Bayesian and Neural Networks for Motion Picture Recommendation

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><"#?@A#@BBC

Abstract

123*#(2&*3*#<DD.3&*#E<F23,&#.&<',3,/#(&F2,3G)&*#(%#<#5<(<*&(#%9#E%63&*#5&*F'3!&5#
!"#F%..<!%'<(36&#H*%F3<.I#<,5#F%,(&,(#<((('3!)(&*#3,#%'5&'#(%#F'&<(&#<#E3J&5#'&F%EE&,5&'#
"'(&E#9%'#E%63&*;#+<"&*3<,#,&(K%'L*#A#(K%#6&'*3%,*#*#%9#,&)'<.#,&(K%'L*#A#M5&F3*3%,#('&&*#A#
<,5#*3ED.&#')&.#&#F.<**393&'*#<'&#F%ED<'&5;#M#3*#5&(&'E3,<(3%,#&5#(2<(#+<"&*3<,#,&(K%'L*#
,&(K%'L*#*#)(D&'9%'E#(2&#%(2&'#E<3,,/#(&F2,3G)&*#;##+%(2#(&F2,3G)&*#&*#F23&6&5#&<'L<!.<!."#
23/2#(%DN?B#D'&F3*3%,,#A#<,#3ED%'(<,(#(&E&'(3F&#9#'&F%EE&,5&,5<(3%,#A#G)<.3("#;#4,#<((&ED#(%#%#
F%,('<*(#(#'&F%EE&,5<(3%,#A#G)<.3("#%9%#'9%%,<,,#%,..&#"#<,5#F%ED<'&*#<*%9##5#5#'&F%EE&,5<(3%,#
F%ED<'&*#<*5#K3(2#<#F%ED<'&*%9#5&*F'3!&5#!"#!%(2#F%,<,(<,(<*&F(#9%'3!.&*#<#&*(%%5##*&.<(<!.
.3(F%,*(3F)(36#&%'/..)'&&3(%,3%,%9#F%,('<*(#(#'%<,3,%,..&"#<,5#F%ED<'&*#<*(<(#&F<*(*<(*(#"#<,&#
'&<*%%%,#9%'#%%(23#23(*;

Introduction

Definition: *A **recommender system** is a system that takes data about a user's past history in a certain industry, such as products they have purchased, movies they have seen, or websites they have visited, and predicts what the user may prefer to purchase or see in the future.*

: %E&#'&F%EE&, 5&'#*"*(&E*#<'&#*collaborative*#*"*(&E*#3, #K23F2#%(2&'#)*&'*0#D<*(# 23*(%'3&*#<'&#)*&5#3, #('"3, /#(%#.3, L#(2&#D<'(3F).<'#)*&'#(%#<#/'%)D#%9#)*&'*#K3(2#*3E3.<'# 3, (&'&*(*#%'#D)'F2<*&*;##123*#/'%)D#K3..#(2&, #3, 9.)&, F&#K2<(#(2&#'&F%EE&, 5&'#*"*(&E#K3..# %)(D)(#!<*&5#%, #K2<(#(2&#/'%)D#.3L&*#%'#53*.3L&*;##P(2&'#*"*(&E*#<'&'&#content-based *"*(&E*#3, #K23F2#5&(<3.*#%9#(2&#D'%5)F(#E%63&#K&! *3(&#%'#%(2&'#3(&E#<'&#F%ED<'&5# </<3, *(#(2%*&#%9#*3E3.<'#3(&E*#(2<(#(2&#)*&'#2<*#!&&, #3, #F%, (<F(#K3(2;##12&*&#*3E3.<'#3# <'&#2&.D&5#(%#/&#K2&(2&'#(23*#)*&'#K3..#.3L&#%'#53*.3L&#(2&#3(&;##: %E&#'&F%EE&, 5&'# *"*(&E*#)*&#<#E3J()'&#%9#F%..<!%'<(36&#<, 5#F%, (&, (N! <*&5#<DD'%<F2&*;

$&F%EE&, 5&'#*"*(&E*#2<6&#!&F%E&#<#D%D).<'#*) !Q&F(#*(<'(3, /#3, #(2&#.<(&#?RRB0* H$&*, 3FL#S#T<'3<, M?RRUI;##><, "#%, .3, &#'&(<3.&'*#M*)F2#<*#4E<=%, ;F%EM)*&# '&F%EE&, 5&'#*"*(&E*#3, #%'5&'#(%#'&F%EE&, 5#, &K#D'%5)F(*#(%%E&'*#3, #%'5&'#(%#(''#(% (%#E<J3E3=&#D'%93(*;##V%'#&J<ED.&M#*)DD%*&#<#F)*(%E&'#'#!)''*#<#*F3&, F&N93F(3%, #! %%L;##12&#, &J(#(3E&#(2&#F)*(%E&'#'63*3(*#(2&#*3(&M#3(&E3/2(#'&F%EE&, 5#! %%L#*#! "#(2&#*<E&#<)(2%'M%'#! E<"#*)//&*(#(2<(#(2&"F3&*, F&N93F(3%, #! %%L#*(2<#(%#(2&'#F)*(%E&'*#!%)/2(#3, #<553(3%, #(%#(2&# (2&#F%, &#(2&#F)*(%E&'#)*(%F&'#3(&'#(2&'#'F2<*&5(2&.<*(#(2&3E&#3#2&#63*3(&5;#+"#2<63, /#(23*#("D&#%9# *"*(&E#3, #D.<F&M#'&#(<3.&'*#K<, !&#(%#E%'&#%&&<*3."#93, 5#D'%5)F(*F(*#2<63, /#(23&'#&)(% (2&"#E<"#! &3, (, (&'&*(&5#3, 3, (&'&*(&5;##: %E&#'&F%EE&, 5&'#

12&'&#K&'&#<#&#*%E&#'&F%EE&, 5&'#*"*(&E*#K23F2#<..%K#)*&'*#(%#'&#(%#(%#*3(&M3%, #(%##3*3(M&'*3(&M/3(&#("D&*3(%%%9%#'&, 5*3(%%9%#'&5%93, /#("D&*#< '&F%EE&, 5&'#*"*(&E*#K23F2#M*)F2#<*#W<2%%;F%E0*#X4YZ−OF<*(#$<53%M#<..%K#<#)*&'#(%#93, 5#("D&%#/&#<#) 3, *(<, (#)D5<(&*#3, #'&F%EE&, 5<(3%, #*#5)&#(%#(2&#)*&'#3, F%'(3%, #*%93<#(#<, &#'3%'<(#%9#'3(&*#%&#'#*#(#4*#'*)F2M)*&'#3(&'#<&#<!3#&#(2&#3, F%*#E%'&#'&E%'&*3(M%'#)*(&'#'&&*(3#5*3(&#(%#E%'&#("D#<'#7#)#;## D&'*%, <.3=&5#*<53#*(*<3%%9*(<3%(3%, ;

><, "#K&!*3(&*#<.*%#)*&'#&F%EE&, 5&'#*"*(&E*#(%#(%%#D&'*%, <.3=&#(2&3'3#3, (&'9<F&#K3(2(2&#)*&'*#3, #%'5&'#(%#(%#(%#63'3*(#*#%9#(2&(2&(3%;##V%'#&5.&#&%)*&'#'*(2&#("D&#%9#%%#(2&# &, (&'*#(2&3'#=3D#F%5&M#(2&3'*#(&E<"#<#<#(&#%93, 5#%'#&#K5%'(*#(&#*D%#'(*#<#)*&'M#5)*#D%*'(*%(#%9#(2&#%9#)&*<, 5#&E<"#5)3#,#!&6#%&!3#&#3'<*#53#'#%+&'#(&'#'#'<*(&#+"#63'3*'&%#'F#%'#&#*3<.#<"E**M#)*3%(#<'(6#%'#&#*'%#'<5'#)&*#<'"'#*)<D)5#%9#<, #3, 53+#%##'F#%+#)*&'#'#*#63'#*(<#)*&'#<#(%#E%'&#("#D&*#<'#3#*#63'#(&5#*%##<#"%9#)*&*#3##53<.#<"#)*3%%)%##9&##<.*%#)*&'#3#

> "#3, (&, (3%, #3*#(%%93, 5, 5#<!((&'#<#./%'3(2E#K23F2#F%E! 3, &*#*#F%, (&, (N!<*&5#

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 1⸭Sample Dataset

Student	Graduation Year	Major	GPA

Decision Trees
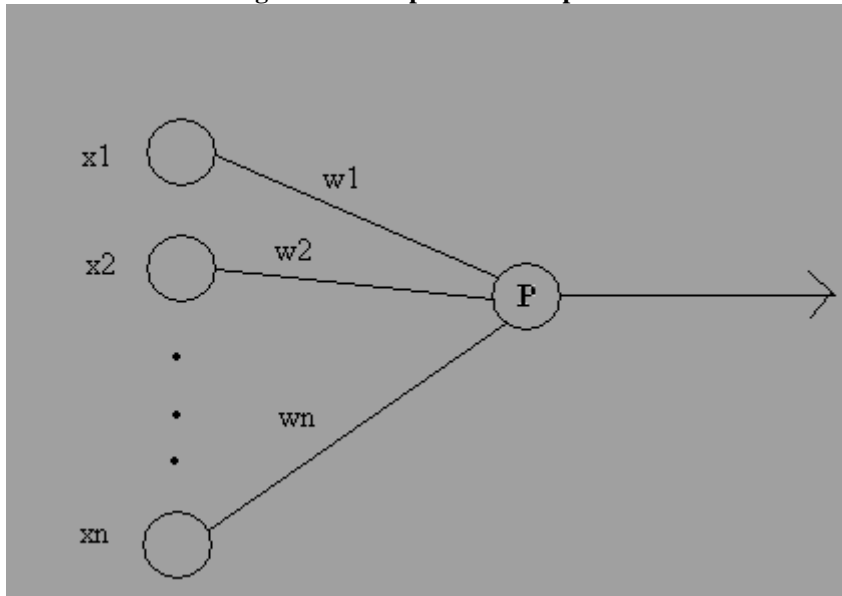
4,%(2&'#F.<**393&'#K23F2#!)3.5*#)D%,#').&#F.<**393&'*#3*#%, &#K3(2#5&F3*3%, #('&&*;##
` &F3*3%, #('&&*#!<*3F<.."#(<L&#<#.%%L#<(#E).(3D.&#<(('3!)(&*#<, 5#!'&<L#(2&E#3, (%#*&D<'<(&#
D<3'3, /*M#D'&53F(3, /#5399&'&, (#6<.)&*#9%'#(2&#(<'/&(#<((''3!)(&#!<*&5#%, #(2&#D<3'3, /#%9#%(2&'#
6<'3<!.&*;##Z&K#!'<, F2&*#<'&#E<5&#9%'#, &K#D<3'3, /*#<, 5#<*#<#'&*).(#<, #&, (3'&#('&&#3*#E<5&#
K23F2#(2&#F.<**393&'#! '<, F23, /#<(#&<F2#D%3, (#5&D&, 53, /#%, #K2<(#(2&#6<.)&#%9#<#D<'(3F).<'#
<(('3!)(&#3*;##><, "#<./%'3(2(2E**#2<6&#!&&, #E<5&#)*3, /#5&F3*3%, #('&&*M#(2&#E%*(#!<*3F#<E%, /#
(2&E#!&3, /#(2&#M` ^#<./%'3(2(2E#Ha)3, .<, M#?RR^I;##O%K&6&'M#5&F3*3%, #('&&*#3, 3(3<.."#2<5#<#
D'%!.&#3, #%6&'93((3, /#5<(<M#3, #(2<(#<#'<, 5%E#%FF)''&, F&*#K%).5#F'&<(&#, &K#!'<, F2&*#(%#
('&&*#<, 5#K%).5#(2&'&9%'&.&<5#(%#%<#E%'&#F%ED.&J#('&&#%, &#(2<(#(%5#D'&53F(#9<.*&#
%)(F%E&*#5)&#(%#*%E&#3, *(<, F&&#%9#(2&#(<, F&*#K2%*&#(<'/&(#(#<((''3!)(&#%#K%).5#!&#5399&'&, (#(%, (#2<, /#
%(2&'#3, *(<, F&*#K3(2#3E3.<'#6<.)&*#9%'#'#3(*#<((''3!)(&#(&*;##4*#<#'&*).(#(M, &K#<./%'3(2(2E#K&'&#
E<5&#)*3, /#3, /#D')', 3, /#8')', 3, /#K%).5#!&#E%6&#!'<, F2&*#%9#(2&#('&&#&#39#3#3ED'%6&#5#(2&#
%6&'<..#<#FF)'<F"#%9#(2&#('&&##bJ<ED.&#*#%9#5&F3*3%, #('&&#<./%'3(2(2E**#3, F.)5&#-\;[#Ha)3, .<, M
?RR^I#K23F2#!)3.(#)D%,#M` ^#!'"#<553, /#D')', 3, /#M#<*#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&#, &)'<.#, *#35&#<#2)E<, #!'<3, #K23F2#F%, , &F(#(%%#9#(%#%#&<F2#%(2&'#<, 5#/&, &'<(&#
%)(D)(*#!<*&5#%, #(2&#3, D)(*#9&#%'(3E#).3#9'%E#%(2&'#, &)'%, *##<'(393F3<.#, &)'<.#, &(K%'L*#M&D&'F&D('%, (%, *#
<'&#)*&5#*<(&5#5#%9#, &)'%, *##&<F2#D&'F&D('%, (#(<L&*#3, #E<, "#3, D)(*#<, 5#<**3/, *#&<F2#
F%, *(<, (#(#F<..&5#5#%9#<F2#D&'F&D('%, (%#(<L&*#3, #E<, "#3, D)(*#<, 5#<**3/, *#&<F2#
3, D)(#(%#%#(2&#D&'F&D('%, ;##M, #(2&#E<F23, &.&<', 3, /#F<*&#(2&#, &)'%, *#(<L&*#3, #(2&#5399&'&, (#<((''3!)(&#
(2&#<((''3!)(&#(%#%#(2&#D&'F&D('%, ;##M, #(2&#E<F23, &.&<', 3, /#F<*&#(2&#, &)'%, *#(<L&*#3, #(2&#

Formula: C36&, #3, D)(*#J?M#J@M#d M#J, M#<#D&'F&D('%, #K3..#<<**3/, /, #K&3/2(*#K?M#K@M#d M#K, #(%#&<F2#
&<F2#3, D)(#(%#(2&#D&'F&D('%, ;##M(#K3..#.#(2&, #<(#J?K?#e#J@K@#e#d #e#J, K, #I#<, 5#(2&, #%)(D)(*#(#<#3, /.&#
6<.)&#!'"#<*&5#%, #(2&#K2&(2&'#%#3(*#<.)&#3*#&<(#<#(2<2#'&/'&**3%, #('&&;

Figure 2: Example of a Perceptron

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

Figure 3: A Network of Perceptrons that Computes the XOR Boolean Function
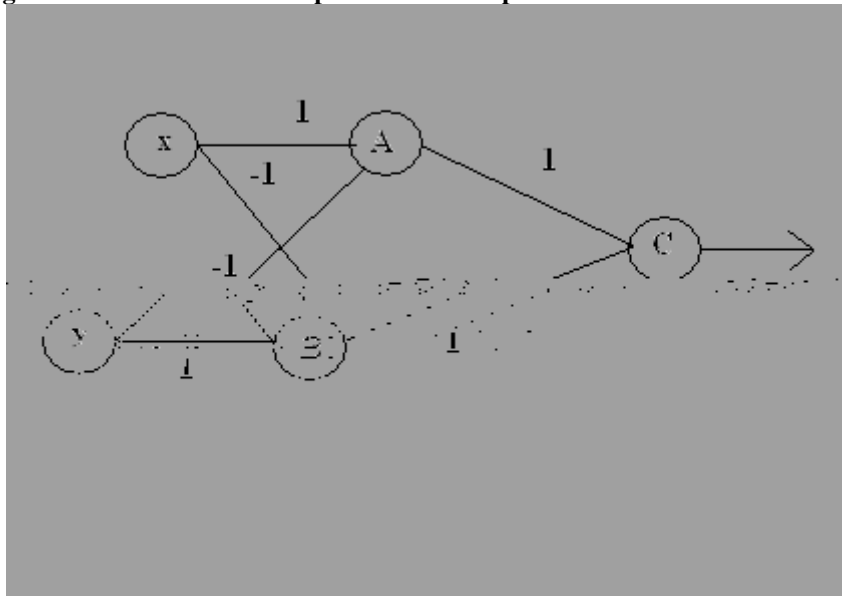
M, #(23*#F<*&A 4M#+M<, 5#-#<'&#D&'F&D('%, *;##4#K%).5#%, .'#%)(D)(#<#?#39#J#3*#?#?#<, 5#'#'#
3*#B;##+#K%).5#%, .'#%)(D)(#<#?#39#J#3*#B#<, 5#'#3*#?#?;##-#K%).5#%, .'#%)(D)(#<#?#39#4#%'#+#3*#
%)(D)((3, /#<#?#;##12&'&9%'&#&M(23*#, &(K%'L#%9#D&'F&D('%, *#E%5&.*#(2&#ƒP$#9), F(3%, ;##V3%, #;##M, #
/&, &'<.#D&'F&D('%, *#<#<'&#&9'&'&9'&#'&5#(%#<#, 5#*M#<, 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&#3,D)(*#(2'%)/2#(2&#,&(K%'L#3*#5%,&A#(2&#%)(D)(#6<.)&*#<'&#F%ED<'&5#</<3,*(#(2&#(<'/&(#<((3!)(&0*#6<.)&*;##12&,#<#F<.F).<(3%,#3*#D&'9%'E&5#(%#F'&<(&#(2&5&.(<#(2<(#E)*(#! &<55&5#(%#(2&#%'3/3,<.#K&3/2(2(;##123*#F%,(3,)&*#,(3.#(2&#K&3/2(*#5%#, %(#F2<,/&A#%')#, (3.#(2&#K&3/2(*#*5%# ,%(#F2&5;##12&'&#<'&#%&'&6&'<.#K<"*#(%#(%#D5<(&#K&3/2(*#*#9%'#D&'F&D('%,*,##P,&#K<"#3*#(%#(%%<**3/,#'<,5%E#K&3/2(*#(*#(%#(2&#,&(K%'L3,5%',#123*#3<#&<'&#*&6&'<.#K<"*#(%#(%)D5<(3,/#(2&#<F2#K&3/2(2(#K3#9%'#3,D)(#J37

Formula: $K_3 \leftarrow #K_3 #e #Âk_3 ####K2&'&####Âk_3 1 fhg#%IJ_3$

M,#(2&#<!%6&#9%'E).<#]g'h\Y`YUfb]b['fUhY'i gYX'hc'XYHYfa]bY'hc'k \UhYl hYbh'h\Y'K&3/2(#K3..#! &#F2<,/&5M#(#3*#(2&#<'/&(#<((3!)(&0*#6<.)&)&A#%*#3*#(2&#%)(D)(#(6<.)&)&#9'/36&,#!"#(2&#D&'F&D('%,M<,5#J_3#3*#(2&#3,D)(,D)(#(6<.)&)&#9&5#3,(%#(2&#D&'F&D('%,;##123*#E&(2%5#/)<,(&&*#(2<(#(2&#<&'*#F%,6&'/&,F&A#!)('<(&#F&#39#(2&#D<(&F,3*,&6(#(2&#2<6&,%)/2>3,*L"#S#8<D&'(M#?RC[I;##O%K&6&'M#E%*(#(#5<(<#*&(*#%(2<(#3,&5<'&,%(#.3,&<'."#*&D<'<(<!.&A#<&,*'."#*&D<'<(<#!.&A#<&,*.&;

4#*%.)(3%,#(%#(%(%#(23*#D'%!.&E#K<*#)#*3,/#%&'#'%#!<FLD'%D</</<(3%,,##M,#(23*#K<"#M#(2&#%)(D)(*,#(%#(%(%#(%)(D)(*%,#(%#(%)(D5<(&5#,&<F.F.F.)<(&5#,&<F.F.)<(&,#(%!<FLK<'5*#'5*#'%E#(2&#%)(D)(#(2&#%)(D)(#(2&#%)(D)(#(2&#%)(D)(#(2&#%)(D)(#(2&#%)(D)(#(2&#%)(D)(#

Formula: $_L \leftarrow %_L H?#g#%_L IH(_L g#%_L I$

O&'&A#%_L#3*#(2&#%)(D)(#(6<.)&)&#9%'#(2&#D&'F&D('%,M<,5#, 5#(_L#3*#(2&#<'/&(#<((3!)(&0*#6<.)&)&);##12&,#*&6&6<.)&)&&*<*#*5#3,#(2&#F<.F).<((3%,,#(%#(%&'&6&'<.#K<"*#(%#%D5<(3,/#(2&##2355&,#,#%5&#2#)*3,/%#(%#(%&)(D)(#9%..)%K3,/%'%9%'E).<#)<7

Formula: $_2 \leftarrow #%_L H?#g#%_L Ł k_{L2 L}$

Z%(&#(2&2<(2&*(&A#%&*'%(2&K&3/2/2/2#(9'%E#(&A#%5&&2#(%#%5&&L;#123&#(&'E#%9'%(#9%'E).<)<'<(<##,#%5&&2#3*#(2&#<'&'%9'%(2&)(D)(*)E&9'%(2&K&3/2/2*(#3E&*'%(2&(2&A'%%'%9'%6<.)&)&..#(2&#%)(D)(,D)(#(%#(%)(,#%5&&*L#(2<(2&<'&F%,#,&F(&5#%9#(2&2#%5&)&&2#_2;

12&#K&3/2/2*(*#(%#%D5<(&5#9%..)%K3,/%'%9%'E).<)<K<"7

Formula: $K_{03} \leftarrow #K_{03} #e #Âk_{03} ####K2&'&######Âk_{03} 1 _0 J_{03}$

123*#(%#D5<(&5#(&*#,&*'<'%9'%(2&2<'/&(9'%E&A#(*#G)<'&&''%9'%%9'%(2&#<D)(D)(*%,(%(%#<."#&'%(%#-%,, &F(3,/#E<,"#D&'F&D('%,*,#%#(%(%#%K3(2#23(2(#E&<,#'%(2&#2355&,#,#.<"&A#%)(D)(/36&*(2&#F<,(2&2#2355&,#,#.<"&6<.)&A#K<F2#'%(2&#<D)(,#%%2&#2355&,#,#.<"&6&*'%*(%,(*(%#(2&#23<D)(#'%(2&2(2&'%6<.)&&A#(#(2&#<D)(,#%%<!<'/&(,##(2&)&'E&A'%*(%(2&*'%(2&2<'/&((2#2355&,#,#(%%5<(&5#(2355&,#,#.<"&'%(*%*(#%&&*'%(%(%#(2&2355&,#,#(%*'%9%'E).<A&,#(2&*<%&*'%(%(%#(2&2355&,#,#(%*'%9%'E).<)<A#(#(2&)&*'%(%#*'%(%(2&*'%(%(2&*'%h35'%KA#S#X&2'M#?RR\I;

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

Formula: $\lfloor \leftarrow \#\%_L H(\lfloor\ g\#\%_L l$

12&#6<.)&#9%'#(2&#&''%'#(&'E#9%'#(&'E#9%'#&<F2#2355&, #, %5&#2#K%).5#(2&, #! &#F<.F).<(&5#3, #(2&#9%..%K3, /#K<"7

Formula: $_2 \leftarrow \#\%_L\ \dot{k}_{L2\ L}$

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%'&#<*#K&..#H+3*2%DA#?RRCl

Bayesian Techniques

4, %(2&'#(''D&#%9#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&;##M#('3&*#(#%#D'%5)F&#(2&#! &*(#(#2"D%(2&*3*#&9"%#E#*%E&#*D<F&#%9#2"D%(2&*&*#*%#O#/36&, #*%E&#&#('<3, 3, /#5<(<#`;#>%*(#%9#+<"&*3<, #.&<', 3, /#&.3&*%#, #+<"&*0#(2&%'&E;#+<"&*0#(2&%'&E#<**) E&*#(2(2<(#%%'#&<F2#2"D%(2&*&3#2M#(2&'&#3*#<#D'3%'#D'%!<!3.3("#<.'&<5"#F<.F).<(&5M#F<..&5#8H2I;##8H` I#3*#(2&#D'3%'#D'%!<!3.3("#<.3("#3*#(2&#D'%!<!3.3(3&*#<, 5#8H2I`#K3..#! &#%! *&'6&5;#8H` i2I#3*#(2&#D'%!<!3.3(3&*#<, 5#8H2I`#K3..#! &#%! *&'6&5/36&, #(2<(#(2&#2"D%(2&*&3#2M#(2&'&#3*#<#D'3%'#D'%!<!3.3("#3*#K3.#!2%.5#/36&, #(2&#('<3, 3, /#5<(<#`;##1%#5&(&'E3, 3, #&8H2I` IM#+<"&*0#(2&%'&E#D'%635&#*#(2&#9%..%K3, /#9%'E).<7

## Formula: $8H2i`\ I\#j\ \#8H`\ i2I8H2I\ k\ 8H`\ I$

+<"&*0#(2&%'&E#<..%K*#F.<**393F<(3%, #! "#*&.&F(3, /#(2&#E<J3E) E#<#D%*(&'3%'3#H>48I#2"D%(2&*3*;#V%"#&6&''2#3, #OM#8H`  i2I8H2I#3*#F<.F).<(&5#! 12&#5&, %E3, <(%'#8H` I#3, #+<"&*0#9%'E).<7#3#'#&E%6&5#! F<>)*&#(2&#('<3, 3, /#5<(<#<#`  #, &6&'#F2<, /&*#9%'2<, /&*#9%'#%9#2#3, #O;##12&#2"D%(2&*&3#K3(2#(2&#23/2&*#(6<.)#&#9%#8H` i2I8H2I#3*#(2&, #)*5#(%#F.<**39"#&<F2#3, #*(<, F&;

Naïve Bayes

12&'&#<'&#(K%#*"(<, 5<'5#E&#(2%5*#13#K23F2#+<"&*3<, #.&<', 3, /#3*#)*3*5%, &;##P, &#3*#<#(&F2, 3G)&#F<..&5#Z<I6&#+<"&*;##M, #Z<I6&#+<"&*A#(2&#./'%*3(2E#F'&<((*#<#(&5#&#(#%9%9#<..#D%**3! .&#(<'/&#(#<.)&*#3#((3!)(&*;##M#(2&, #F<.F).<(&*#(2&#D'%!<!3.3("#(2&#E'*#8H2I#<, 5#8H`  i2I#<'*#"#(<(5#<!%6&;##O%K&6&'A#3(#! '&<F2#5399&'&, 5&#'&, (<(#%9%'#(2&#D'%!<!3.3("#(<'/&(#<.)&#9%'#%9#2#3, #O#&#3#((3!)(&*;#(3D.3&5#! ! ! "#(2&#D'%5)F(#%9#<..#(2&#D'%!<!3.3(3&*#(2<(#%9%9#8H` i2I;#V%"'&#&J<ED.&A#F%, *35&'#(&#*35&'#V3/)'"#'&#\;##

Figure 4: Example of a Naïve Bayes model
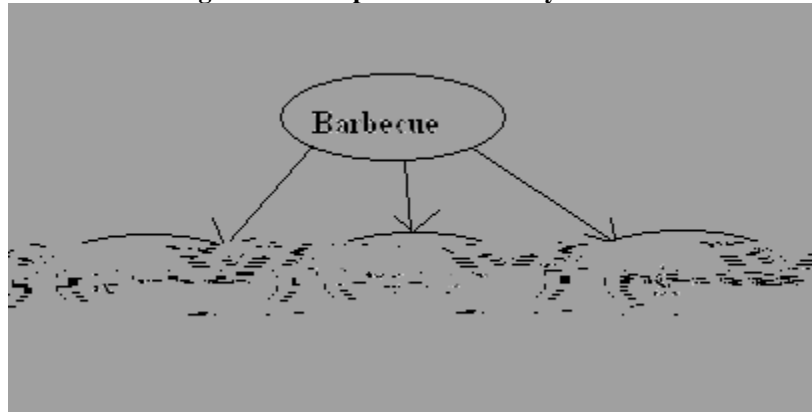
+<'!&F)&#3*#(2&#(<'/&(#<(('3!)(&M#<,5#2<*#(2&#6<.)&*#"&*#%'#,%;#12&#F.<**393&'#K%).5#93'*(#!)3.5#)D#(2&#5399&'&,(#3,*(<,F&*#%9#(2&#!<'!&F)&#5<(<#`#<,5#F<.F).<(&#&<F2#D'%!<!3.3("#/36&,#&3(2&'#"&*#%'#,%;#M(#K%).5#<.*%#F<.F).<(&#(2&#%6&'<..#D'%!<!3.3("#"#%9#!<'!&F)3,/;#V%'#&J<ED.&M#(%#F.<**39"#(2&#3,*(<,F&#H:),#j#%)(M#$<3,#j#,%,&M#1&ED&'<()'&#j#2%(IM#(2&#F.<**393&'#K%).5#F<.F).<(&#(2&#8H"&*#I#m#8H%)(i"&*#I#m#8H,%,&i"&*#I#m#8H2%(i"&*#I#<,5#8H,%I#m#8H%)(i,%I#m#8H2%(i,%I#12&#&,5#'&*).(#K%).5#!&#(2&#F.<**393&'#'*&.&F(3,/#(2&#E<J3E)E#6<.)&#%9#(2&#(K%#<,5F2%%*&#&3(2&'#"&*#%'#,%;##Z<I6&#+<"&*#2<*#!&&,#)*&5#9%'#(<*L*#"*)F2#<*#(&E*#F2#<*#"#%'(3,/#%)(#,&K*#<'(3F.&.&*#,#)*&5#9%'#(<*L*#")F2#<*#(&E*#F2#<*#(3F.&.&H]%<F23E*M?RRCI;

Bayesian Networks

Z<l6&#+<"&*#<**) E&*#(2<(#<..#<(('3!)(&#6<.)&*#<'&#F%, 53(3%, <.."#3, 5&D&, 5&, (#/36&, # <#(<'/&(#<(('3!)(&#6<.)&;##12)*M#(2&'&#, &&5*#(%#! &#<#K<"#(%#F.<**39"#*%E&#<(('3!)(&*#<*# F%, 53(3%, <.."#3, 5&D&, 5&, (M#!)(#, %(#%(2&'*; 12&#*%.)(3%, #3*#<#+<"&*3<, #, &(K%'L;

Definition: *Attributes are* **conditionally independent** *of one another if given the value of one or more attributes* $Y_1...Y_m$ *determines the value of attributes* $X_1...X_m$ *independent of values of attributes* $Z_1...Z_m$ H>3(F2&..M#?RRUI;

M, #(23*#K<"M#<#, &(K%'L#3*#F'&<(&5#! "#F%, , &F(3, /#<(('3!)(&*#(2<(#<'&#'&#, %(# F%, 53(3%, <.."#3, 5&D&, 5&, (#%9#%, &#<, %(2&'<, 5#F<.F).<(3, /#(2&3'#F%, 53(3%, <.#D'%! <! 3.3("; ## 12&'&9%'&#<#*"'*(&E#%9#, %5&*#3*#F'&<(&5#*3E3.<'#(%#(2&#*"'*(&E#F&<(&5#! "#, &)'<.#, &(K%'L*; ## M, #(23*#*3()<(3%, M#"%)#F<, #3, 9&'#(<'/&(#6<.)&*#9%'#<(('3!)(&*#! "#)*3, /#(2&#D'3%'# D'%! <! 3.3("#%9#&<F2#6<.)&#&#/36&, #(2&#D<'&, (*#%9#(2&#, %5&#;#M, #(23*#K<"#"#"%)#F<, #, &F(# , %5&*#%(/&(2&'#<, 5#2<6&#&#, &(K%'L#%9#, %5&*#%(2<63, /#E<, "#D<'&, (*#(*;##4 , #&J<ED.&#%9#<# +<"&*3<, #, &(K%'L#3*#*2%K, #3, #V3/)'&*#[<#<, 5#[!;

Figure 5a: Example of a Bayesian Network
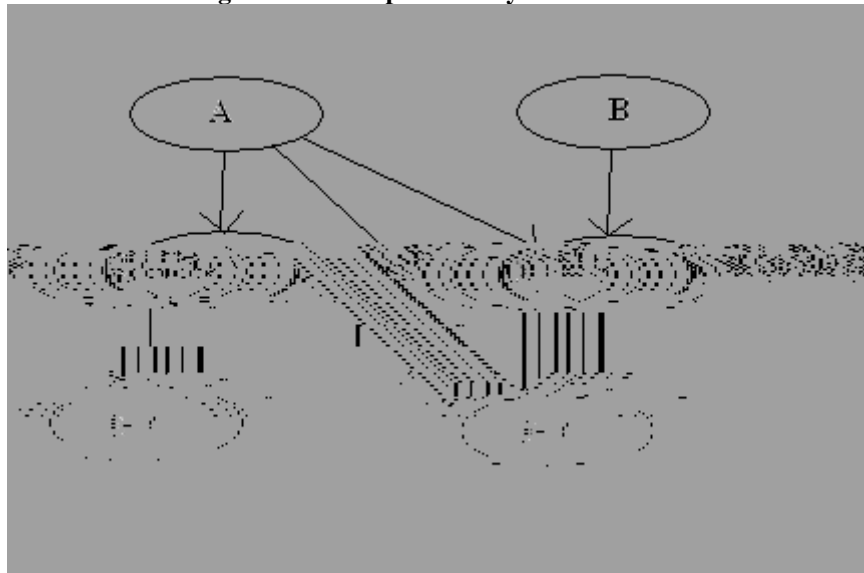
Figure 5a: Example of a Conditional Probability Table

	<A5	<M#n5	n<A5	n<M#n5
9	B;\	B;?	B;o	B;@
n9	B;C	B;R	B;@	B;o

M, #(23*#&J<ED.&#+-#2<*#D<'&, (# #`M#b#2<*#D<'&, (&, (#-M`#2<*#D<'&, (&, (*#4 #<, 5#+M#<, 5#VM#(2&# (<'/&(#<(('3!)(&#<(('3!)(&#<(('3!)(&M#(2<*#D<'&, (&, (*#4 #<, 5#`;##M(#3*#, %(#%3, &5#3, #.<"#&'*#<*#3, #, &)'<.#, &(K%'L*M#<*#(2&#D<'&, (*#*#%9#, %5&*#<'&#(&#D<'&, (2&3'#F23.5'&, #, ##12&'&9%'&#&#F<.F).<(3, /#(2&# D'%! <! 3.3("#%9#V#! &3, /#, /9M#/36&, #(2&#5<(<#2<*(#4 #3*#<#, 5`#3*#5#K%).5#! &M#9%'#&#J<ED.&#&M#

K%).5#!&#8HVj 9i4j <A`j 5I;##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<*&I%50#*239(<K%\)D5<1(F<)j 9i4j <A`j 5#(2&#, &(K%'L#23*#6<.)

Machine Learning Work with Recommender Systems

><, "#F%..<!%'<(36&#93.(&'3, /#(&F2, 3G)&*#2<6&#!&&, #)*&5#!&9%'&;##V%'#&J<ED.&M
$3, /%#K<*#<#*%F3<.#3, 9%'E<(3%, #93.(&'#)*&5#(%#('"#<, 5#E<L&#E)*3F#'&F%EE&, 5<(3%, *#(%#
.3*(&, &'*#H: 2<'5<, <, 5#S#><&*M?RR[I;##M, #*)F2M'&F%EE&, 5<(3%, *#*#<'&#D<**&5#(2'%)/2#
pK%'5#%9#E%)(2qM'<(2&'#(2<, #F%, (&, (M*%#E)*3F#'&F%EE&, 5<(3%, *#<(3%, *#, *#(%2D.&E*#<)*&<#(3F<..."#
5399&'&, (#(2<, #(2%*&#(2<(#<#)*&'#93.(&'*#%'#&5#(%#!&9%'&;#12&'&#<#E%)(2&#, #<2<&5#(%EE&, (&#3, ('<52&#"#%(2&'#(2<(#, #E%(2&, #*#('"#
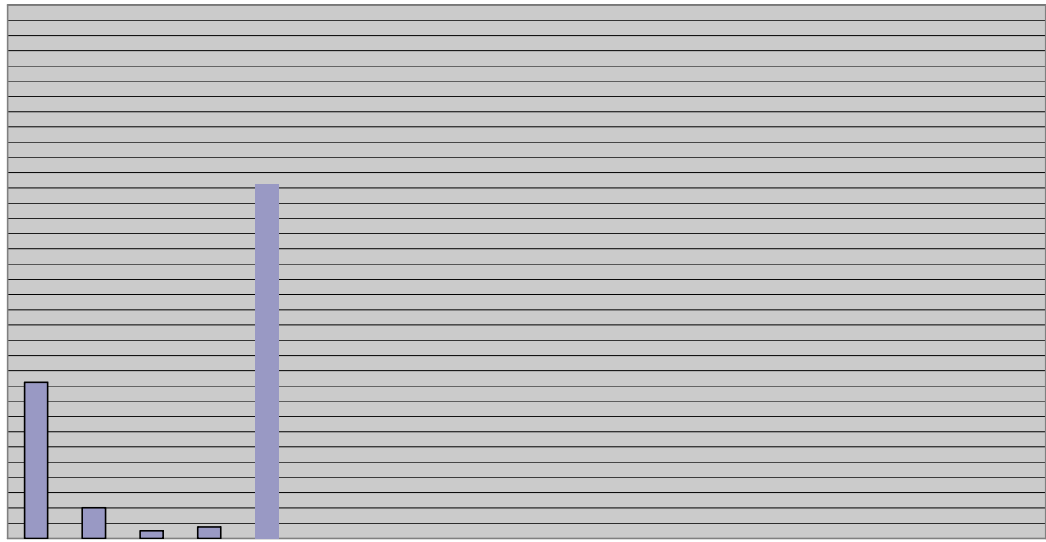
Figure 7c: Genre3 Distribution
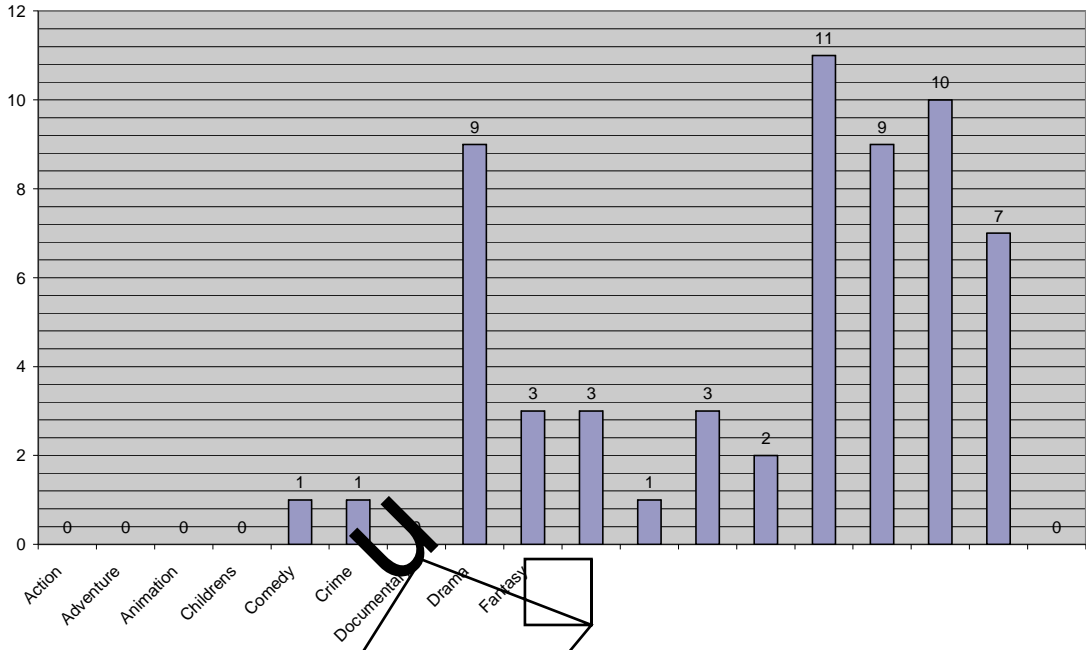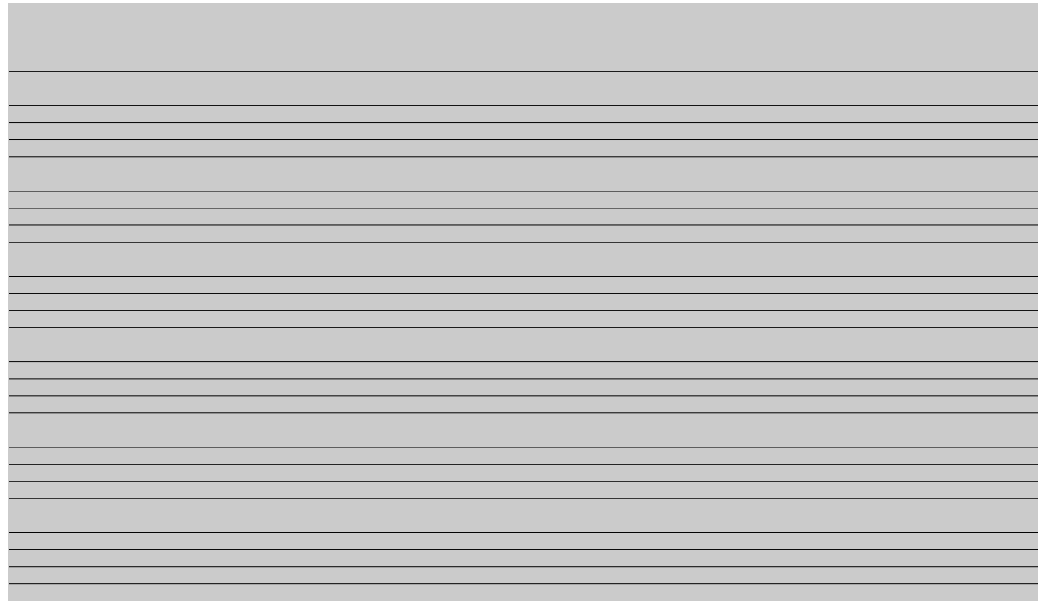
Performance Metrics and Evaluation Protocol

M#5&F35&5#(%#&6<.)<(&#(2&#'&*).(*#%9#(&*(*#%9#(2&#E<F23,&#.&<',3,/#<./%'3(2E*#%,#(2&#5<(<*&(#!"#)*3,/#<FF)'<F"M#D'&F3*3%,M#<,5#(%DNZ#D'&F3*3%,,;

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

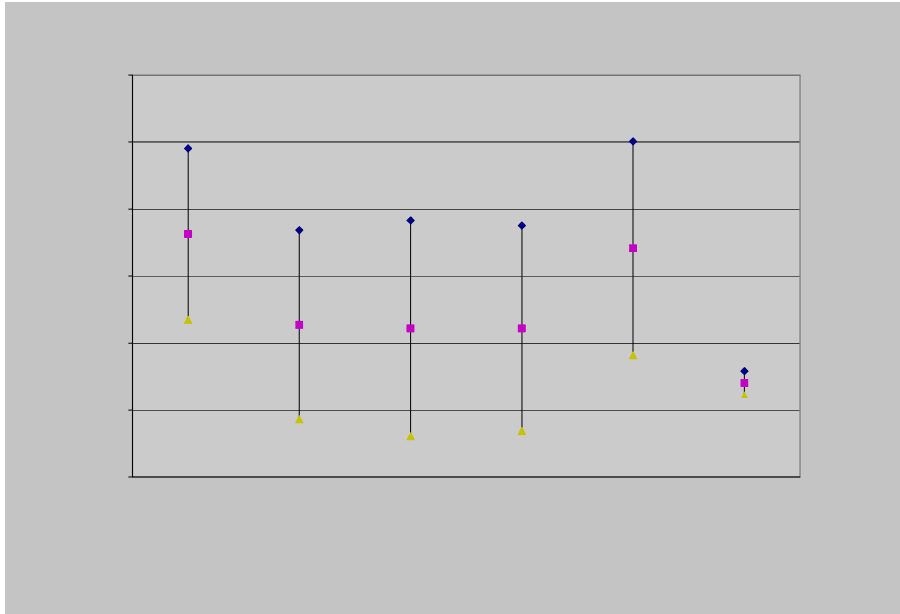**Definition:** *Precision* is the percentage of like predictions that agree with the user's taste.

‒&'(<3,#E<F23,&#.&<',3,/#<./%'3(2E*M*)F2#<*#+<"&*3<,#<,5#,&)'<.,&(K%'L*M#

Results

Attribute Selection

M#(&*(&5#!%(2#D'3, F3D<.#F%ED%, &, (*#<, 5#+&*(V3'*(#(%#*&.&F(#(2&#<(('3!)(&*#(%#!&#9&5#<*#3, D)(*#
(%#(2&#6<'3%)*#E<F23, &#.&<', 3, /#<./%'3(2E*;##

Principal Components

V3/)'&*#o<M#o!M<, 5#oF#*2%K#(2&#D&'9%'E<, F&#%9#(2&#5399&'&, (#E<F23, &#.&<', 3, /#<./%'3(2E*#
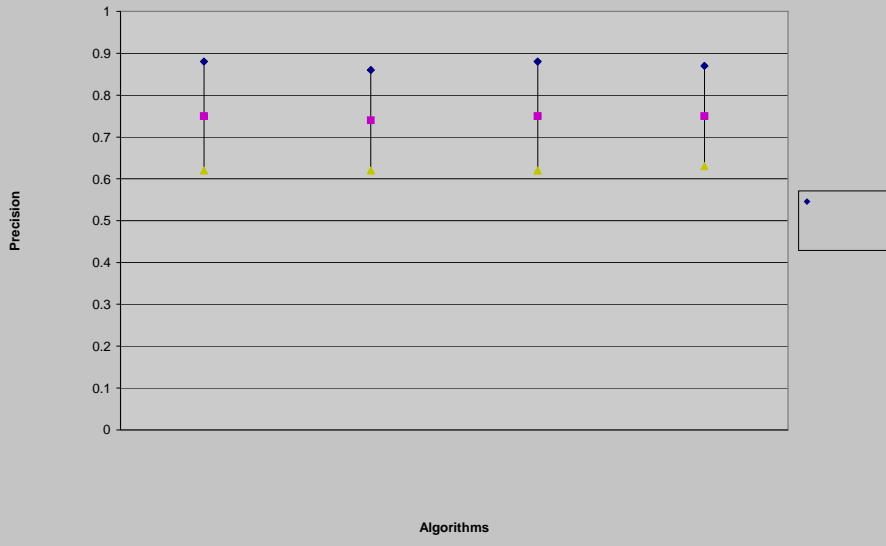%6&'#5<(<#(2<(#K<*#D'&D'%F&**&5#)*3, /#D'3, F3D<.#F%ED%, &, (*#<((('3!)(&#*&.&F(3%, ;

BestFirst

Figure 9c: Top-10 Precision Using BestFirst Attribute Selection
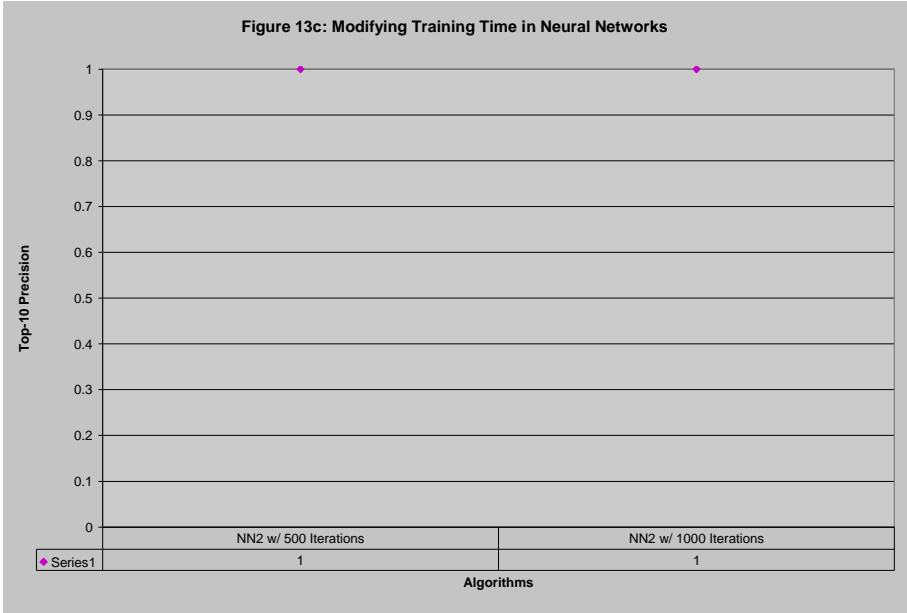
0.5
0.4
0.3
0.2
0.1
0
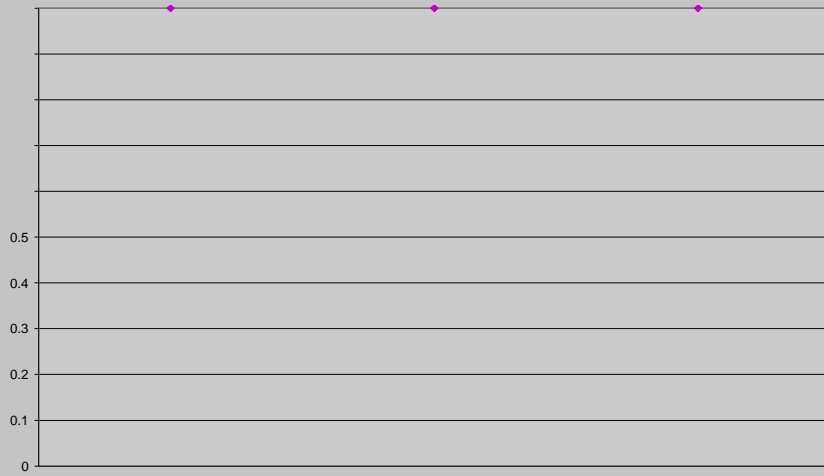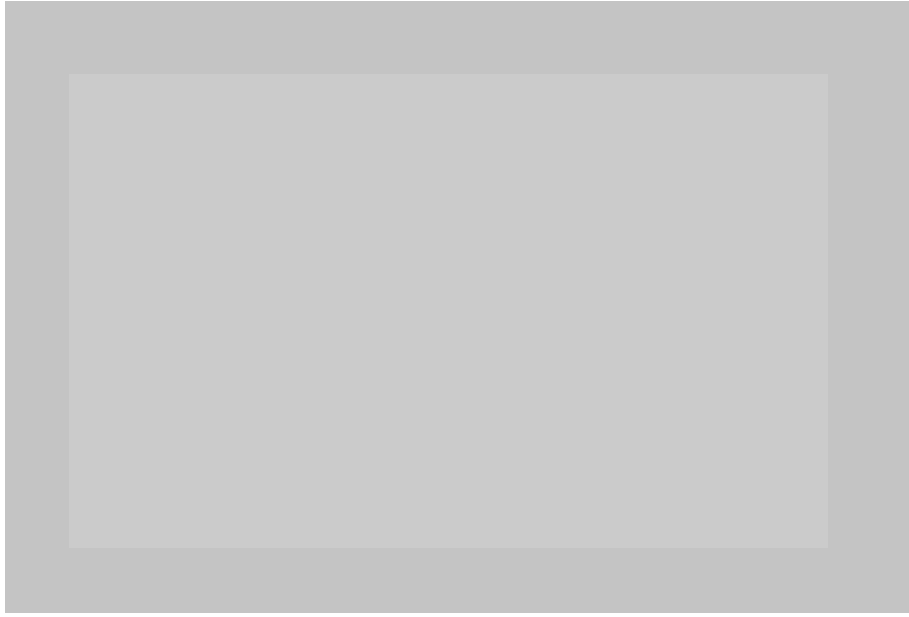
Neural Networks

Figure 12b: Modifying Hidden Nodes in Neural Networks

Number of Training Epochs

M#(2&,#5&F35&5#(%#3,F'&<*&#(2&#*(<,5<'5#('<3,3,/#(3E&#%,#(2&#5<(<#9'%E#[BB#
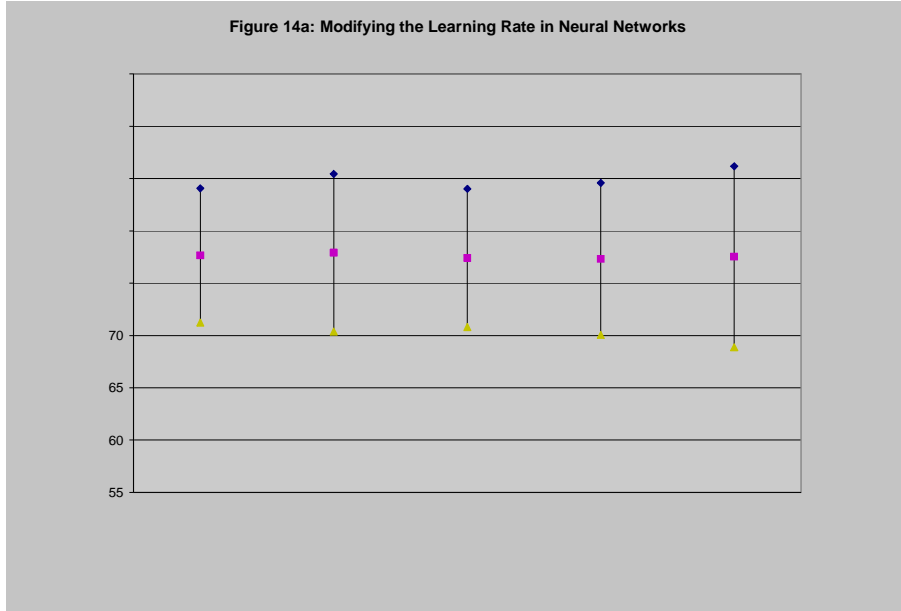3(&'<(3%,*#(%#?BBB#3(&'<(3%,*;##12&#'&*).(*#<'&#*2%K,#3,#V3/)'&*#?^<A?^!#<,5#?^F;

Figure 13c: Modifying Training Time in Neural Networks

Top-10 Precision

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

	NN2 w/ 500 Iterations	NN2 w/ 1000 Iterations
◆ Series1	1	1

Algorithms

X%%L3, /#<(#(2&#'&*).(*M#(%DN?B#D'&F3*3%, #K<*#(2&#*<E&#5&*D3(&#3, F'&<*3, /#(2&# ('<3, 3, /#(3E&; #4FF)'<F"#*.3/2(."#5&F'&<*&5M#<, 5#(2&#*(<, 5<'5#5&63<(3%, #*.3/2(."#3, F'&<*&5;## 8'&F3*3%, #<.*%#*.3/2(."#5&F'&<*&5;##12&'&9%'&M#5&*D3(&#3, F'&<*3, /#(2&#('<3, 3, /#(3E&M#(2&# <FF)'<F"#<, 5#*#(<, 5<'5#5&63<(3%, #5353#*, %(2*+#535(#, %(#2<6&#<#*3/, 393F<, (#F2<, /&;##12&'&9%'&&M#<M#535#, %(# !%(2&'#3, F'&<*3, /#(2&#('<3, 3, /#(3E&#9%'#9)()'&&JD&'3E&, (*;

Learning Rate

M#<.*%#F%, *35&'&5#E%539''3, /#(2&#.&<', 3, /#'<(&#K3(23, #, &)'<.#, &(K%'L*#(%#5&(&'E3, &# K2&(2&' F%, 6&'/&, F& (%#<#! &((&'#E3, 3E) E#F%).5#! &#<F23&6&5;##12&#'&*).(*#<'&#53*D.<''&5 3, #V3/)'&* ?\<A ?\!#<, 5#?\F;

Figure 14a: Modifying the Learning Rate in Neural Networks

70
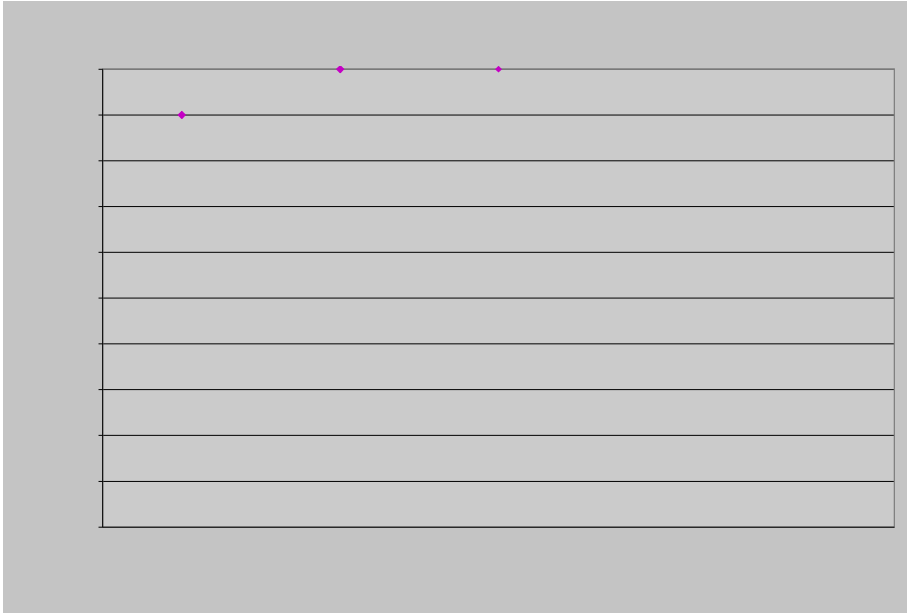
Bayesian Networks

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

Collaborative Data Only

V3/)'&*#?C<M?C! <,5#?CF#*2%K#(2&#/'<D2*#9%'#F%..<!%'<(36&N%,."#+<"&*3<,#,&(K%'L*;
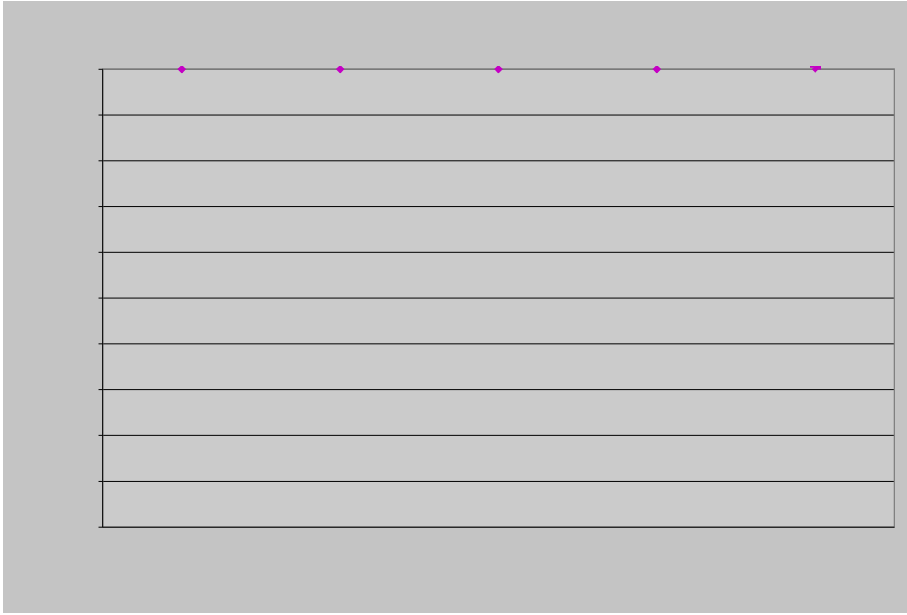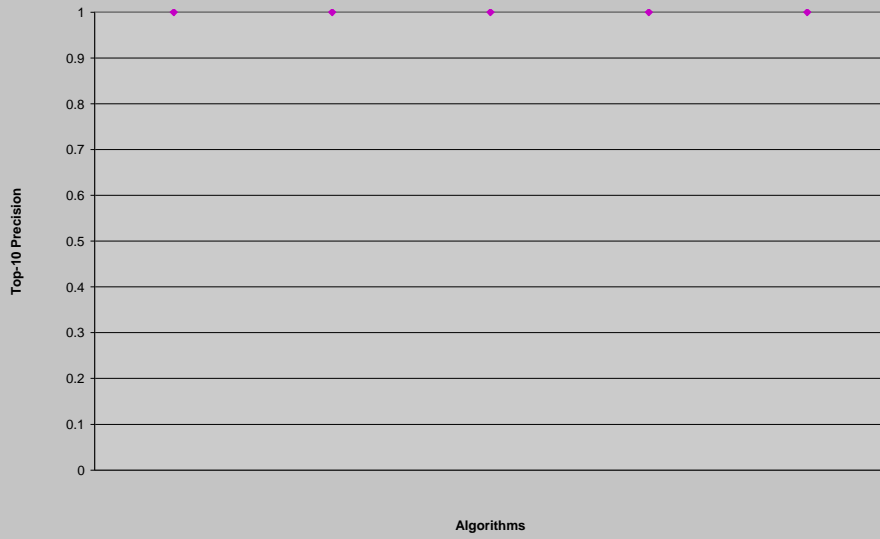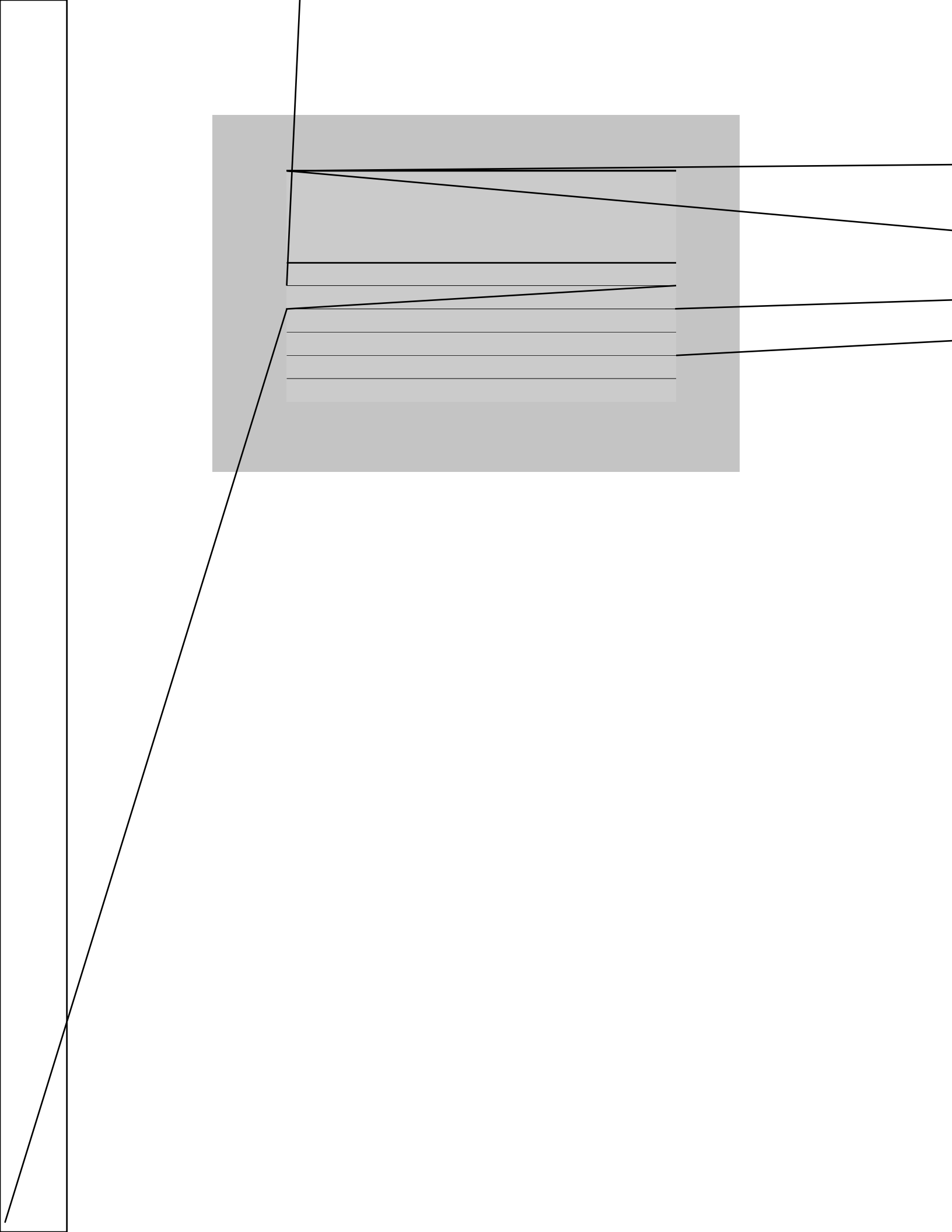
Figure 16c: Varying the Number of Parents in Bayesian Networks (Collaborative-Only)

Enhanced Content Data

Figure 18e: Varying the Number of Parents in Bayesian Networks (More Content)

Top-10 Precision

Algorithms

Conclusions and Future Work

3, F'&<*3, /#%6&'<..#<FF)'<F";# O%K&6&'M3(#K%).5#!&#3, (&'&*(3, /#(%#*&&#K2<(#K%).5#2<DD&,#
39#&6&,#E%'&#F%, (&, (#5<(<#K<*#<55&5M#*)F2#<*#<F(%'*M#<*#*%E&#E%63&/%&'*#2<6&#9<6%'3(&#
<F(%'*#<, 5#<'&#E%'&#.3L&."#(%#*&&#93.E*#! "#(2%*&#<F(%'*;

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

References

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

+<.<!<, %63FM#>;M#S#: 2%2<EM#W;#H?RRUI;#-%E!3, 3, /#F%, (&, (#N+<*&5<, 5#F%..<!%'<(36&#
'&F%EE&, 5<(3%, ;M#Communications of the ACM#M#\BH^IM#DD;#CCNU@;

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

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

+'&&*&M#];#: ;M#O&FL&'E<, M`;M#S#_<53&M#-;#H?RRoI;#bED3'3F<.#<, <."*3*#%9#D'&53F(36&#
<./%'3(2E*#9%'#F%..<!%'<(36&#93.(&'3, /;M#, #Proceedings of the Fourteenth Conference on
Uncertainty in Artificial Intelligence#M#DD;#\^g[@;

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

O<'D&'M#V;#X3M#f;#M#-2&, M#W;#S#_%, *(<, M#];#H@BB[I;#4, #bF%, %E3F#>%5&.#9%9#Y*&'#$<(3, /#3, #
<, #P, .3, &#$&F%EE&, 5&'#: "*(&E;M#Proceedings of the 10th International Conference on
User Modeling;

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

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

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

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

a)ℨ, .<, ₦];#$;#H?RR^I;#*C4.5: Programs for Machine Learning*;#: <, #><(&%₦– 4₮#>%'/<, #
_<)⁹E<, , ;

Appendix

Top-N Precision w/ NN1 Code

```
3ED%'(#0<6<;3%;+)99&'&5$&<5&'u
3ED%'(#0<6<;3%;+)99&'&5ᑋ'3(&'u
3ED%'(#0<6<;3%;V3.&$&<5&'u
3ED%'(#0<6<;3%;V3.&ᑋ'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#<'/*Iv

                ('"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<(<;,)E4(('3!)(&*HI#N#?Iu


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

                >).(3.<"&'8&'F&D('%,#E.D#j#,&K#>).(3.<"&'8&'F&D('%,HIu
                E.D;*&(O355&,X<"&'*Hy^yIu        #kk#*&(#(2&#2355&,#,#%5&*
                E.D;*&(X&<',3,/$<(&HB;@Iu #kk#*&(#(2&#.&<',3,/#'<(&
                E.D;*&(1'<3,3,/13E&H[BBIu        #kk#*&(#(2&#('<3,3,/#(3E&
                E.D;!)3.5-.<**393&'H5<(<Iu##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;,)E4(('3!)(&*HI#N#?Iu
                kk#F'&<(#F%D"
                M,*(<,F&*#.<!&.&5#j#,&K#M,*(<,F&*H),.<!&.&5Iu
                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#3ee Iv
                        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;,)E4(('3!)(&*HIEM,*(<,F&*HIu#3ee I#v
                ##5%)!.&wxF.*X<!&.#j#E.D;53*(<,F&*('3!)(&3,*(<,F&HV%'M,*(<,F&HI,.<!&.&5;3,*(<,F&H3IIu
```

```
##39H6<.)&*wBx#zj #F.*X<!&.w?xI#v#kk.3L&#D'%!<!3.3("
##          9%'H3,(#0#j #?u#0#z#?Bu#0eeIv
                    39H6<.)&*w0x#zj #F.*X<!&.w?x#SS#0#|j #RIv
                              6<.)&*w0N?x#j #6<.)&*w0xu
                              3,*(<,F&*w0N?x#j #3,*(<,F&*w0xu
                    {
                    &.*&#39#H0#j j #RIv
                              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&H3Iu
                    {
                    &.*&v
                              6<.)&*w0N?x#j #F.*X<!&.w?xu
                              3,*(<,F&*w0N?x#j #),.<!&.&5;3,*(<,F&H3Iu
                              !'&<Lu
                    {
               {
##{
{

.<!&.&5;5&.&(&HIu
9%'H3,(#3#j #Bu#3#z#?Bu#3eeI
        39H3,*(<,F&*w3x#|j #,)..I
               .<!&.&5;<55H3,*(<,F&*w3xIu

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

kkK'3(&#3,*(<,F&*#H(%#5%)!.&#F2&FL#,%#5%)!.&*I
+)99&'&5h'3(&'#K'3(&'#j #,&K#+)99&'&5h'3(&'H
####################,&K#V3.&h'3(&'Hy,,?;<'99yIIu
K'3(&';K'3(&H.<!&.&5;(%:('3,/HIIu
K'3(&';,&KX3,&HIu
K'3(&';9.)*2HIu
K'3(&';F.%*&HIu

{F<(F2HbJF&D(3%,#&Iv
        &;D'3,(:(<FL1'<F&HIu
    {
  {
{
```

Top-N Precision w/ NN2 Code

3ED%'(#0<6<;3%;+)99&'&5$&<5&'u
3ED%'(#0<6<;3%;+)99&'&5Һ'3(&'u
3ED%'(#0<6<;3%;V3.&$&<5&'u
3ED%'(#0<6<;3%;V3.&Һ'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#<'/*Iv

            ('"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<(<;,)E4(('3!)(&*HI#N#?Iu

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

            >).(3.<"&'8&'F&D('%,Z&K#E.D#j#,&K#>).(3.<"&'8&'F&D('%,Z&KHIu
            E.D;*&(O355&,X<"&'*Hy^yIu   #kk#*&(#(2&#2355&,#,#%5&*
            E.D;*&(X&<',3,/$<(&HB;@Iu#kk#*&(#(2&#.&<',3,/#'<(&
            E.D;*&(1'<3,3,/13E&H[BBIu   #kk#*&(#(2&#('<3,3,/(3E&
            E.D;!)3.5-.<**393&'H5<(<Iu##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;,)E4(('3!)(&*HI#N#?Iu
            kk#F'&<(&#F%D"
            M,*(<,F&*#.<!&.&5#j#,&K#M,*(<,F&*H),.<!&.&5Iu
            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#3ee Iv
                3,*(<,F&*w3x#j#,)..u
                6<.)&*w3x#Bu
            {

            kk'<,L#3,*(<,F&*#N#%,."#L&&D#(%D#Z
            9%'H3,(#3#j#Bu#3#z#?#),.<!&.&5;,)EM,*(<,F&*HIu#3ee I#v
            ##5%)!.wxF.*X<!&.#j#E.D;53*('3!)(3%,V%'M,*(<,F&H),.<!&.&5;3,*(<,F&H3IIu
            ##39H6<.)&*w*wBx#zj#F.*X<!&.w?xI#v#kk#3L&#D'%!<!3.3("
                ##   9%'H3,(#0#j#?u#0#z#?Bu#0ee Iv
                        39H6<.)&*w*w0x#zj#F.*X<!&.w?x#SS#0#|j#RIv

```
                                                   6<.)&*w0N?x#j #6<.)&*w0xu
                                                   3,*(<,F&*w0N?x#j #3,*(<,F&*w0xu
                                     {
                                     &.*&#39#H0#j j #RIv
                                                   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&H3Iu
                                     {
                                     &.*&v
                                                   6<.)&*w0N?x#j #F.*X<!&.w?xu
                                                   3,*(<,F&*w0N?x#j #),.<!&.&5;3,*(<,F&H3Iu
                                                   !'&<Lu
                                     {
                              {
                 ##{
                 {

                 .<!&.&5;5&.&(&HIu
                 9%'H3,(#3#j #Bu#3#z#?Bu#3eeI
                        .<!&.&5;<55H3,*(<,F&*w3xIu

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

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


                 {F<(F2HbJF&D(3%,#&Iv
                        &;D'3,(:(<FL1'<F&HIu
                 {
           {
      {
```

Top-N Precision w/ BN Code

3ED%'(#0<6<;3%;+)99&'&5$&<5&'u
3ED%'(#0<6<;3%;+)99&'&5н'3(&'u
3ED%'(#0<6<;3%;V3.&$&<5&'u
3ED%'(#0<6<;3%;V3.&н'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;<'99ylllu
                kk*&((3,/#F.<**#<(('3!)(&
                5<(<;*&(-.<**M,5&JH5<(<;,)E4(('3!)(&*HI#N#?lu

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

                +<"&*Z&(#E.D#j#,&K#+<"&*Z&(Hlu
                _@#L@#j#,&K#_@Hlu
                L@;*&(><JZ'P98<'&,(*H?lukk#*&(#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;<'99ylllu
                kk#*&(#F.<**#<(('3!)(&
                ),.<!&.&5;*&(-.<**M,5&JH),.<!&.&5;,)E4(('3!)(&*H#I#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%)!.&wxF.*X<!&.#j#E.D;53*('3!)(3%,V%'M,*(<,F&H),.<!&.&5;3,*(<,F&H3lllu

```
##39H6<.)&*wBx#zj #F.*X<!&.w?xI#v#kk.3L&#D'%!<!3.3(''
##          9%'H3,(#0#j #?u#0#z#?Bu#0eeIv
                    39H6<.)&*w0x#zj #F.*X<!&.w?x#SS#0#|j #RIv
                              6<.)&*w0N?x#j #6<.)&*w0xu
                              3,*(<,F&*w0N?x#j #3,*(<,F&*w0xu
                    {
                    &.*&#39#H0#j j #RIv
                              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&H3Iu
                    {
                    &.*&v
                              6<.)&*w0N?x#j #F.*X<!&.w?xu
                              3,*(<,F&*w0N?x#j #),.<!&.&5;3,*(<,F&H3Iu
                              !'&<Lu
                    {
              {
##{
{

.<!&.&5;5&.&(&HIu
9%'H3,(#3#j #Bu#3#z#?Bu#3eeI
        .<!&.&5;<55H3,*(<,F&*w3xIu

kk&6<.)<(&#(2&#3,*(<,F&*
b6<.)<(3%,#&6<.#j #,&K#b6<.)<(3%,H.<!&.&5Iu
&6<.;F'%**T<.35<(&>%5&.H
######E.DM.<!&.&5M#?BM.<!&.&5;/&($<,5%EZ)E!&'c&,&'<(%'H?IIu
:"*(&E;%)(;D'3,(.,H&6<.;(%:)EE<'":('3,/H(')&IIu

kkK'3(&#3,*(<,F&*#H(%#5%)!.&#F2&FL#,%#5%)!.&*I
+)99&'&5h'3(&'#K'3(&'#j #,&K#+)99&'&5h'3(&'H
#####################,&K#V3.&h'3(&'Hy!,;<'99yIIu
K'3(&';K'3(&H.<!&.&5;(%:('3,/HIIu
K'3(&';,&KX3,&HIu
K'3(&';9.)*2HIu
K'3(&';F.%*&HIu

{F<(F2HbJF&D(3%,#&Iv
        &;D'3,(:(<FL1'<F&HIu
    {
  {
{
```