(2&E;#M(#K3..#(2&, #F<F).<(&#J?K?#eJ_#K_#e#d #eJ, K, #1#<, 5#(2&, #%) (D)(#<#*3, /.&#
6<.)&#&#<'&5#%, #K2&(2&'#%# , %(#2<(#6<.)*#/'&#<(&'#2<, #B;

Figure 2: Example of a Perceptron



8&'F&D('% , *#F<, #! %%L&5#)D#K3(2#%, &#<, %(2&'#.3L&#, &)'%, *A#3, #'% '5#'(%#F'&<(&# , &(K%'L *#F%, *3*(3, /#%9#E).(3D.&#.<'&'*#%9#D&'F&D('% , *;##V%'#&J<ED.&A#*)F2#<#, &(K%'L#F<, # !&#)*&5#(%#F%ED)(&#(2&#+%%.&<, #.%/3F#9) , F(3%, #fP\$;##V3/)'&#^#3*#<#53</'<E#%9#2%K#5%3, /# J#fP\$#"#K%).5#K%'L;

Figure 3: A Network of Perceptrons that Computes the XOR Boolean Function



M, #(23*#F<*#A 4A#+#<, 5#-#<'&#D&'F&D('% , *;##4#K%).5#%, .''#%) (D) (#<#?#39#J#3*#?#<, 5#''# 3*#B;##+#K%).5#%, .''#%) (D) (#<#?#39#J#3*#B<, 5#''#3*#?;##-#K%).5#%, .''#%) (D) (#<#?#39#4#?'#+#3*# %) (D) ((3, /#<#?;##12&'&9%'&A#(23*#, &(K%'L#%9#D&'F&D('% , *#E%5&.*#(2&#fP\$#9) , F(3%, ;##M, # /&, &'<.A#D&'F&D('% , *#<'&#&9%'&'&5#(%#<*#, %5&*A#<, 5#D&'F&D('% , *#(2<(#%, .''#%) (D) (#6<.)&*#(2<(# /%#3, (%#E%'&#D&'F&D('% , *#<'&#F<..&5#2355&, #, %5&#;

Network Training

12&#K<'<#&#)'<.#, &(K%'L#.&<' , *#3*#! ''#(' <3, 3, /#3(*#K&3/2(#6<.)&*;##b<F2#(3E&#<, #
3(&'<(3%, #9#D<***3, /#(2, D)(*#(2%')/2#(2&#, &(K%'L#3*#5%, &A#(2&#%) (D) (#6<.)&*#<'&#
F%E D<'&5#</<3, *(#(2&#(<' /&#(<('!)&0*#6<.)&*;##12&, #<#F<.F).<(3%, #3*#D&'9%' E&5#(%#F' &<(&#
(2&.<#(2<(#E) *(!&#<55&5#(%#(2&#%'3/3, <.#K&3/2(##123*#F%, (3,)&*#), (3.#(2&#K&3/2(*#5%#
, %(#F2<, /&A#%'#), (3.#(2&#<E%), (#9#D' &N5&(&' E3, &5#3(&'<(3%, *#3*#&'<F2&5;##12&#&'&#&'&6&'<.#
K<'*#(%#)D5<(&#K&3/2(*#9%'#D&'F&D('%, *, ##P, &#K<'*#3*#(%#<***3/ , #'<, 5%E#K&3/2(*#(%#&<F2#
3, D) (#<, 5#(2&, #3(&'<(3, /#(2&#D&'F&D('%, #)*3, /#(2	%..%K3, /#') .	%'#)D5<(3, /#&<F2#K&3/2(#
K_#9%'#3, D) (#J_7

Formula: $K_3 \leftarrow \#K_3 \#e\# \hat{A}k_3 \# \# \# \# \# K2\&' \& \# \# \# \# \hat{A}k_3 \cdot 1' \text{ fhg}\%I J_3$

M, # (2&#<! %6	%' E).<A# 'jg'hY'YUfb]b[fUY'i gY'hc'XYHfa]bY'hc'k \UhYI HYbh'hY'
K&3/2(#K3.#! &#F2<, /&5A#(#3*#(2&#(<' /&#(<('!)&0*#6<.)&A#%#3*#(2&#%) (D) (#6<.)&# /36&, #! ''#(2&#
D&'F&D('%, A#<, 5#J_#3*#(2, D) (#6<.)	&5#3, (%#(2&#D&'F&D('%, ;##123*#E&(2%5#/) '<<, (&*#
F%, 6&' /&, F'#(2&#F.<***&'<', &<'.'''*#D<'<!.&#H>3, *L''#S#8<D&'(A#?RC[I;#O%K&6&'A#
E%*(#5<(<*&'5%# , %2<6, &<'.'''*#D<'<!.&#F.<***&*;
4*#%.) (3%, #(%#(23*#D%'! .&E#K<*#)*3, /#&'%'#! <FLD%'D</<(3%, ;##M, #(23*#K<'A#(2&#
) (D) (*#<'&#F<.F).<(5A#<, 5#(2&, #2&#&'%'#3*#&, (#1 <FLK<'5*#(2%')/2#(2&#, &(K%'L#(%#)D5<(&#
(2&#K&3/2(*;##b<F2#%) (D) (#D&'F&D('%, #L#F<.F).<(&*]rg'Yffcf'hYfa ' _#)*3, /#(2	%..%K3, /#
9%' E).<7

Formula: $L \leftarrow \%LH? \#g\%L IH(L g\%L I$

O&'&A#%_#3*#(2&#%) (D) (#6<.)	%'#(2&#D&'F&D('%, A#<, 5#(L#3*#(2&#(<' /&#(<('!)<.)&#;
12&*#&6<.)&*#<'&#)*&5#3, #F<.F).<(3, /#(2&#&'%'#(&' E#9%'#&<F2#2355&, #, %5#)*3, /#(2&#
9%..%K3, /#9%' E).<7

Formula: $2 \leftarrow \#LH? \#g\%L \text{ k } L_2 L$

Z%(&#(2<(#K_L2#5&, %(&*#(2&#K&3/2(#9%'E# , %5#(%# , %5&#L;#12&#(&'E# 'k L2 L 9%'#
2355&, #, %5#3*#(2&'&9%'&#(2&#*) E#%9#(2&#K&3/2(*#(3E&*#(2&#&'%'#6<.)&*#%9#<.#(2&#%) (D) (#
, %5&*#L#(2<(#<'&#F%, , &F(&5#9%'E 2;

12&#K&3/2(*#<'&#(2&, #)D5<(&5#3, # (2	%..%K3, /#K<'7

Formula: $K_{03} \leftarrow \#K_{03} \#e\# \hat{A}k_{03} \# \# \# \# \# K2\&' \& \# \# \# \# \hat{A}k_{03} \cdot 1' \quad J_{03}$

123*#)D5<(&#') .&#&'&5)F&*#(2&#E&<, #*G)<'&#&'%'#<#(2&#%) (D) (#<'&' ;##- , , &F(3, /#
E<, ''#D&'F&D('%, *#%/&(2&#K3(2#E<, ''#2355&, #<'&'*)*3, /#&'%'#! <FLD%'D</<(3%, #F<, #2&.D#
3ED%'6&#<FF)'<F''!) (#.&<5*#(%#<#2<'D#3, F'&<*, #'<3, 3, /#(3E&##T<'''3, /#(2&#(2'&'2%.5A#
(2&#,)E! &'#%9#<'&'*A#<, 5#(2&#<E%), (#%9#(3E&#(<L&, #(%#('<3, #2&#, &(K%'L#F<, #<..#2&.D#
3ED%'6&#<FF)'<F'';##1&*(#2<6&#!&&, #5%, &#)*3, /#(2&*#5399&'&, (#6<'3<(3%, *; H\$)E&.2<'(A#
h35%'KA#S#X&2'A#?RR\I;

Y*3, /#&'%'#! <FLD'D%</<(3%, #3, #(&#K<'<'#!%6&#) *&*<#(2'&*2%.5#3, #'5&'#(##
 F%, 6&' /&#(%##, <.)&;#O%K&6&'A#(2&'*#<#K<'#(%#E%539''#&'%'#! <FLD'D%</<(3%, #K2&'&#
 3, *(&<5#9#) *3, /#(2&#(2'&*2%.5A#<#D'#! <! 3.3(''3*#3, *(&<5#F%ED) (&5A#<, 5#(2<(#3*#) *&5#3, #
 5&(&'E3, 3, /#(2&#%) (D) (#<((!3!)) (<.)&;###, #(&23*#K<'A#(2<.)	%'#(2&#&'%'#(E'9%'#&<F2#
 %) (D) (#, %5&#L#K%) .5#(2&, #! &#F<.F) .<(&5#3, #(&2	%..%K3, /#K<'7

Formula: $L \leftarrow \#_L H(L \text{ g} \#_L I)$

12<.)	%'#(2&#&'%'#(&'E'9%'#&<F2#235&, #, %5#K%) .5#(2&, #! &#F<.F) .<(&5#3, #
 (2	%..%K3, /#K<'7

Formula: $2 \leftarrow \#_L k_{L2} L$

M, #(&23*#K<'A#(2&#(2'&*2%.5#K%) .5#! &#&E%6&5#<, 5#! &#&D.<F&5#K3(2#<#D'#! <! 3.3('';##
 T<'3%) *#K%'L#2<#*! &&, #5%, &#) *3, /#(23*#E%5393&5#9%'E#<#K&..#H+3*2%DA#?RRCI

Bayesian Techniques

4, %(2&'#(D	#F.<*393&'#) *&#*+<'&*3<, #&<*, 3, /;##+<'&*3<, #(&F2, 3G) &#<'&#
 !<*5#%, #D'#! <! 3.3(''53*('3!)) (3%, *#<, 5#(2<(#) *3, /#(2&*&#D'#! <! 3.3(3&*#%, #'! *'6&5#5<(<#F<, #
 3ED'%6&#D&'9%'E<, F&;###('#3&*(%#D'%5) F&#(2&#! *#(2''D%(2&*3*9%'E#*%E&#*D<F	#
 2''D%(2&*&#O#/36&, #*%E&#(<3, 3, /#5<(<#` ;#>%*(#9#9#<'&*3<, #.&<', 3, /#&.3&#*%, #+<'&*0
 (2&%&E;#<+<'&*0#(2&%&E#<*) E&#*(2<(#9%'#&<F2#2''D%(2&*3*#2A#(2&'*#<#D'3%'#D'#! <! 3.3(''
 <.'&<5''F<.F) .<(&5A#F<..&5#8H2I;##8H` 1#3*#(2&#D'3%'#D'#! <! 3.3(''2<(#(2&#('<3, 3, /#5<(<#` #K3..#
 !&#%!'&'6&5;##8H` i21#3*#(2&#D'#! <! 3.3(''2<(#(2&#('<3, 3, /#5<(<#` #K3..#! &#%!'&'6&5#/36&, #(<2(#
 (2''D%(2&*3*#2#2%.5*##4, 5#8H2i` 1#3*#(2&#D'#! <! 3.3(''2<(#(2''D%(2&*3*#2#K3..#2%.5#
 /36&, #(&2&#('<3, 3, /#5<(<#` ;##1%#5&(&'E3, H2i` 1A#+<'&*0#(2&%&E#D'%635&*(2	%..%K3, /#
 9%'E) .<7

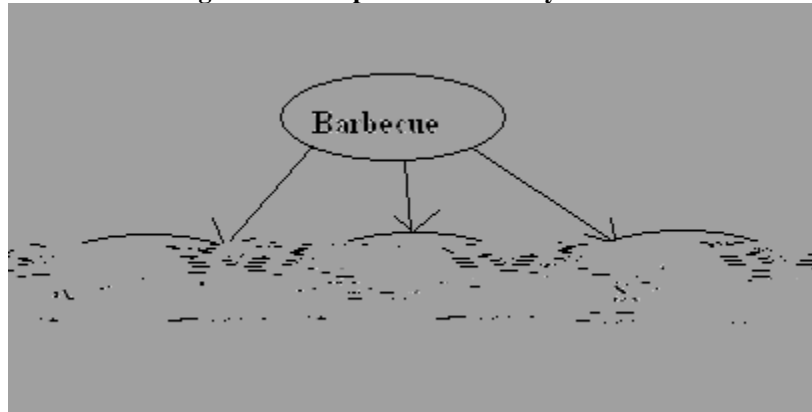
Formula: $8H2i` 1#j \#8H` i218H2I k 8H` I$

+<'&*0#(2&%&E#<..%K*#F.<*393F<(3%, #!'&#&F(3, /#(2&#E<J3E) E#<#D%*(&'3%'3#
 H> 481#2''D%(2&*3*##V%#&6&'''#2#3, #O#8H` i218H2I#3*#F<.F) .<(&5;##12&, %E3, <(%'#8H` 1#3, #
 +<'&*0#9%'E) .<#3*#&E%6&5#! &F<)*&#(2&#('<3, 3, /#5<(<#` #, &6&'#F2<, /#*9%'#&<F2#F2<, /#%9#
 2#3, #O;##12''D%(2&*3*#2#K3(2#(2/2*#6<.)	#8H` i218H2I#3*#(2&, #) *5#(#F.<*39''#
 &<F2#3, *(<, F&;

Naïve Bayes

12&'&#<'&#(K%#*(<, 5<'5#E&(2%5*3, #K23F2#+<'&*3<, #.&<', 3, /#3*5%, &;#P, *#<#
 (&F2, 3G) &#F<..&5#Z<16&#+<'&*##, #Z<16&#+<'&*A#(2&#<./%'3(2E#F'&<(&*#<#&(#9#<..#D%*3! .&#
 (<' /&#(<((!3!)) (&#;###(2&, #F<.F) .<(&*#(2&#D'#! <! 3.3(''(&'E*#8H2I#<, 5#8H` i21#<#*#(<(&5#<'%6&;#
 O%K&6&'A#3(#! '&<L*#&<F2#5399&'&, (#<((!3!)) (<.)#9#(2&#('<3, 3, /#5<(<#` #<, 5#F<.F) .<(&*#
 &<F2#%, 	#(2&E#*#D'<(&.';###(2&, #(<L&*#(2&#E<J3E) E#6<.)&*#9#8H2I#E) .(3D.3&5#! ''#(2&#
 D'%5) F(#9#<..#(2&#D'#! <! 3.3(3&*#9#8H` i21;#V%#&J<ED.&A#F%, *35&'#V3/) '&#;\##

Figure 4: Example of a Naïve Bayes model



+<'! &F) *(2&#(<' /&#<('3!) (&A#<, 5#2<*(2<.) &*#' &*'%'#, %;#12&#F.< **393&'#K%).5#
93'*(#!)3.5#)D#(2ᔗ&'&, (#3, *(<, F&*'%'9#(2&#!<'! &F) <(<#` #<, 5#F<.F).<(&#&<F2#D' %! <! 3.3(' '#
/36&, #&3(2&' #' &*'%'#, %;#M(#K%).5#<.*%'#F<.F).<(&#(2&#%6&'<..#D' %! <! 3.3(' '#9#!<'! &F)3, /;#V%'#
&J<ED.&A#(%#F.< **39''#(2, *(<, F&#H:), #j #%) (A#\$<3, #j #, %, &A#1&ED&'<())' &#j #2%(1A#(2&#
F.< **393&'#K%).5#F<.F).<(H'' &*l#m#8H%) (i'' &*l#m#8H, %, &i'' &*l#m#8H2%(i'' &*l#<, 5#8H, %l#m#
8H%) (i, %l#m#8H, %, &i, %l#m#8H2%(i, %l#12&#&, 5#' &*) .(#K%).5#! &#(2&#F.< **393&'#* &. &F(3, /#(2&#
E<J3E)E#6<.)&#%9#(2&#(K%#<, 5#F2%*%&#&3(2&' #' &*'%'#, %;#Z<16&#+<' &*#2<*#! &&, #) * &5#9%'#
(<*L***)F2#<*'%' (3, /#%) (#, &K*#<' (3F.&*#H] %<F23E*A#?RRCI;

Bayesian Networks

$Z \perp\!\!\!\perp X \mid Y$ if and only if $P(Z, X, Y) = P(Z \mid Y)P(X \mid Y)$

Definition: Attributes are **conditionally independent** of one another if given the value of one or more attributes $Y_1 \dots Y_m$ determines the value of attributes $X_1 \dots X_m$ independent of values of attributes $Z_1 \dots Z_m$

$X \perp\!\!\!\perp Y \mid Z$ if and only if $P(X, Y \mid Z) = P(X \mid Z)P(Y \mid Z)$

Figure 5a: Example of a Bayesian Network

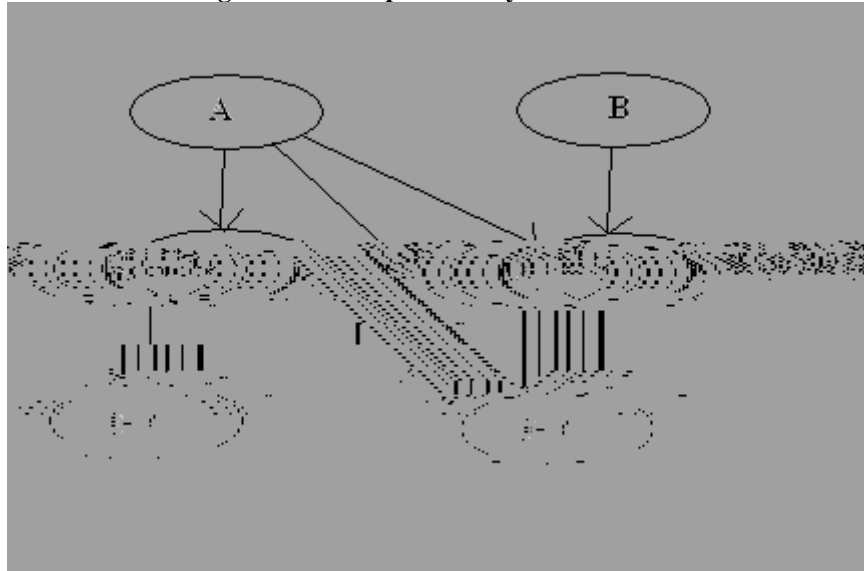


Figure 5a: Example of a Conditional Probability Table

	A=0	A=1	A=0	A=1
9	B; \	B; ?	B; 0	B; @
n9	B; C	B; R	B; @	B; 0

$P(X \mid Y, Z) = P(X \mid Y)$ if and only if $P(X, Y, Z) = P(X \mid Y)P(Y, Z)$

K%).5#! HVj 9i4j <A` j 5l;##Y*3, /#(2&#F%, 53(3%, <.#D'#! <! 3.3(''#(<! .&#<! %6&A#(23*#6<.) &#
K%).5#(2&'&9%'&#! &#B;\;

Y, .3L&#, &)'<.#, &(K%'L*A#3, #K23F2#&'%'*#K<, (#(%#! &#E3, 3E3=&5A#+<'&*3<, #, &(K%'L*

F<, #! &#('<3, &5#(%#E<J3E3=&#(2&#D'#! <! 3.3(''#%9#(2&#%!*&'6&5#5<(<#/36&, #(2&#, &(K%'L#

D<'<E&(&'*;#h &3/2(*#H/Tf<ETB.15Tf<ETW2<*&1%50#*239(<K%\)D5<1(F<)j 9i4j <A` j 5#(2&#, &(K%'L#23*#6<.)

Machine Learning Work with Recommender Systems

><, "#F%..<!%'<(36].(&'3, /#(&F2, 3G)&*#2<6&#! &&, #)*&5#! &9%'&#V%'#&J<ED.&A#
\$3, /%#K<*#<#*%F3<.#3, 9%'E<(3%, #93.(&'#)*&5#(%#('"#<, 5#E<L&#E)*3F#'&F%E E&, 5<(3%, *#(%#
.3*(&, &'*#H: 2<'5<, <, 5#S#><&*A#?RR[I;##M, #*)F2A#'&F%E E&, 5<(3%, *#<'&#D<*&5#(2'%) /2#
pK%'5#%9#E%) (2qA#' <(2&'#(2<, #F%, (&, (A#*%#E)*3F#'&F%E E&, 5<(3%, *#E<"#! '<*(3F<..'#
5399&'&, (#(2<, #(2%*&#(2<(#<#)*&'#2<*.3*(&, &5#(%#! &9%'&'<6&#! &&, #E<, "'#%(2&'#(&*(#

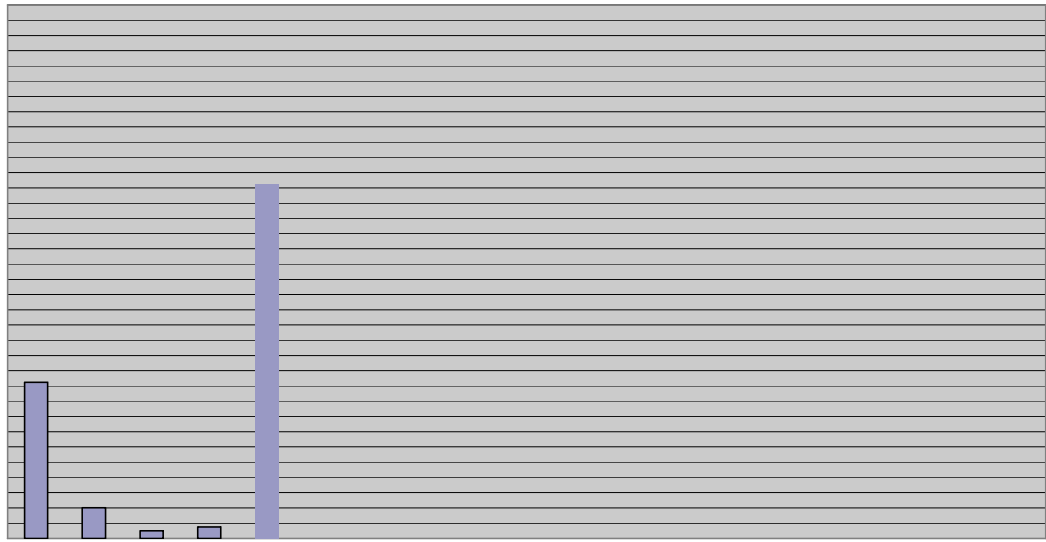
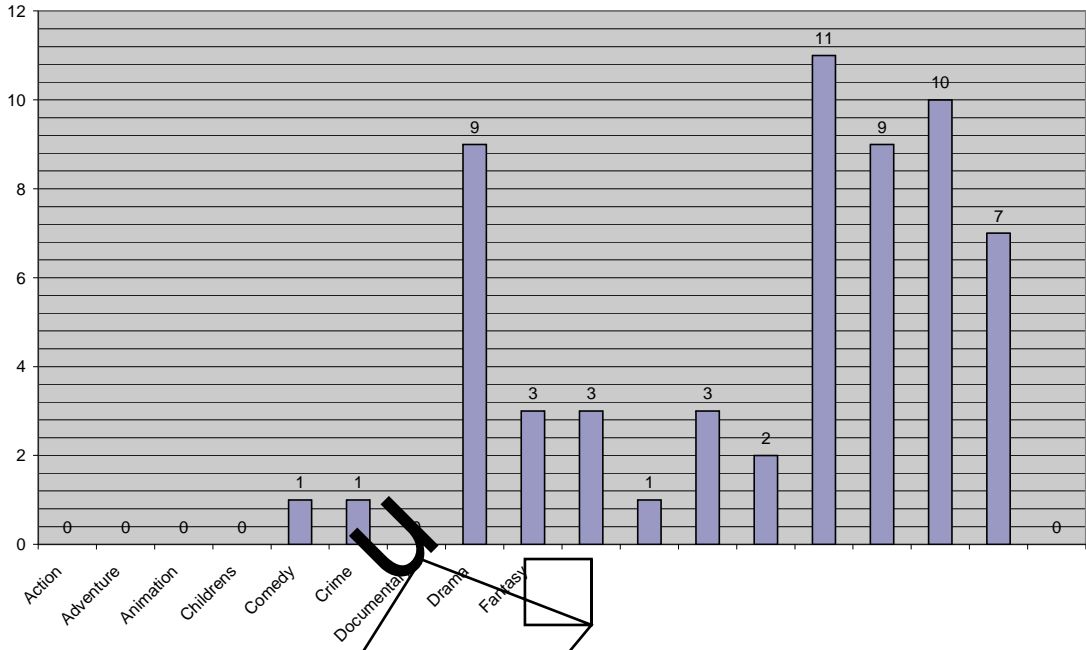
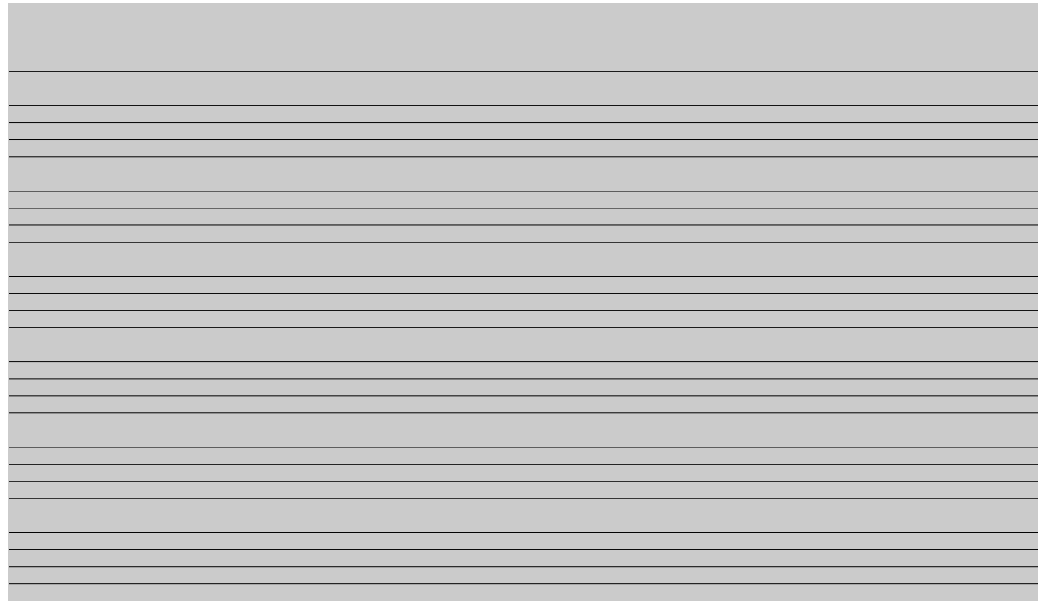


Figure 7c: Genre3 Distribution





Performance Metrics and Evaluation Protocol

$$\frac{\sum_{i=1}^n \text{TP}_i}{\sum_{i=1}^n (\text{TP}_i + \text{FP}_i)}$$

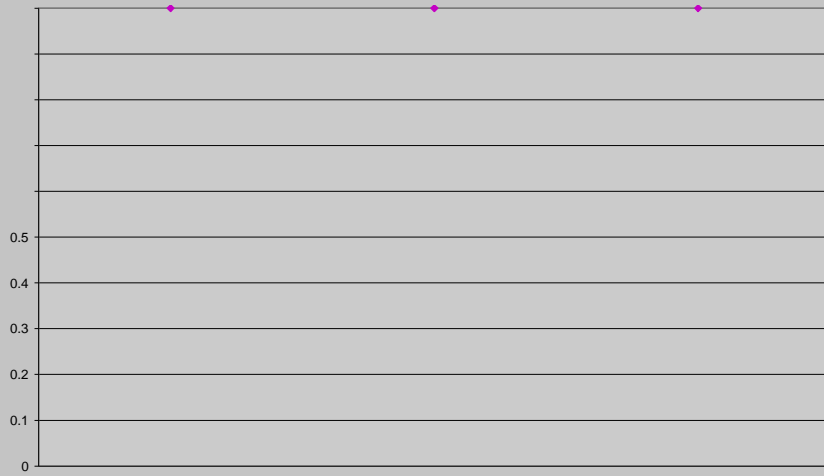
Definition: Accuracy is the percentage of instances that are correctly classified by the system.

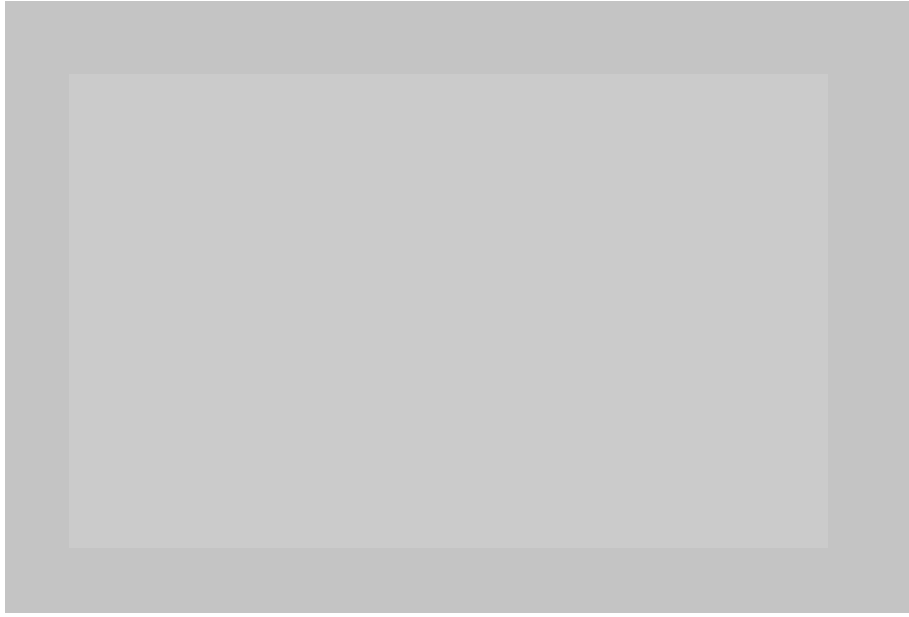
Definition: Precision is the percentage of like predictions that agree with the user's taste.

$$-\frac{\sum_{i=1}^n \text{TP}_i}{\sum_{i=1}^n \text{TP}_i}$$

BestFirst

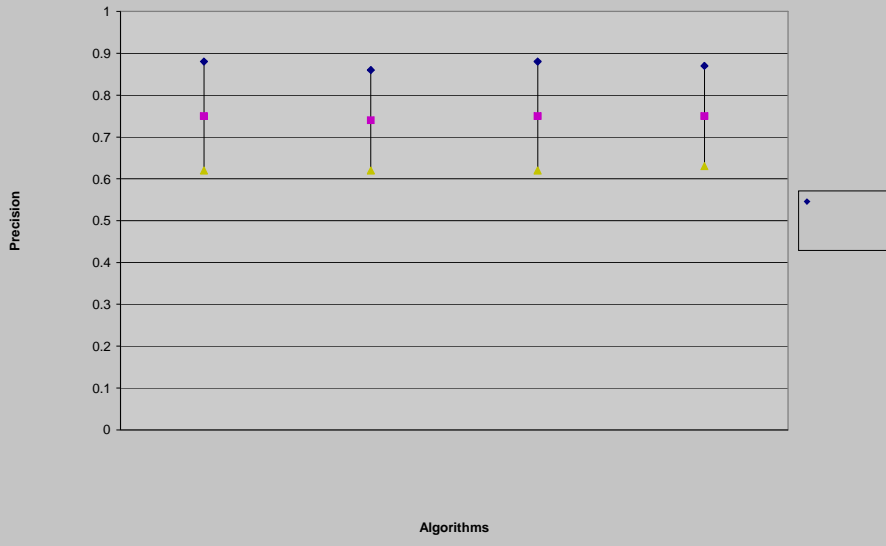
Figure 9c: Top-10 Precision Using BestFirst Attribute Selection

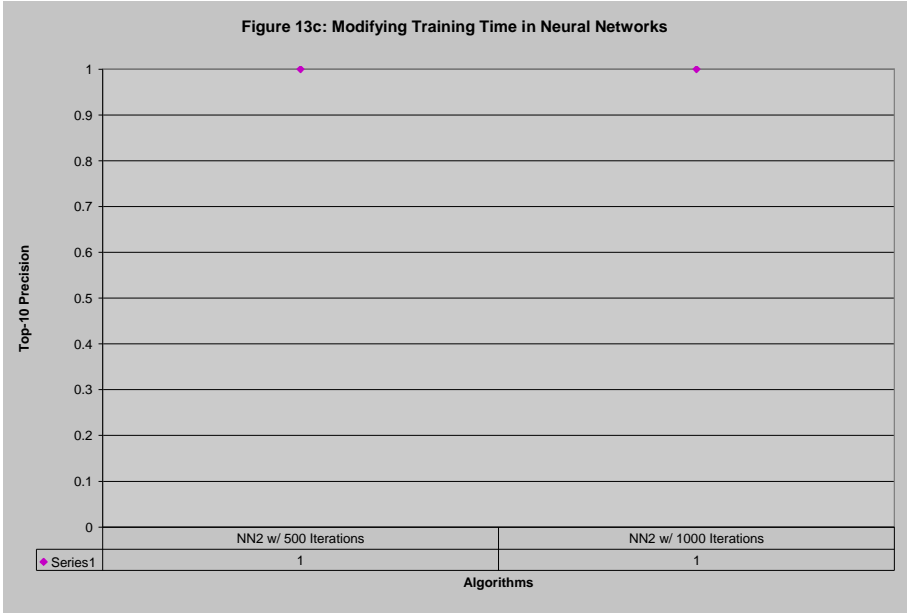




Neural Networks

Figure 12b: Modifying Hidden Nodes in Neural Networks

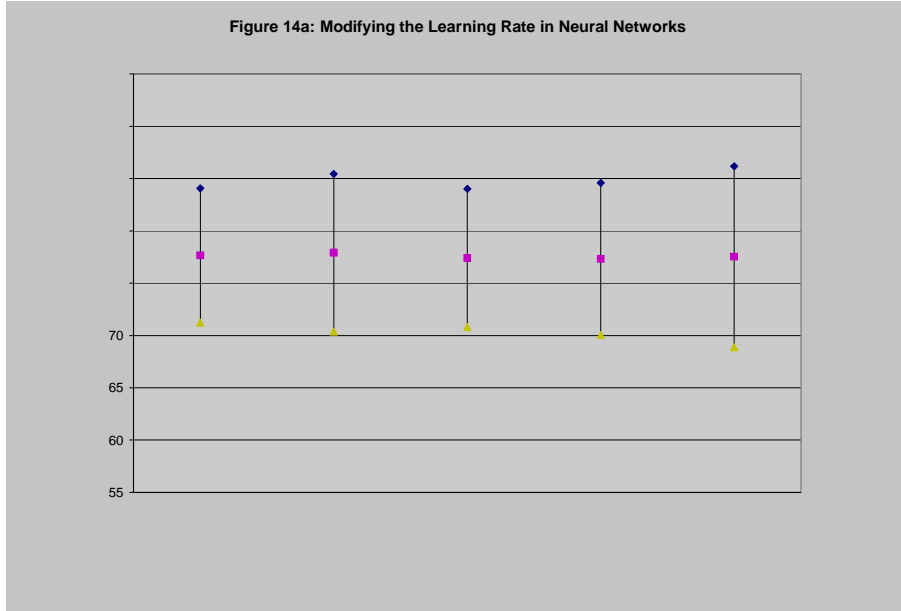




X%%L3, /#<(#(2&# ' & *).(*A#(%DN?B#D' &F3*3%, #K<*(2&#* <E&*D3(, F' &<*3, /#(2&# ('<3, 3, /#(3E& ; #4FF)'<F''#*.3/2(''5&F'&<* &5A#<, 5#(2&#*(<, 5<'5#5&63<(3%, #*.3/2(''3, F' &<* &5;# 8'&F3*3%, #<. *%#*.3/2(''5&F'&<* &5;##1 2&' &9%'&A#5&*D3(, F' &<*3, /#(2&#('<3, 3, /#(3E &A#(2&# <FF)'<F''#<, 5#*(<, 5<'5#5&63<(3%, #535#, %(#2<6&#<#*3/, 393F<, (#F2<, /&##1 2&' &9%'&A##535#, %(# !%(2&'#3, F' &<*3, /#(2&#('<3, 3, /#(3E	%'#9)())'&##JD&'3E&, (*;

Learning Rate

Learning rate is a hyperparameter that controls how much the weights in a neural network are updated during training. A high learning rate can cause the model to diverge, while a low learning rate can cause it to converge very slowly. The optimal learning rate depends on the specific problem and model architecture.



70



Bayesian Networks

W#5&F35&5#(%#(&*(#(2&#E<J3E)E#,)E! &'#%9#D<'&, (*#&<F2#, %5&#F<, #2<6&#%, #(2&#

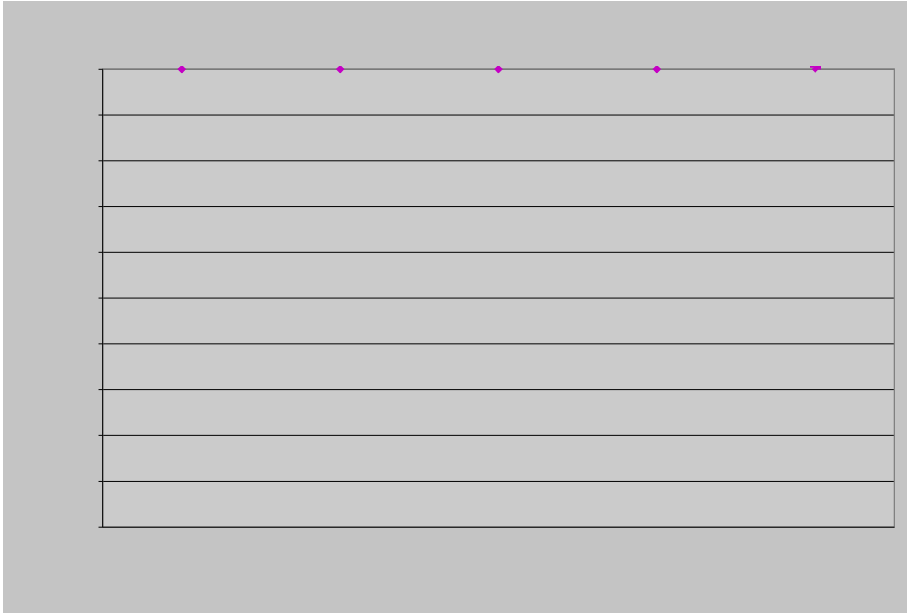
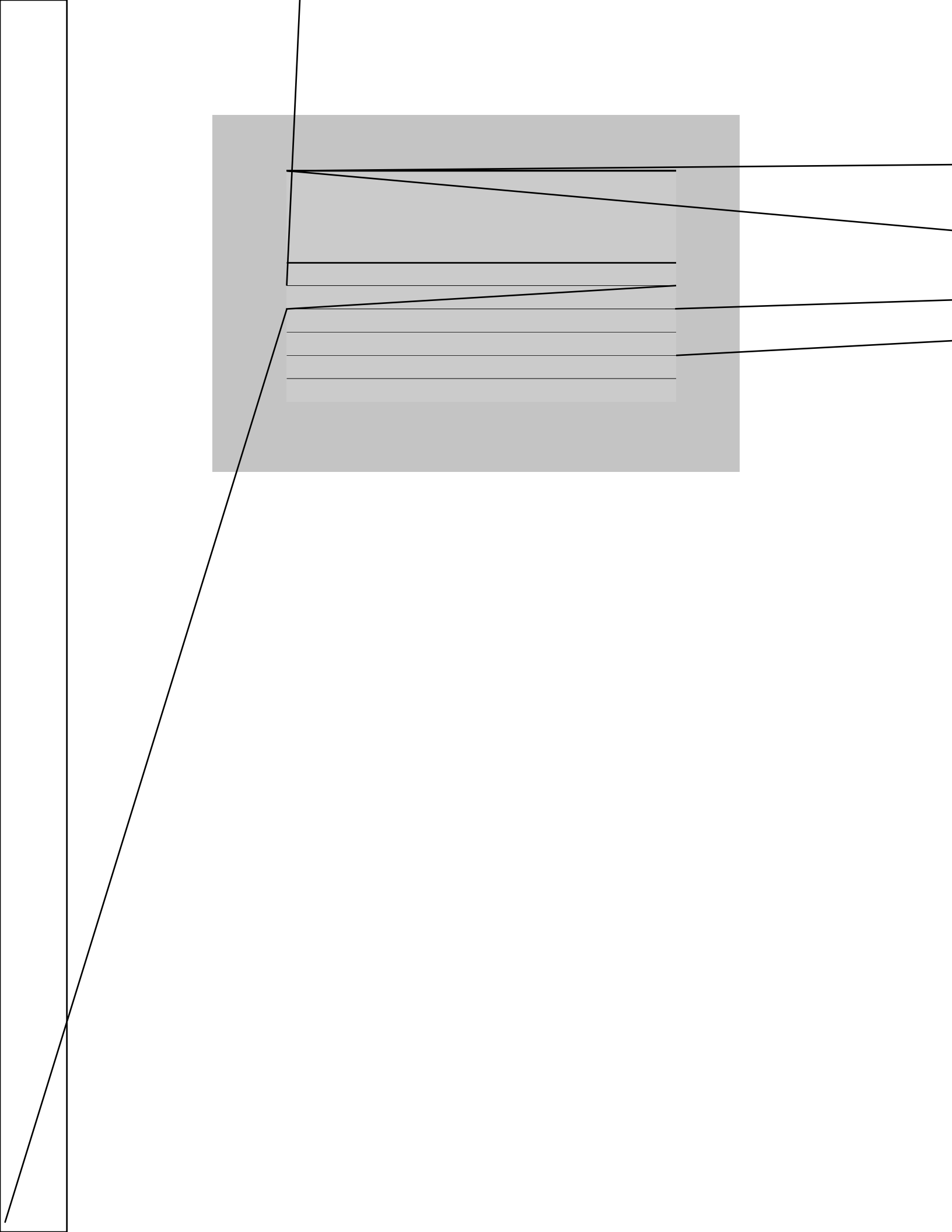


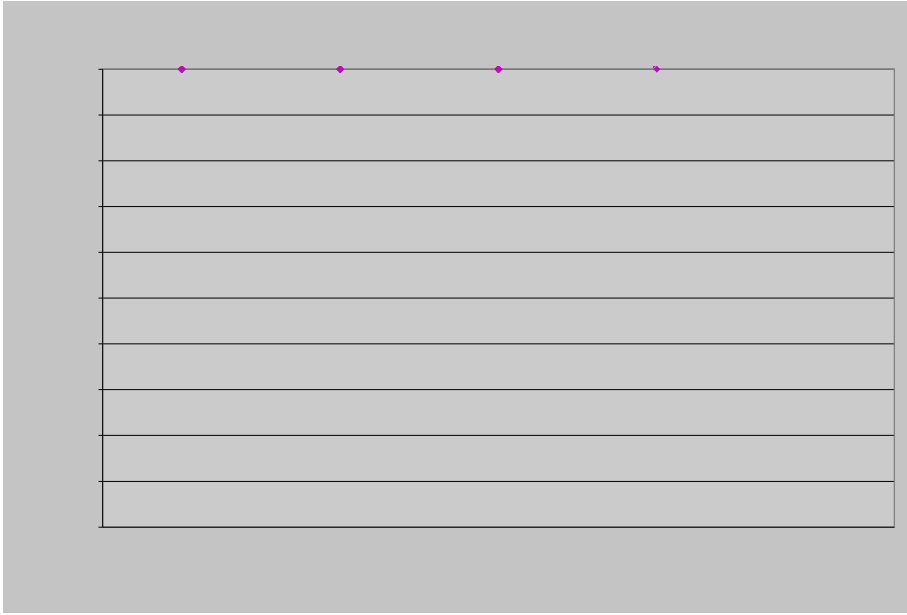
Figure 16c: Varying the Number of Parents in Bayesian Networks (Collaborative-Only)





Enhanced Content Data





Conclusions and Future Work

12&#D)'D%*	#(23*(2&*3*#K<*&#%#<, <.'=&#E<F23, &#.&<' , 3, /#(&F2, 3G)&*#<, 5#<DD.'"# (2&E#(#&'&F%E E&, 5&'#*''*(E*#3, #%'5&'#%#E<L&#&'&F%E E&, 5<(3%, *#9%'#E%63& D<('%, *;#+'#<DD.'"3, /#5399&'&, (#('<(&/3&*#(%#!(2#(2<<*&#(<, 5#(2ᔗ&'&, (<./%'3(2E*#(2%D&#K<*&# (%#93, 5#<, #D(3E3=&5#K<'#%9#D' &53F(3, /#K2&(2&'#)*&'*#K%).5#.3L&#F&' (<3, #E%63&*#!<*&5#%, #F%, (&, (#3, 9%'E<(3%, #<!)#(2&#E%63&#<, 5#F%..<!'<(36, 9%'E<(3%, #9%'E%#(2&'# E%63&/%&'*0#<(3, /:*#V'%'E#(2&#K%'L5%, (#F<, #!&#F%, F.)5&5#(2<(F&'<(3, #E<F23, &#&<' , 3, /#<./%'3(2E*#F<, #3, 5&&5#D&'9%'E#K&.#3, #E<L3, /#E%63&#&'&F%E E&, 5<(3%, *;

M, #(&'E*#%9#(%DNZ#D'&F3*3%, #, &)'<.#, &(K%'L*#<, 5#D'3, F3D<.#F%ED%, &, (*#D&'9%'E# &J('E&.'#K&.#9%'#<.#%K#6<.)&#%9#Z#1,)E!&'%9#E%63&*#&'&F%E E&, 5&5!;##123*#3*6&'# 3ED%'<, (#9%'E%63&#&'&F%E E&, 5<(3%, *#<#E%*(#)*&'*#K%).5#%, .'#K<, (#%#*#'(2'%) /2#?B# %'#9&K&'E%63&*#3, #%'5&'#(%#D3FL#%, &##12	<F#(2<(D#DNZ#D'&F3*3%, #'&E<3, *#23/2#)D#(%# Zj @BB#3*#<.*%#<#/%%5#*%)'F&#%9#%#(2&'*#%'(#%9#&'&F%E E&, 5<(3%, *#&#)F2#<#&'&F%E E&, 5<(3%, *# 9%'#D&D.#&K2#%!)!%'#&'&, (# T` *#%#&'#K<(F2#E%63&*#%, #(&.&63*3%, ;##12*#&#D&#D.#E3/2(# , &&5#<#13//&'#3*(#<*(2&'#K<, (#<#3*(#%9#E%63&*#(%#K<(F2#<(2&'#(2<, #0)*(#<#&.&F#9&K;

+<'&*3<, #, &(K%'L*#<(L&#E)F2#.&*#'(<3, 3, /#(3E&#(2<, #, &)'<.#, &(K%'L*#K23.&# 2<63, /#(2&#<E&#(%DN?B#D'&F3*3%, #*#%#3(#F%).5#!&#E%'&#)*9).#9%'#&N'<3, 3, /#K2&, #)*&'*# <55#(2&3*#3L&*#<, 5#53*#3L&*#3, (%#<#*''*(E;##4.*#A#3, #(&'E*#%9#<FF)'<F''#+'&*3<, #, &(K%'L*# 53*D.<'<#*3/ , 393F<, (#3ED'%'6&E&, (#%6&'&, &)'<.#, &(K%'L*#K3(2#!%(2#(2&#&'<, 5<'5#6&'*3%, # <, 5#E%5393&5#6&'*3%, #%9#&'%'#D'%'D</<(3%, #<#*#K&.#<#5&F3*3%, #('&#*#Z<16&#+'&'&#*#?#&#<, 5# B\$F.<*#393&'*#;#+'&'&*3<, #, &(K%'L*#D&'9%'E#K&.#K3(2#!%(2#D'3, F3D<.#F%ED%, &, (*#<, 5#(2&# +&'(V3'*(#<('3!)&#*#&.&F(3%, #*#%E&(23, /#(2<(#, %, &#%9#(2&#%#(2&'#<./%'3(2E*#(&'&5#5%, ##M#3*# F.*#&#K3(2#?#, #D'3, F3D<.#F%ED%, &, (*#!)(#(23*#F%).5#!)&#(%#(2&#*3=&#%9#(2<<*&#(##4# 5<<*&#(K3(2#E%6&#E%63&*#9%'#&<F2#''&'&#F%).5#D%*#3!.'#%K&'#?#0*#D&'9%'E<, F&#

+&'(V3'*(#<DD&<'*#(%#!&#<, #&99&F(36&#(&F2, 3G)	%'#<('3!)&#*#&.&F(3%, ;##M('5)F&*# (2&#,)E!&'%9#&#<('3!)&#*#F%, *35&'<!'#A#/36&*#?BB#r#(%DN?B#D'&F3*3%, #<, 5#3, F'&<'&'&#(2&# E<J3E)E#<FF)'<F''#9%'E#(2&#B\$#!<*&3, &##+&'(V3'*(#3*#<.*%#9<*&'#(2<, #D'3, F3D<.# F%ED%, &, (*#3, #<(3(#*#&.&F(*#9&<)'&'&'<(2&'#(2<, #<DD.'"3, /#K&3/2(*#(%#<.#%9#(2&E#*#3(#3*# !&((#3, #(&'E*#%9#<FF)'<F''#D'&F3*3%, #<, 5#(3E&#A#!)(#, %(#3, #%6&'<.#(%DNZ#D'&F3*3%, ;

12&'%&*#%, #(<DD&<'#(%#!&#<#13/F2<, /#&3, (%DN?B#D'&F3*3%, #<FF)'<F''#%'# D'&F3*3%, #K2&, #F%ED<'3, /#, &)'<.#, &(K%'L*#K3(2#(2&#&'<, 5<'5#6&'*3%, #%9#&'%'# # !<FLD'%'D</<(3%, #<, 5#(2&#E%5393&5#6&'*3%, ;##>'&#(&'&3, /#K%).5#, &&5#%#%, &#%6&'# .%, /&'#<E%), (*#%9#(3E&#(%#*#'#%, *#*3/ , 393F<, (. '#!&((&'#(2<, #<2&#%#(2&'#;

>%&#(&'&3, /#F%).5#!%, &#%, #<2&#D<'<E&#&'&#(3, /#%9#&, &)'<.#, &(K%'L*#3, #%'5&'# (%#5&(&'E3, &#K2<#D<'<E&#&'<.)&'*#%D(3E3=&#<FF)'<F''A D'&F3*3%, #<, 5#(%DN?B#D'&F3*3%, ;##M#<DD&<'*#(2<#<50)*3, /#(2&#&'<3, 3, /#(3E&#A#&'<3, /#<(&#<, 5#%(2&'#6<'3<!.&'*5%&*#%, %# 3/ , 393F<, (. '#F2<, /#&(2&#<FF)'<F''#<, 5#(2&#D'&F3*3%, #%9#(2&#&'&F%E E&, 5<(3%, *;

12&#&'&#).(*#%9#(2&#%#D(3E<#<./%'3(2E*#&#JF&&5#(2&#!&, F2E<'L*#*#&'#B\$ 3/ , 393F<, (. '##12&#!&'&#D&'9%'E3, /#<./%'3(2E*#2<6&#?BB#r#(%DN?B#D'&F3*3%, #K23F2#3*#<# 6&'#3ED%'<, (#<(3*(3F;#12&'&', F'&<'&5#(2&#<FF)'<F''#<, 5#D'&F3*3%, #9%'E#C@r#(%#o^r <, 5#C@r#(%#oBr#&'&D&F(36&#.';

M#<DD&<'*#(2<#)*3, /#F%, (&, (N%, .''#F%..<!'<(36&N%, .''#%#<#F%E!3, &5#5<(<*%&*# , %#(F2<, /#&(2&#(%DN?B#D'&F3*3%, #<#<#<.#(2'<(<*&'*3%, *#/<6&#?BB#r#(%DN?B#D'&F3*3%, ;## ?BB#r#(%DN?B#D'&F3*3%, #3, #F%, (&, (N%, .''#5<(<#3*#&'D&F3<..''#/%%5#9%'#<#&, &K#E%63	%'#K23F2# , %#F%..<!'<(36<(<#3*#<6<3.<!.&#;##-..<!'<(36<(<#%, .''#D'%'6&5#E%'&#)*9).#3, #

3, F' < *3, /#%6&' <..#<FF)' <F'' :# O%K&6&'A#3(#K%) .5#! , (&' &* (3, /#(%#* &&#K2<(#K%) .5#2<DD&, #39#&6&, #E%' &#F%, (&, (#5<(<#K<*#<55&5A#*) F2#<*#<F(%' *A#<*#%E&#E%63&/%&' *2<6	<6%'3(&#<F(%' *#<, 5#<' &#E%' L&.' '#(%#* &]. E *#! ''#(2%* &#<F(%' *#< ;

V3, <..''A#+<' &*3<, #<, 5#, &)' <.#, &(K%'L#(&F2, 3G) &* *2%) .5#! &#(&*(&5#%, #%(2&' #5<(<* &*(#(2<(#F%, (<3, #E%' <(<#12<(<* &*(#F2%* &, #K<*#<(2&' *#E<..#5) &#(%#(2&#(3E &#F%ED.&J3(3&*#%9#<#.<' /&' #5<(<* &*(;##M(#*2%) .5#! &(&' E3, &5#K2&(2&' #2&#F%, F.) *3%, #(<L&, #9%'E#(23*#&*(#%9#&JD&'3E&, (*#<DD.3&*#(%#.<' /&' #5<(<* &*(;##4553(3%, <.#(<' /&(#) * &' *#*2%) .5#! &F%, *35&' &5 <*#K&..;

References

4.6<' &#=#: ; 4:A#)\$)3=#- ;A#_<K<(%A#1 ;A#S#_ %/&.A#h ;#H@BBCI ;#Z&)' <. #bJD&' #Z&(K%'L *#9%' #V<* (&' # - %E!3, &5# - %..<! %' <(36&#<, 5# - %, (&, (N+<* &5#\$&F%EE&, 5<(3%, ;#M, #*Journal of Computational Methods in Sciences and Engineering*,#(%#<DD&<' ;

+<.<! <, %63FA#> ;A#S# : 2%2<EA#W ;#H?RRUI ;# - %E!3, 3, /#F%, (&, (N+<* &5#<, 5#F%..<! %' <(36&#&' &F%EE&, 5<(3%, ;#M, #*Communications of the ACMA#^BH^IA#DD ;#CCNU@* ;

+3..*) *#A#` ;A#S#8<==<, 3A#> ;] ;#H?RRoI ;#X&<' , 3, /#F%..<! %' <(36, 9%'E<(3%, #93. (&' * ;#M, #*Proceedings of the Fifteenth International Conference on Machine Learning*#DD ;#\CN[\ ;

+3*2%DA#- ;#> ;#H?RRCI ;#*Neural networks for pattern recognition* ;#PJ9%'5A#b, /.<, 57#PJ9%'5#Y, 36&' *3(' #8' *#* ;

+ '&* &#A#] ;# : ;#O&FL&'E<, A#` ;A#S#_<53&A#- ;#H?RRoI ;#bED3'3F<.#<, <..''*3*#%9#D' &53F(36&#<./% '3(2E *#9%' #F%..<! %' <(36]. (&' 3, / ;#M, #*Proceedings of the Fourteenth Conference on Uncertainty in Artificial Intelligence*#DD ;#\^g[@ ;

- %D&'A#C ;A#S#O&' *L%63(*A#b ;#H?RR@I ;#4# +<' &*3<, #E&(2%5#9%' #2, 5) F(3%, #%9#D%' !< 3.3*(3F# , &(K%'L *#9%'E#5<(< ;#M, #*Machine Learning*#RA#DD ;#^BRN^ \ ;

O<'D&'A#V ;#X3A#f ;#A#- 2&, AW ;#S#_%, *(<, A#] ;#H@BB[I ;#4, #bF%, %E3F#>%5&.#%9#Y* &'#\$<(3, /#3, #<, #P, 3, &#\$&F%EE&, 5&'# : ''*(&E ;#M, #*Proceedings of the 10th International Conference on User Modeling* ;

] %<F23E *#1 ;#H?RRCI ;#*A probabilistic analysis of the Rocchio algorithm with TFIDF for text Categorization*#H1 - %ED) (&' # : F3&, F#1 &F2, 3F<.#\$&D%' (# - > YN - : NRCN??oI ;# - <' , &/3&#> &..% , #Y, 36&' *3(' ;

>3, *L''A#> ;A#S#8<D&' (A# : ;#H?RCRI ;#*Perceptrons* ;# - <E! '35/&A#> 47#> M#b#8' &*#* ;

>3(F2&..#1 ;#> ;#*Machine Learning* ;#H?RRUI ; +%*(%, A#> 47#12&#> Fc' <KNO3. # - %ED<, 3&*#M, F ;

a)3, <., A#] ;#\$;#H?RoCI ;#M, 5) F(3%, #%9#5&F3*3%, #(' &#* ;#M, #*Machine Learning*#H?IA#DD ;#o?N?BC ;

a)3, .<, #]#\$;#I?RR^I;#C4.5: *Programs for Machine Learning*;#: <, #><(&%A#- 47#>%'/<, #
_<)9E<, ,;

Appendix

Top-N Precision w/ NN1 Code

3ED%'(#0<6<;3%;+)99&'&5\$&<5&'u

3ED%'(#0<6<;3%;+)99&'&5h'3(&'u

3ED%'(#0<6<;3%;V3.&\$&<5&'u

3ED%'(#0<6<;3%;V3.&h'3(&'u

3ED%'(#K&L<;F%'&M, *(<, F&u

3ED%'(#K&L<;F%'&M, *(<, F&*u

3ED%'(#K&L<;F.<***393&'*;9), F(3%, *, >).(3.<'&'8&'F&D('% , u

3ED%'(#K&L<;F.<***393&'*;b6<.)<(3%, u

D)! .3F#F.<***#1%DZ8'&F3*3%, #v

D)! .3F#*(<(3F#6%35#E<3, H: ('3, /wx#<'/*lv

('"v

M, *(<, F&*#5<(<#j #, &K#M, *(<, F&*H

, &K#+)99&'&5\$&<5&'H

#, &K#V3.&\$&<5&'HyF%E! +V;<'99yIIIu

kk*&((3, /#F.<***#<('3!)(&

5<(<*&(-.<***M, 5&JH5<(<;,) E 4(('3!)(&*HI#W#?lu

kk#.%<5#), .<! &.&5#5<(<

>).(3.<'&'8&'F&D('% , #E.D#j #, &K#>).(3.<'&'8&'F&D('% , HIu

E.D;*&(O355&, X<'&'Hy^ylu #kk#*&(#(2ळ&, #, %5&*

E.D;*&(X&<' , 3, /\$<(&HB;@lu #kk#*&(#(2&#.&<' , 3, /#<(&

E.D;*&(1'<3, 3, /13E&H[BBlu #kk#*&(#(2&#('<3, 3, /#(3E&

E.D;!)3.5-.<***393&'H5<(<lu##kk#!)3.5#F.<***393&'

M, *(<, F&*#), .<! &.&5#j #, &K#M, *(<, F&*H

, &K#+)99&'&5\$&<5&'H

#, &K#

V3.&\$&<5&'HyF%E! +V;<'99yIIIu

kk#*&(#F.<***#<('3!)(&

), .<! &.&5;*&(-.<***M, 5&JH), .<! &.&5;,) E 4(('3!)(&*HI#W#?lu

kk#F'&<(&F%D"

M, *(<, F&*#.<! &.&5#j #, &K#M, *(<, F&*H), .<! &.&5lu

kk#.<! &.#3, *(<, F&*#

M, *(<, F&wx#3, *(<, F&*#j #, &K#M, *(<, F&w?Bxu

5%)! .&wx#6<.)&*#j #, &K#5%)! .&w?Bxu

9% 'H3, (#3#j #Bu#3#z#?Bu#3eelv

3, *(<, F&*w3x#j #,)..u

6<.)&*w3x#j #Bu

{

kk'<, L#3, *(<, F&*#W#%, .''#L&&D#(%D#Z

9% #H3, (#3#j #Bu#3#z#), .<! &.&5;,) EM, *(<, F&*HIu#3eelv

##5%)! .&wx#F.*X<! &.#j #E.D;53*('3!)(3%, V%M, *(<, F&H), .<! &.&5;3, *(<, F&H3lu

```
##39H6<.)&*wBx#zj #F.*X<! &.w?x1#v#kk.3L&#D'#! <! 3.3('
#          9%'H3, (#0#j #?u#0#z#?Bu#0eelv
          39H6<.)&*w0x#zj #F.*X<! &.w?x#SS#0#j #Rlv
          6<.)&*w0N?x#j #6<.)&*w0xu
          3, *(<, F&*w0N?x#j #3, *(<, F&*w0xu
          {
          &.*#39#10#j j #Rlv
          6<.)&*w0N?x#j #6<.)&*w0xu
          3, *(<, F&*w0N?x#j #3, *(<, F&*w0xu
          6<.)&*w0x#j #F.*X<! &.w?xu
          3, *(<, F&*w0x#j #, .<! &.&5;3, *(<, F&H3lu
          {
          &.*&v
          6<.)&*w0N?x#j #F.*X<! &.w?xu
          3, *(<, F&*w0N?x#j #, .<! &.&5;3, *(<, F&H3lu
          !' &<Lu
          {
          {
##{
{
```

```
.<! &.&5;5&.&(&Hlu
9%'H3, (#3#j #Bu#3#z#?Bu#3eel
          39H3, *(<, F&*w3x#j #, )..l
          .<! &.&5;<55H3, *(<, F&*w3xlu
```

```
kk&6<.)<(&#(2&#3, *(<, F&*
b6<.)<(3%, #&6<.#j #, &K#b6<.)<(3%, H.<! &.&5lu
&6<.;F'***T<.35<(&>%5&.H
#####E.DA#.<! &.&5A#?BA#.<! &.&5;/&($<, 5%EZ)E! &'c&, &'<(%'H?llu
: ""(&E;%)(:D'3, (., H&6<.;(%: )EE<'": ('3, /H(')&llu
```

```
kkK'3(&#3, *(<, F&*#H(%#5%)! .#F2&FL#, %#5%)! .&*l
+)99&'&5h'3(&'#K'3(&'#j #, &K#+)99&'&5h'3(&'H
#####, &K#V3.&h'3(&'Hy, , ?;<'99yllu
K'3(&'K'3(&H.<! &.&5;(%: ('3, /Hllu
K'3(&' ;, &KX3, &Hlu
K'3(&'9.)*2Hlu
K'3(&'F.%*&Hlu
```

```
{F<(F2HbJF&D(3%, #&lv
&:D'3, (: (<FL1'<F&Hlu
{
```

```
{
{
```

Top-N Precision w/ NN2 Code

3ED%('#0<6<;3%;+)99&'&5\$&<5&'u

3ED%('#0<6<;3%;+)99&'&5h'3(&'u

3ED%('#0<6<;3%;V3.&\$&<5&'u

3ED%('#0<6<;3%;V3.&h'3(&'u

3ED%('#K&L<;F%'&;M,*(<,F&u

3ED%('#K&L<;F%'&;M,*(<,F&*u

3ED%('#K&L<;F.<***393&'*;9),F(3%,*;>).(3.<'&'8&'F&D('% ,Z&Ku

3ED%('#K&L<;F.<***393&'*;b6<.)<(3%,u

D)! .3F#F.<***1%DZ8'&F3*3%,@#v

D)! .3F#*(<(3F#6%35#E<3,H:('3,/wx#<'/*lv

('v

M,*(<,F&*#5<(<#j #,&K#M,*(<,F&*H

,&K#+)99&'&5\$&<5&'H

#,&K#V3.&\$&<5&'HyF%E!+V;<'99y11lu

kk*&((3,/F#<***#<('3!)&

5<(<*&(-.<***M,5&JH5<(<:,)E4('3!)&*H1#W#?lu

kk#.%<5#),.<!&.&5#5<(<

>).(3.<'&'8&'F&D('% ,Z&K#E.D#j #,&K#>).(3.<'&'8&'F&D('% ,Z&KHlu

E.D;*&(O355&,X<'&'*Hy^ylu #kk#&#(2ळ&,#,%5&*

E.D;*&(X&<' ,3,/ \$<(&HB;@lu #kk#&#(2&#&<' ,3,/ #<(&

E.D;*&(1'<3,3,/13E&H[BBlu #kk#&#(2&#('<3,3,/ #3E&

E.D;!)3.5-.<***393&'H5<(<lu##kk#!)3.5#F.<***393&'

M,*(<,F&*#),.<!&.&5#j #,&K#M,*(<,F&*H

,&K#+)99&'&5\$&<5&'H

#,&K#

V3.&\$&<5&'HyF%E!+V;<'99y11lu

kk#&#(F#<***#<('3!)&

,.<!&.&5;*&(-.<***M,5&JH),.<!&.&5;,)E4('3!)&*H1#W#?lu

kk#F'&<(&#F%D''

M,*(<,F&*#<!&.&5#j #,&K#M,*(<,F&*H),.<!&.&5lu

kk#<!&.#3,*(<,F&*#

M,*(<,F&wx#3,*(<,F&*#j #,&K#M,*(<,F&w?Bxu

5%)!.&wx#6<.)&*#j #,&K#5%)!.&w?Bxu

9%#H3,(#3#j #Bu#3#z#?Bu#3eelv

3,*(<,F&*w3x#j #,)...u

6<.)&*w3x#j #Bu

{

kk'<,L#3,*(<,F&*#N#%,.'#L&&D#(%D#Z

9%#H3,(#3#j #Bu#3#z#),.<!&.&5;,)EM,*(<,F&*Hlu#3eelv#

##5%)!.&wx#F.*X<!&.#j #E.D;53*('3!)(3%,V%'M,*(<,F&H),.<!&.&5;3,*(<,F&H31lu

##39H6<.)&*wBx#zj #F.*X<!&.w?x1#v#kk.3L&#D'#!<13.3('

9%#H3,(#0#j #?u#0#z#?Bu#0eelv

39H6<.)&*w0x#zj #F.*X<!&.w?x#SS#0#j #Rlv

6<.)&*w0N?x#j #6<.)&*w0xu
3, *(<, F&*w0N?x#j #3, *(<, F&*w0xu

{
&.*#39#H0#j j #Rlv
6<.)&*w0N?x#j #6<.)&*w0xu
3, *(<, F&*w0N?x#j #3, *(<, F&*w0xu
6<.)&*w0x#j #F.*X<! &.w?xu
3, *(<, F&*w0x#j #), .<! &.&5;3, *(<, F&H3lu
{
&.*&v
6<.)&*w0N?x#j #F.*X<! &.w?xu
3, *(<, F&*w0N?x#j #), .<! &.&5;3, *(<, F&H3lu
!'&<Lu

{
##{
{

.<! &.&5;5&.&(&Hlu
9%'H3, (#3#j #Bu#3#z#?Bu#3eel
.<! &.&5;<55H3, *(<, F&*w3xlu

kk&6<.)<(&#(2, *(<, F&*
b6<.)<(3%, #&6<.#j #, &K#b6<.)<(3%, H.<! &.&5lu
&6<.;F'***T<.35<(&>%5&.H
#####E.D#.<! &.&5A#?B#.#.<! &.&5;/&(\$<, 5%EZ)E!'&c&, &'<(%'H?lllu
: ""(&E.%)(:D'3, (.H&6<.:(%:)EE<'": ('3, /H(')&lllu

kkK'3(, *(<, F&*#H(%#5%)! .&#F2&FL#, %#5%)! .&*l
)99&'&5h'3(&'#K'3(&'#j #, &K#+)99&'&5h'3(&'H
&K#V3.&h'3(&'Hy, , @,<'99ylllu
K'3(&' ;K'3(&H.<! &.&5;(%: ('3, /Hlllu
K'3(&' ;, &KX3, &Hlu
K'3(&' ;9.)*2Hlu
K'3(&' ;F.%*&Hlu

{F<(F2HbJF&D(3%, #&lv
&:D'3, (: (<FL1'<F&Hlu

{

{

{

Top-N Precision w/ BN Code

3ED%'(#0<6<;3%;+)99&'&5\$&<5&'u
3ED%'(#0<6<;3%;+)99&'&5h'3(&'u
3ED%'(#0<6<;3%;V3.&\$&<5&'u
3ED%'(#0<6<;3%;V3.&h'3(&'u

3ED%'(#K&L<;F%'&;M, *(<, F&u
3ED%'(#K&L<;F%'&;M, *(<, F&*u
3ED%'(#K&L<;F.<***393&'*;! <"&*;+<"&*Z&(u
3ED%'(#K&L<;F.<***393&'*;! <"&*; , &('*<'F2;/.%! <. ;mu
3ED%'(#K&L<;F.<***393&'*;b6<.)<(3%, u

D)! .3F#F.<***#1%DZ8'&F3*3%, ^#v

D)! .3F#*(<(3F#6%35#E<3, H: ('3, /wx#<'/*lv

('"v

M, *(<, F&*#5<(<#j #, &K#M, *(<, F&*H
, &K#+)99&'&5\$&<5&'H
#, &K#V3.&\$&<5&'HyF%E! +V;<'99y11lu

kk*&((3, /#F.<***#<('3!)(&
5<(< ;*&(- .<***M, 5&JH5<(< ; ,) E 4 (('3!)(&*H1#N#?lu

kk#.%<5#) , .<! &.&5#5<(<

+<"&*Z&(#E.D#j #, &K#+<"&*Z&(Hlu
@#L@#j #, &K#@Hlu
L@:*&(> <JZ'P98<'&, (*H?lu kk#&(#E<J#}#9#D<'&, (*
E.D;*&(: &<'F24./%'3(2EHL@lu#kk#&(#*<'F2#<./%'3(2E

E.D;!)3.5- .<***393&'H5<(<lu##kk#!)3.5#F.<***393&'

M, *(<, F&*#) , .<! &.&5#j #, &K#M, *(<, F&*H
, &K#+)99&'&5\$&<5&'H
#, &K#

V3.&\$&<5&'HyF%E! +V;<'99y11lu

kk#*&(#F.<***#<('3!)(&
) , .<! &.&5;*&(- .<***M, 5&JH) , .<! &.&5; ,) E 4 (('3!)(&*H1#N#?lu
kk#F'&<(&F%D"

M, *(<, F&*#<! &.&5#j #, &K#M, *(<, F&*H) , .<! &.&5lu

kk#<! &.#3, *(<, F&*
M, *(<, F&wx#3, *(<, F&*#j #, &K#M, *(<, F&w?Bxu
5%)! .&wx#6<.)&*#j #, &K#5%)! .&w?Bxu

9%'H3, (#3#j #Bu#3#z#?Bu#3eelv
3, *(<, F&*w3x#j #,)..u
6<.)&*w3x#j #Bu

{

kk'<, L#3, *(<, F&*#N#%, .'"#L&&D#(%D#Z
9%'#H3, (#3#j #Bu#3#z#) , .<! &.&5; ,) EM, *(<, F&*Hlu#3eel#v
##5%)! ..*X<! &.#j #E.D;53*('3!)(3%, V%'M, *(<, F&H) , .<! &.&5;3, *(<, F&H31lu

```
##39H6<.)&*wBx#zj #F.*X<! &.w?x1#v#kk.3L&#D'#! <! 3.3('
#          9%'H3, (#0#j #?u#0#z#?Bu#0eelv
          39H6<.)&*w0x#zj #F.*X<! &.w?x#SS#0#j #Rlv
          6<.)&*w0N?x#j #6<.)&*w0xu
          3, *( <, F&*w0N?x#j #3, *( <, F&*w0xu
          {
          &.*#39#H0#j j #Rlv
          6<.)&*w0N?x#j #6<.)&*w0xu
          3, *( <, F&*w0N?x#j #3, *( <, F&*w0xu
          6<.)&*w0x#j #F.*X<! &.w?xu
          3, *( <, F&*w0x#j #), .<! &.&5;3, *( <, F&H3lu
          {
          &.*&v
          6<.)&*w0N?x#j #F.*X<! &.w?xu
          3, *( <, F&*w0N?x#j #), .<! &.&5;3, *( <, F&H3lu
          !' &<Lu
          {
          {
```

```
##{
{
```

```
.<! &.&5;5&.&(&Hlu
9%'H3, (#3#j #Bu#3#z#?Bu#3eel
.<! &.&5;<55H3, *( <, F&*w3xlu
```

```
kk&6<.)<(&#(2&#3, *( <, F&*
b6<.)<(3%, #&6<.#j #, &K#b6<.)<(3%, H.<! &.&5lu
&6<.;F'***T<.35<(&>%5&.H
#####E.DA#.<! &.&5A#?BA#.<! &.&5;/&($<, 5%EZ)E!&'c&, &'<(%'H?llu
: ""*(&E.%)(:D'3, (., H&6<.;(%: )EE<'": ('3, /H(')&llu
```

```
kkK'3(&#3, *( <, F&*#H(%#5%)! .#F2&FL#, %#5%)! .&*l
+)99&'&5h'3(&'#K'3(&'#j #, &K#+)99&'&5h'3(&'H
#####, &K#V3.&h'3(&'Hy! , ;<'99yl lu
K'3(&' ;K'3(&H.<! &.&5;(%: ('3, /Hllu
K'3(&' ;, &KX3, &Hlu
K'3(&' ;9.)*2Hlu
K'3(&' ;F.%*&Hlu
```

```
{F<(F2HbJF&D(3%, #&lv
&:D'3, (: (<FL1'<F&Hlu
```

```
{
```

```
{
```

```
{
```