

# An Exploration of the Interplay between Causality and Cognition in Complex Systems

Dr. Alethea J. Thompson, Dr. Kaidën M. Reyes

Department of Cognitive Science, Rutgers University, New Brunswick, NJ, USA; Department of Physics, University of California, Los Angeles, CA, USA

**Abstract**—7KLV VWXG\ LV DERXW DQ DOJRULWKPLF GHSHQGHQFH RI

\$UWLILFLDO1HXUDO1HWZRURNOXOWLOD\HU3HUFHS WURQO3/SHUWDLQLQJ WR WKHFODVVLILFDWLRQDQG FOXVWHULQJ SUHVHQWDWLRQVIRU oRELOH\$GKRF 1HWZRUNYXOQHUDELOLWLHVORUHRYHUPRELOHDGKRF QHWZRUNO\$1(7 LVXELTXLWRXVLQWHOOJHQWLQWHUQHWRUNLQJGH YLFHVLQZKLFKLVKDWVWKH DELOLW\WRGHWHFW WKHLUHQYLURQPHQXVLQJDQDXWRQRPRXV V\VWHPRI PRELOHQRGHVWKDWDUHFRQQHFWHG YLDZLUHOHVVOL QNV6HFUXULW\DIIDLUVDUH WKHPRVWVWPSRUWDQVXEMHFWLQO\$1(7GXHWRWKHH DV\SHQHWUDWLYH VFHQDULRVRFXUHGGLQVXFKDQDXWRFRQILJXUDWLR QQHWZRUN2QHRIWKH SRZHUIXO WHFKQLTXHV XVHG IRU LQVSHFWLQJ WKH QHWZRUN SDFNHVW LV ,QWUXVLRQ'HWHFWLRQ6VWHP,'6LQWKLVDUWLFOHZH DUHJRLQJWRVWRZ WKH HIIHFWLYHQHV RI DUWLILFLDO QHXUDO QHWZRUNV XVHG DV D PDFKLQH OHDUQLQJDORQJZLWKVWRFKDVWLFDSURDFKLQIRUPD WLRQJDLQWRFDVLI\ WKHPDOLFLRXVEHKDYLRUVLQVLPXODWHGQHWZRUNZL WKUHVSFWWRGLIIHUHQW ,6 WHFKQLTXHV 7KH PRQLWRULQJ DJHQW LV UHVSQRVLEOH IRU GHWHFWLRQ LQIHUHQFHHQJLQHWKHDXGLWGDWDLVFRROHFVHG IURPFRROHFWLQJDJHQWE\ VLPXODWLRQJ WKH QRGH DWDFN DQG FRQWUDVWHG RXWSXWV ZLWK QRUPDO EHKDYLRUVRIWKHIUDPHZRUNZKHQHYHU,QWKHHYHQ WVKDWVWKHUHLVDQ\ GHYLDWLRQIURPWKHRUGLQDU\EHKDYLRUVWKHQWKH PRQLWRULQJDJHQWLV FRQLGHUHG WKLVIHQW DV DQDWWDFN LQ WKLVDUWLFOH ZH DUH JRLQJ WR GHPRQVWUDWH WKH VLJQDWXUHEDVHG ,6 DSSURDFK LQ D O\$1(7 E\ LPSOHPHQWLQJWKHEDFN SURSDJDWLRQDOJRULWKPRYHUHQVHPEOHEDVHG

7UDILF 7DEOH77 WKXV WKH VLJQDWXUH RI PDOLFLRXV EHKDYLRUV RU XQGHVLUDEOH DFWLYLWLHV DUH RIWHQ VLJQLILFDQWO\ SURJQRVWLFDFWHG DQG HIIHFWLQWO\ILJXUHGRXWE\LQFUHDVLRQJWKHSDUDPH WULFVHWSRI%DFN SURSDJDWLRQ DOJRULWKP GXULQJ WKH H[SHULPHQWDO UHVXOWV ZKLFK HPSLULFDOO\VKRZQLWVHIIHFWLYHQHVIRUWKHUDWL RRGHWHFWLRQLQGH[XS WRSHUFHQWDJH&RQVHTXHQWO\LWLVSURYHGLQHPSL ULFDUHVXOWVLQ WKLVDUWLFOHVKHSHUIRUPDQFHPDWULFVHVDUHOVR EHLQJLQFOXGHGLQWKLVDUWLFOH DUWLFOHZLWK;JUDSKVFUHHQVQRZE\GLIIHUHQWVKUR XJKSXVWOLNH3DFNHW 'HOLYHU\5DWLR3'57KURXJK3XW73DQGYHJDJH'HOD\\$\

V\VWHP EDFN SURSDJDWLRQ DOJRULWKP QHXUDO QHWZRUNV WUDILF WDEOH PXOWLOD\HU SHUFHWSURQ IHHGIRUZDUG EDFNSURSDJDWLRQ QHWZRUN VLPXODWLRQ

,,1752'8&7,21

\$

O\$1(7LVDVHOIFRQILJXULQJQHWZRUNWKDWLVIRU PHG DXWRPDWLFDOO\OLNHZLVHVKHPRELOHQRGHV DUHIUHHWRPRYH

O DDG .DPDO \$O\$QQL LV ZLWK 1, /REDFKHVYV\ ,QVWLWXWH 2) &RPSXWHU ODKHPDWLFVDQG,QIRUPDWLRQDO7HFKQRORJLHV.DJQ9 ROJD5HJLRQ)HGHUDO 8QLYHUVLW\ .UHPO\RYVND\D VW .D)DQ 5XVVLDPDLO PDDGN DQQL#OLYHFRP LQWRWKUHHDSURDFKHVILUVVWKHVLJQDWXUH HEDVHG,'6XVHVSUH NQRZQDWDFNVFHQDULRVVULVJQDWXUHVDQGF RPSDUHWKHPZLWK LQFRPLQJSDFNHVVWUDILFVHFRQGO\WKHDQRPD O\EDVHG,'6 DWWHPSVWVRGHWHFWDFWLYLWLHVWKDWGLII HUIURPWKHQRUPDOH[SHFWHG V\VWHPHVKDYLRUXOWLPDWHO\ 7KH6SHFLILFDWLRQEDVHG,'6LVPLQJQHGEHWZ HHQERWKWKH PLVXVHG DQGWKHDQRPDORXVGHWHFWLRQDSSU RDFKHVDFKLQ OHDUQLQJLVDFRPSXWHUVRIWZDUHUHO\LQJQ,' 6DSSURDFKHVWR PHFKDQLJHWKHFVHQDULRVRIQHWZRUNDWDFN VDQGEGLQJ



GLJLWDOLJHGVRIWZDUHWRGHWHFWDQGZDUQW  
 KHDGPLQLVWUDWRUDERXW  
 LWVULVNLVQLVSLWHRI%3KDVXWLOLJHGIRUDFRQ  
 VLGHUDEOHOHQJWKRI  
 WLPHDQGDGDFSDOEHPDFKLQHOHDUQLQJFDOFXO  
 DWLRQ)HHG)RUZDUG  
 %DFN3URSDJDWLRQ))%3)UDPHZRUNVDUHVWLOO  
 WKHPRVW QRUPDOO\ SRZHUIXO \$11 WRSRORJ\ WR  
 DFKLHYH WKH  
 PDWKHPDWLFDQO\VRSKLVWLFWDHGUHODWLRQ  
 VKLSV))%3\$11VDUH  
 FRQQHFVHGLQDEURDGVFRSHRIDSSOLFWDWLRQVL  
 QFOXGLQJVSHHFK UHFRJQLWLRQ UHPRWH  
 VHQLVQJ DQG LPDJH FODVVLILFDWLRQ  
 KDQZULWVHQ FKDUDFWHUGLJLWV  
 UHFRJQLWLRQ GDWD PLQLQJ  
 LQIRUPDWLRQUHWULHYDOWUDYHOLQJVDHVPD  
 Q9/&,SODFHPHQWDQG  
 URXLWQJDQGDVQRWVWKHOHDVWVWKH,'6oXOW  
 LOD\HUHG\$11  
 SHUIRUPDQFHGHSHQGVPDLQO\XSRQWKH1HWZR  
 N7RSRORJ\  
 ZKHQWKHo/3WHFKQLTXHLVSDUDPHWHULJHGZL  
 WKGLIHHUHQWYDOXH  
 ZKLFK\LHOGVWRREWDLQWKHGLIHHUHQWLQIRUP  
 DWLRQDERXWVWKH  
 SHUIRUPDQFHRI\$11WKURXJKSXWVDQGDV\PSWRW  
 LF7KHUHDUH  
 PDQ\DOJRULWKPVIURU\$11OHDUQLQJDOJRULWKPV  
 XFKDV\$GDOLQH +HEELDQ 3HUFHWSURQ  
 /HDUQLQJ UXOH %DFN SURSDJDWLRQ  
 \$UWLILFLDO%HH&RORQ\

.,5(/\$7(:25.6

\$YDVWPDMRULW\UHVHDUFKHVIRUDO\$1(7DUHQD  
 PHO\HLWKHU  
 GLVWULEXWHGDSSURDFKLHORFDOQRGHEDVHG,'  
 6RUV\QHUJLVWLF

DSSURDFKLHFOXVWHUHGQRGHEDVHG,'6KHUHDE  
 RXWZHZLOO  
 KDYHDVKRUWJODQFHDERXWVWKHPRVWKLJKOLJK  
 WHGUHVHDUFKZRUNV  
 'HWHFWLRQ6\VWHPWKURXJKDVFUXSXORXVWVX  
 G\RIGLYHUHV  
 YXOQHUDELOLWLHVLQo\$1(7WKH\LPEHGGHGWKH  
 ,6DVWKH  
 VHFUXULW\DUFKLWHFWXUHIRUDGKRFZLUHOHV  
 QHWZRUNVZKLFKGHWHFWW  
 QRGHVPLVEHKDYLRUDQRPDOLHVLQSDFNHWIRUZ  
 DUGLQJVVFKDV LQWHUPHGLDWH QRGHV

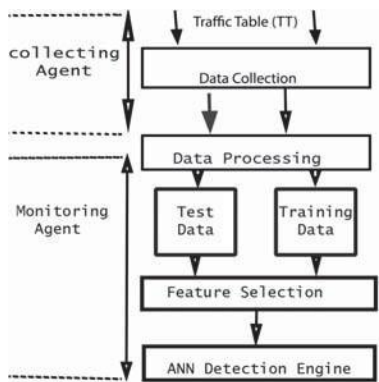
GURSSLQJ RU GHOD\LQJ SDFNHWV  
 HDYHVGURSSLQJDQGPVTVXHUDGLQJDUHDOVRDS  
 SOLFDEOHWKXV  
 LPSOHPHQWDWLRQZLWKPXOWLOD\HUVHFXULW\  
 SURWHFWLRQV  
 HIIHFWLYHO\FRQVXPPDWHGWKHFRRQLYLQJSHU  
 LORXVHOHPHQWLQWR  
 WKHFRXQWRIWKHSDWKUHOLDELOLW\ZKLFKFRQ  
 VLGHUVWKHGLVWDQFH  
 DQGWKHSRSXODULW\FRQFHUQLQJQRGHVVREHD  
 EOH[DPLQLQJERWK  
 WKHVRXUFHSURILOHDQGWKHUHWUDQVPLWWH  
 GRQH\$OVRWKHLUV  
 SURORQJHGVWUXFWXUHHIILFLHQWO\GHWHFWW  
 PDOLFRLXVDQGFRRQLYLQJ  
 QRGHVZLWKLQWKHRUGHUDIWHULVRODWLQJWK  
 HPRUVKLHOGWKH QHWZRUN 7KH VLPXODWLRQV  
 ODXQFKHG ZLWKLQ D YDULHW\ RI  
 o\$1(7VFRQWDLQLQJVVFKDXTLWHSURSRUWLRQV  
 RQFHUQLQJ  
 PDOLFRLXVDVZHOODVFRQQLYLQJQRGHVVLWVCRZ  
 VDVKHLUSURSRVHG VROXWLRQ LQ ZKLFK  
 RIIHUV D FRQVLGHUDEOH WKURXJKSXW JDLQ  
 FRPSDUHGWRFXUHQVWVROXWLRQV  
 LQVWDQFHEDVHGRQWKHUHVXOWVIURPWKHWZR  
 DQDO\]HUV  
 SUHVHQWHG D JHQHUDO LQWUXVLRQ  
 GHWHFWLRQ DJHQW PRGHO DQG  
 SURSRVHDODUNRY&KDLQEDVHGDQRPDO\GHWHF  
 WLRQDOJRULWKP  
 7KH\KDYHIRFXVHGRQWKHSURWHFWLRQRIo\$1(7U  
 RXWLQJ  
 SURWRVROVDQGSUHVHQWVWKHGHWDLOVUHJDUG  
 LQJHHDWXUHVHOFWLRQ  
 GDWDFROOHFWLRQGDWDSUHSURFHVVODUNRY&K  
 DLQFRQVWUXFWLRQ  
 FODVVLILHUFRRQVWUXFWLRQDQGSUDPHWHUWX  
 QLQJ  
 FKDUDFWHULVWLVFRIDWVDFNV

,,, 6<67(o\$5&+,7(&785(

,6PRQLWRUVSDFNHWGDWVWUHDPLQJLQWKH  
 QHWZRUNVLRUGHU WR GLVFRYHU DQ\  
 DEQRUPDO EHKDYLRUV KHUHDIWHU LW LV LWV  
 UHVSRLVLELOLW\WRLPPHGLDWHO\DOHUWVWK  
 HQHWZRUNDGPLQLVWUDWRU  
 IRUDVXFKGHWHFWLQJDOUPV7KHFODVLPEDOD  
 QFHSUREOHPLVRQH RI WKH PRVW LPSRUWDQW  
 IDFWRU WKDW VRPHWLPHV OHG WR WKH  
 GHWHULRUDWLRQRIRYHUDOOSHUIRUPDQFHKHQ  
 FHWKHUHGXFWRQLQ  
 WHUPVRIGDWDVHWVL]DEOHLVQHGHGGE\UHGQX  
 GDQWRIVRPHRIWKH

IHDWXUHVKDWFRQWULEXWHOLWVOHWRWKH  
 GHWHFWRQRURFHVV7RKDQGOH  
 WKHUHGXFWRRLQWQKHLV]HRIGDWDVHWZHXVH  
 DQRYHUVDPSOLQJ  
 WHFKQLTXHWKDWLVVHPDQWLFDOO\VLPLQDUW  
 R>@WKHEDVLFGLHDLVWR  
 DPSOLI\WKHGHQVLW\RIDWDFNLQVWDQFHVE\J  
 HQHUDWLQJ\QWKHLWLF  
 DWWDFNLQVWDQFHVUDWKHUWKDQVLPQSO\UHSO  
 LFDWLQJUHODDWDWDFN  
 7KHSURSRVHG,'6DSSOLHGLQo\$(7LVGLVWULEXW  
 HGLQDQDXUH  
 VRLWFRQVLVWHGRIDFROOHFWLQJJDJHQWQDQDP  
 RELOHDJHQWHTXLSHG  
 ZLWKDQ,'66\VWHPDUFKLWHFWXUHRISURSRVHG,'6  
 FRPSULVHV  
 IRXUFRPSRQHQWVVDVVKRZQLQJLJ

HHSUWVWUDLQLQJVVHW  
 WHVWLQJVVHWYDOLGDWHGWHVWUDLQLQJGDWD  
 VHWLVFUHDWHGWRWUDLQWKH  
 PDFKLQHODUQLQJFODVVLILHU7UDLQLQJGDWD  
 FRQVLVWRIODEHOLQJ  
 RIHYHQVZKHWHULWLVQDQRPDOHYHQWRUDQ  
 DWWDFN7HVWDQD  
 YDOLGDWHGGDWDLVFROOHFWHGQGHVLPXO  
 DWHGDDWDFNHQYLURQPHQW  
 DQGLVLYHULILHGWRSLQSLQWQHYHQWZKH  
 WKHULWLVQDQDWWDFNRU QDQD ZLWK UHDO  
 OLIH FLUFXPVWDQFHV ZKLOH WKH RYHDOO  
 DUFKLWHFWXUHURUWUDLQLQJYDOLGDWLRQDQ  
 WHVWLQJGDWDVHWKDYH  
 WKHVDPHQWZRUNWRSRORJ\DQ\$UFKLWHFWX  
 UH,QSXW+LGGHQ  
 8QLWV2XWSXWV1XPEHUVRIKLGGHQOD\HUVW\SH  
 RIDFWLYDWLRQ  
 IXQFWLRQXVHGVDVVKRZQLQJ7DEOH,



)LJ\$SURSRVHG6\VWHPIRU'LVWULEXWHGORELOH,'6\$JH  
 QW

*A.Data Collection*

7KHFROOHFWLQJJDJHQWLVUHVSRQVLEOHIRUG  
 DWDFFROOHFWLRQ  
 WKHUHIRUHWKHSURSRVHGV\VWHPVVKLJKO\GHS  
 HQGHQWDERXW  
 SUHGRPLQDWLQJQRUPDOLQVWDQFHVRYHUDWW  
 DFNLQVWDQFHVZKLOH  
 ERWKLQVWDQFHVUDUHFUHDWHGGXULQJWKHVLP  
 XODWLRQWLPHOLNHZLVH  
 WKLVDGDWDVHWZDVGHULYHGIURPUHDOOLIHVSD  
 FHQHWZRUNZLWK  
 VLPXODWLQJWKHQDQRPDOVFDULQRUPDOSDF  
 NHWIROORZDVZHO  
 DVWKHDWDFNVFHDULREODFNKROHDQGIORR  
 GLQJDWDFNV

*B.Data Processing*

\$XGLWGDWDLVWUDQVIRUPHGLQWRDQDSSURS  
 ULDWHIRUPDWZKLFK EH XWWHU  
 XQGHUVWDQGDQD LQ WKH FRPSXWHULJDWLRQ  
 SURFHVV  
 8OWLPDWHO\SURFHVVHGGDWXPIDOOQWRWVKU

	7\$%/(, 7+(%\$&.3523\$*7,21\$5&+,7(&785(
'DWD6HW	\$UFKLWHFWXUH :HLJKWV7UDLQLQJ9DOLGDWLRQ 7HVWLQJ

)ORRGLQJ\$WDFN  
 %ORFNKROH\$WDFN  
 C.Feature Selection

7KLVWHFKQLTXHILUVVFDQDWHVWVKHLQIRU  
 PDWLRQJDLQIG)RI  
 HDFKIHDWXUHDQGWKHQRXWSXWVWKHUDQRI  
 HDFKIHDWXUHEDVHGRQ  
 LQIRUPDWLRQJDLQYDOXHV7KHKLJKHUWKHLQIR  
 UPDWLRQJDLQWKH  
 PRUHLPSRUWDQWVKHHDWXUHLVZLWKUHVSHF  
 WWRWKHFODVVDUJHW  
 YDULDEOH7KHLQIRUPDWLRQJDLQIG (F)  
 FDOFXODWHGE\RI  
 IHDWXUH)M)LYHQFODVVYDULDEOH<LVFDOFXOD  
 WHGE\WKHIRUPXOD  
 HQWURS\ZKHUHDQGDUHWKHHQWURS\RI<EHIRU  
 HDQGDVHWU

5.2.1.1. The role of the data collection agent

The role of the data processing agent

The role of the feature selection agent



FDUU\RQWKH  
 XSGDWLQJZHLJKWXQWLOQRFKDQJHVLVEHHQRFF  
 XUUHGRUWKH  
 QXPEHURILWHUDWLRQVLVRYHUPHDQVTXDUHHU  
 URULVRQHRI  
 WKHVHVWRSSLQJFULWHULDGHQRWHGE\o6(LVFD  
 OFXODWHGE\  
 LWWHOOVXVKRZFORVHUHJUHVVLVRQOLQHLVWR  
 DVHWRISRLQWV

உகமாகக் கொண்டுள்ள பண்புகள் பற்றி பண்புகள் பற்றி

தொடர்பு கொண்டுள்ள பண்புகள் பற்றி பண்புகள் பற்றி

7KHSDUWLDQOGHULYDWLYHE\RIWKHORJLVWLF  
 XQFWLRQLV  
 WKHRXWSXWPXOWLSOLHGE\PLQXVWKHRXWSXW

உகமாகக் கொண்டுள்ள பண்புகள் பற்றி பண்புகள் பற்றி

பண்புகள் பற்றி பண்புகள் பற்றி

7KHWRWDOHUURUDVDFODFXODWHGE\IRUWKHQ  
 HXUDOQHWZRUNLV WKHVXPRIWKHVHHUURUV

உகமாகக் கொண்டுள்ள பண்புகள் பற்றி பண்புகள் பற்றி

உகமாகக் கொண்டுள்ள பண்புகள் பற்றி பண்புகள் பற்றி

)LQDOO\KRZPXFGRHVWKHWRWDOQHWLQSW  
 RIÖFKDQJHZLWK  
 WKHUHVSHFWWRÖVHHQLQDQ

x7KH%DFNZDUGV3DVV7KHJRDOZLWKEDFNSURSDJD  
 WLRQDW  
 WKHEDFNZDUGVSDVVGGLPLQLVKHVWKHHUURUSU  
 RGXFLQJGXULQJ WKHIRUZDUGVSDVV  
 FRQVHTXHQWO\HUURULVDSHUWDLQLQJLQ  
 DFFRUGDQFHZLWKFKDQJHVKHZZHLJKWVZLWKLQV  
 XFKDZD\WKDW  
 WKHHUURUZLOODUULYHVPDOOHUWKHPHWKRGV  
 UHSHDWHGRQFH  
 PRUHRUDJDLQWLOOWKHSWLPDOIXQFWLRQLVPL  
 QLPDOWKDWLV  
 FRPSXWHGE\XVLQJVWHSVEDFNZDUGV

பண்புகள் பற்றி பண்புகள் பற்றி

உகமாகக் கொண்டுள்ள பண்புகள் பற்றி பண்புகள் பற்றி

7KLVDFODFXODWLRQFRPELQHGQGLQWKHIRUP  
 RI  
 WKHGHOWDUXOHWKXVLWLVREWDLQHG

x 2XWSXWKLGGHQ OD\HU XSGDWH %DFN  
 SURSDJDWLRQ  
 DOJRULWKPLVEDVHGRQGHOWDOHQUQLQJUXOHLQ  
 ZKLFKWKH  
 ZHLJKWVPRGLLFDWLRQLVGRQHWKURXJKPHDQVT  
 XDUHHUURURI  
 WKHRXWSXWPDSSLQJOD\HUWRWKHLQSWPSSLQ  
 JOD\HUZKLFK  
 LVPRGXODWHGWKHOD\HUDGMXVWPHQWEADQG  
 VPRHVLPHVFDQHG &KDLQ 5XOHDV  
 LVDSUWLDQ

பண்புகள் பற்றி பண்புகள் பற்றி

\$OWHUQDWLYHO\ZHKDYH DQG ZKLFKFDQEH  
 பண்புகள் பற்றி பண்புகள் பற்றி

DND<sub>oi</sub>  
 WKH\*UHHNOHWWHU'HOWDDNDWKH  
 Node பண்புகள் பற்றி

**Delta,**

:HFDQXVHWRUHZULWHWKHFDFODFXODWLRQ<sup>∇</sup><sub>oi</sub>  
 E\

பண்புகள் பற்றி பண்புகள் பற்றி

'ZDFODFXODWHGE\  
 பண்புகள் பற்றி பண்புகள் பற்றி

பண்புகள் பற்றி பண்புகள் பற்றி

GHUYLDWLRQRI(WRWDQZLWKUHVSHFWWR:L  
 7RILQGRXWKRZPXFQDGHGTXDWHPRGLLFDWLRQ  
 RIHUURUFKDQJH  
 WKDWPXVWEHRFFXUHGWRUHDVFKWKHJOREDOP  
 LQLPDZLWKUHVSHFW  
 RIWKHRXWSXWVRZHQHGWRLJXUHRXWHDFKSL  
 HFHLQWKL  
 TXHVWLRQDQGHYDOXDWHLWUHO\LQJRQWKHGL  
 IHHUHQWLDQGHULYDWLYH

K

:HIXQFWLRQWKHUHDOZHLJKWXS GDWHV LQWK
HQHXUDOQHWZRUN
WKHQZHEHDUWKHFRQVHFVWLYHZHLJKWFKDQJ
HVLQWRWKHWKHLGGHQ OD\HUQHXURQVE\

WROH DUQLQJWKHPRGHOLQRUGHUWRGHWHFVW
KHPDOLFLRXVDFWLYLWLHV RI PRELOH DG KRF
LQWUXGHUV E\ PRQLWRULQJ LWV PDOLFLRXV
VLJQDWXUHV RUPLVEHKDYLRUV

,9 6<67(0,03/(0(17\$7,21

o a e o o a 9 d d d d d o o o

7KHSURSRVHGV\ VWHPXVHV16YHUVLRQV[8EXQ
WX

ZKHUH H WDLVOH DUQLQJUDWH

&DQG2EMHFWRULHQWHG7RRO&RPPDQG/DQJXDJ
H27FO
VFULSWIRUVPXODWLQJWKHDWDFNVLQo\$1(7D
QGLWVVPXODWLRQ
HQYLURQPHQWUHLJYHQWDEOH,,W LV
XWLOLJHG IRUWKH UHSURGXFWLRQ RI V\ VWHP
SURWRFR ZLWK YDULRXV V\ VWHP
WRSRORJLHVLWLVLPSOLFLW&DQGJLYHVWKHPDQ
LSXODWLRQ

x +LGGHQLSXW /D\HU XSGDWLRQ 1H[W
FRQLQXH WKH
EDFNZDUGVSDVVE\FDOFXODWLQJQHZYDOXHV
IRUDOOZHLJKWV
IURPKLGGHQQHXURQVWRLQSWXWOD\HU,WX
WLWL]HVDVDPH
SURFHGXUHDVKDGIKRWKHXWSXWOD\HU\H
WDELWGLVVLPLQDULW\
WRUHSUHVHQWVKHZD\WKDWKHL\HOGRIH
DFKKGGLQD\HU
QHXURQDGGVWRWKHXWSXWDQGFQRVHTXH
QWO\HUURURI
QXPURXVRXWSXWQHXURQV:HUHDOLJHWKD
W287KH\

LQWHUIDFHWKURXJK27FO\$GGLWLRQDOO\LWLVD
QRSHQVRXUFH
HYHQWGLYHQVLPXODWRUGHVLJQHGVSFLILFD
OO\IRUHVHDFKHLVLRQ
FRPSXWHUFRPPXQLFDWLRQQHWZRUNV,WSURYLG
HVDZLGHSUHDG
DVVLVWDQWLQFRQIRUPLW\ZLWKWKHVLPXODWH
GHQYLURQPHQWRYHU

LQIOXHQFHVWRWK287XVHDQGOU2WKHUHIRUH
WKH

SURWRFRQDV7&3)738'3+773WKHQ'65ZLKFQDNHV
XVHRI27FOLQLPLWDWLRQRISURSDJDWLRQDORQJ
ZLWKFRQILJXUHD

QHHGVWRWDNHLQWRFRQLGHUWLRQLWVHIIIH
FWRQWKHERWKRXWSXW

QHWZRUNRU&DFFRUGLQJWROHDGVLQXODWLRQ
WKHUHIRUH&

QHXURQV

FRGHVQHGHGWRHFRPSLOHGDQGLQNHGDIWHUF
UHDWHDQH[HFVWDEOH

7KHSDUWLDOGHYLDWLRQRIKLGGLQWRLQSWXWS
GDWLQJPLJKWDOVR

ILOH:HKDYHWRXVHQRGHVWRIRUPWKHo\$1(7XVLQ
J\$'29

EHVHHQZULWVHQE\DQG

URXWLQJSURWRFRQ(DFKRIZKLFKDUHDOOPRELO
HQRGHV7KHQWKH

d a d d d o o

d d o e o o a d d d d d d d d d d d d d d d d

VRXUFHQRGHZLOOVHQGWKHVHFRQGURXWHUHT
XHVV55(4WRDOO

d a d d d o o

d d o e o o a d d d d d d d d d d d d d d d d

QHDUHVWQRGHWRUHDFKWKHGHVWLQDWRQDQ
GDOVRVHQGWKHURXWH

:HFDQQRZXS GDWHZHLJKWV FDOFXODWHGE\

UHVSRQVH55(3WRDOOQHDUHVWQRGHWRUHDFK
WKHVXUFHQGXULQJ

o a e o o a 9 d d d d d o o o

)LQDOO\ZHKDYHXS GDWHGDOORIZHLJKWVDQGF
RQLQXHSVVVLQJ
WKURXJKWKHWZRSKDVHVXQWLOWKHGHVLUHGR
XWSXWRFFXUUHG7KXV
WKLWVHFQKLTXHZRXOGEHYHU\ DGYDQW DJHGFO
DVVLILFDWLRQVWUDWHJ\

WKH55(4DQG55(3WKHDWDFNVHUQRGHZLOOEHJH
WWKHGDWD\VE\

H[SORLWLQJWKHPDVTXHUDGHVVFHQDULREXWQR
WWUDQVIHUWRQH[WWR

QRGHWKDWZHFDOOHGDVWKHIUDXGXOHQFHYYH
QWWKHQGHWHFVWVKH

DWDFNVHUQRGHUHO\LQJRQWKH%%3\$GGLWLRQ
DOO\ZHFRXOGEH

DEOHWRXVHWKH;JUDSKVUFUHHQWRHYDOXDWH
WKHSDWKEHWZHHQWKH

VRXUFHQDQGHVWLQDWRQ)RUURXWHVHOHFWL

RQZXVH'65URXWLQJ
SURWRFRO7KLVVHOHFWVWKHEHVWDQGDQOVVK
RUWHVWSDWKEHWZHHQ
WKHVRXUFHDQGGHVWLQDWLRQ

Simulated

Attack, QWKLVSURMHFWWKHEODFNKROHDWDFN
DQG
IORRGLQJDWDFNDUHVLPXODWHG

Flooding Attack: LW FRQFHULQJ ZLWK WKH
SHQWUDWLLYH
SKHQRPQRQZKHQDPDOLFLRXVQRGH&VHSDUDW
HVWKHLOOLFLW
DSSURDFKIRU55(4IORRGLQJDQGGWDIORRGLQJD
PHO\
FDOOHG'LVWULEXWHG'HQLDORI6HUYLEFH\$WDFN
'R67KH
PDOLFLRXVQRGH&FDQODXQFKIDNH55(4VRUGDWD
SDFNHVW E\ IORRGLQJ WKH QHWZRUN ZLWK VR
PDQ\ UHTXHVWV
FRQVHTXHQWO\OHDGVWRWKHFRQJHVWLRQRIW
KHQHWZRUNDQG
UHGXFHVWKHSUREDELOLW\RIGDWDWUDQVPLV
LRQRIWKHJHQXLQH
QRGHV(YHQWXDOO\OHDGVWRORVHWKHSRWHQ
WLDOLQIRUPDWLRQ
WUDQVPLVWHGWKHIORRGLQJDWDFNL00XVW
UDWHGLQ)LJ

7\$%/(,
166,08/\$7,21(19,5210(17

Table with 3 columns: 6QR, 3DUDPHWHUV, 9DOXH. Rows include 6LPXODWRU'XUDWLRQ, VHFRRQV, 7RSRORJ, P P, 1XPEHURIORELOH1RGHV, 7UDQVLWLRQ5DQJH, P, 1RGH0RYHPHQW0RGHO, 5DQGRP:D\SRQW0RGHO, 7UDIILF7\SH, &%58'3, 'DWD3D\ORDG, E\WHV

)LJ%ODFN+ROH\$WDFN

1RUPDO SURILOH LV DFFXPXODWHG WRJHWKHU
ZLWK WKH QRQ
H[LVWHQFHFRIDWDFNV:KHUHDVWKHDWDFNS
URILOHLVFRQVWUXFWHG
WKURXJKVLPXODWLQJWKHEODFNKROHDQGIORR
GLQJDWDFNV9DULRXV

7\$%/(,,
75\$),&5(/\$7C)(\$785(6
3DFNHV7\SH

'DWD5RXWH5HTXHVW5RXWH5HSO\5RXWH(UURUDQG+HOO
R

)ORZ'LUHFWLRQ 6HQG5HFHLYH)RUZDUGHG'URSSHG

7KHURJLQDOGDWDVHWH[WUDFWHGIURPDWUD
IILFWDEOHLQZKLFKLW
FRQVLVRIWKHSDFNHWW\SHDQGWKHIORZW\SHI
LUVWRQHKKDVLVYH
FRPSRQHQVHDFKRQHRIWKHPVKRZVDVSHFILFUR
OHLQWKH
GLVFRYHU\SURFHVVOLNHWKH5RXWH5HTXHVW55
(4VHDFKQJWKH
URXWHIURP6RXUFH1RGHWR'HVWLQDWLRQ1RGHO
DWWHUFRRQDLQV
IRXUW\SHVREYLRXVO\GHVFULSWHGE\LWVIORZG
LUHFWLRQOLNHWKH
'URSSHGDFWLRQPHDQVGLVFKDUJLQJWKHSDFNH
WVLQDVSHFILFQRGH
LQZKLFKWKRVHVGURSSHGSDFNHWVKDYHQRIIHF
WDQ\PRUHKHQFH
WKHUDZGDWDVHWSVVHVWKURXJKWKHSUHSUR
FHVWRIRUPXODWH
WKHVHGDWDVHVLQWRDQDSSURSULDWHIRUPH
DGDEOHE\WKHPDFKLQH
OHDUQLQJDVZHOOWKHGHWDLOHGIHDWXUHVFD
SWXUHLQYROYLQJWKH
DFWXDOHQFRGLQJFDUU\VRXWZLWKLQ27FOOLNH
ZLVH+HOORSDNHVW
HQFRGE\WKH27FOVFULSWDV NBHelloSend and
NBHelloRecv. 7KHUHIRUHWRWDOO\
IHDWXUHVDUHFRQVLGHUHGIURU

7\$%/(,9
&2/(&7C)(\$785(6

Table with 2 columns: 'DWD3DFNHVW, NBDataSend, NBDataRecv, NBDataDrop, NBDataFwd. Rows include 55(4, 3DFNHVW, NBRREQSend, NBRREQRecv, NBRREQDrop, NBRREQFwd, 55(3, 3DFNHVW, NBRREPSend, NBRREPRecv, NBRREPDrop, NBRREPFwd, 5(55, 3DFNHVW, NBRERRSend, NBRERRRecv, NBRERRDrop, NBRERRFwd, +HOOR3DFNHVW, NBHelloSend, NBHelloRecv

Training

Data:VRIDUZHKKDYHH[SODLQHGWKHVKDIIOLQJ
SURFHVVIRUJDWKHULQJWKHUDZGDWDVHWD
VZHOODVWKH SUHSURFHVVHG VWDJH KHQFH
WKH GDWD VHW LV UHDF\ IRU
FRPSXWHUL]LQJDQGSUHVHQWLQJWRWKHPDF
KLQHOHDUQLQJWKH
V\QWKHWLFDSSURDFKWXQHVSZLWKQRUPDO
DQGODEHOHG
SURILOHVQDPHO\WZRFODVVHVQRUPDODQGD
EQRUPDO7KLV
GDWDVHVLVXVHGDVWRFKDVWLFHIDWXUHV

HOHFWLRQDQGFODVVLILHU
HDFKIHDWXUHLVUHSUHVHQWHGE\DSDFNHW
W\SHDQGIORZ GLUHFWLRQ

Testing and validation data

:7KHDFFXPXODWHGWUDLQHGGDWD
ZLOOEHVHSDUDWHGDVYDOLGDWLRQGDWDDQG7
HVWGDWD7HVWGDWD
DUHDFFXPXODWHGE\XVLQJWKHVLPXODWHGEOD
FNKROHDQG
IORRGLQJDWWDNFVVKURXJKYDU\LQJWKHDWWD
FNHUV,WZLOOEH
SXWIRUZDUGDVOLNHLQSWWRWKHFODVVLILHU
LQRUGHUWRLGHQWLI\
ZKHWKHUWKHSUDUWLFXODUHYHQWLVDQDWWDF
NRURUPDO2QFH
WKHGDWDLVDFFXPXODWHGLWZLOOEHJLYHQIRU
WKHIHDWXUH
VHOHFWLRQPRGXOH7KHDFFXPXODWHGIHDWXU
HVWUDQVIRUPHGLQ DFFRUGDQFH ZLWK
FRPSXWHU UHGDDEOH IRUP WKHQ WKH
VWRFKDVWLFODVVLILHULVFRQVWUXFWHG&RQ
VWUXFWHGFODVVLILHULV
WUDLQHGLWZLWKWUDLQLQJGDWDDQGYDOLGD
WHGWKURXJK

9352%/(0,'(17.),&\$7,21\$1'62/87,21

&ODVVLILFDWLRQDQGFODVVLILHU
RQ'HWHFWLRQIRU
o\$1(7KDVEHHQGHILQHGDVWKHFRQYHUVLRQRI7U
DIILF7DEOH
,QWKLVDSSURDFKZHYLHZRXUDJHQWVVDXWR
QRPRXPVRELOH
SURDFWLYHDQGFRRSHUDWLYHHQWLWLHV\$JHQ
WVDUHHTXLSSHGZLWK%3
LQZKLFKUHVSQRVLEOHIRUDOHUWLQJV\VWHPQH
WZRUNDGPLQLVWUDWRU
ZLWKDQ\SRVVLEOHDFNUHODWHGDFWLYLW
LHV

2XUDSSURDFKFRQVLVWVRIWZRW\SHVRIDJHQW
V&ROOHFWLRQ \$JHQWDQGoRQLWRULQJ\$JHQW

Collecting Agent: ,W JHWV WKH WUDIILF

IHDWXUHV RI WKH
QHLJKERULQJQRGHVDQGFUHDWHVD7UDIILF7DEO
H77VXFQDV
o 3DFNHHW\SH o
)ORZGLUHFWLRQ o
6DPSOLQJSHULRG
V o
6WDWLWVWLFPHDV
XUHV

Monitoring

Agent: ,WLVQRWSUHVHQWLQDOOWKHQRGHVEXW
LWLV

SUHVHQWRQO\LQDVXEVHWRIQRGHV%\XVLQJWK
H77LQIRUPDWLRQ
IHHGLQJWR%3WRFODVVLILHU\WKUHDWVDPQJVLXPX
ODWHGQHWZRUNVLW
PRQLWRUVLWVQHLJKERUQRGHVEHKDYLRU:KHQD
QDEQRUPDO
EHKDYLRURUDQ\GHYLDWLRQLQWKHWUDIILFSDW
WHUQRIWKHQQRGHV
RFFXUVWKHQLWUDLVHVDQDODUPIRULQWUXVLR
Q

7KHNHUQHORI%3LPSOHPHQWDWLRQVXSSRUWL
YHRIORQLWRULQJ
\$JHQW:RUNLVFRPSURPLVHGRIH[SHULPHQWVVDV
KRZQLQ
7DEOH9DVZHOODV)LJVDQ:HQHHGWRXVHGWKHI
ROORZLQJ
V\PEROVLQWKHWDEOHRI%3LPSOHPHQWDWLRQ
o([SHULPHQWIXPEHU
oIXPEHURI,WHUDWLRQV
o/HDVV)LWQHVVV0HDQ6TXDUH(UUR
U
o\$FFXUDFVHYHORIWKH/HDUQLQJ
o^\$/J\$OJRULWKP

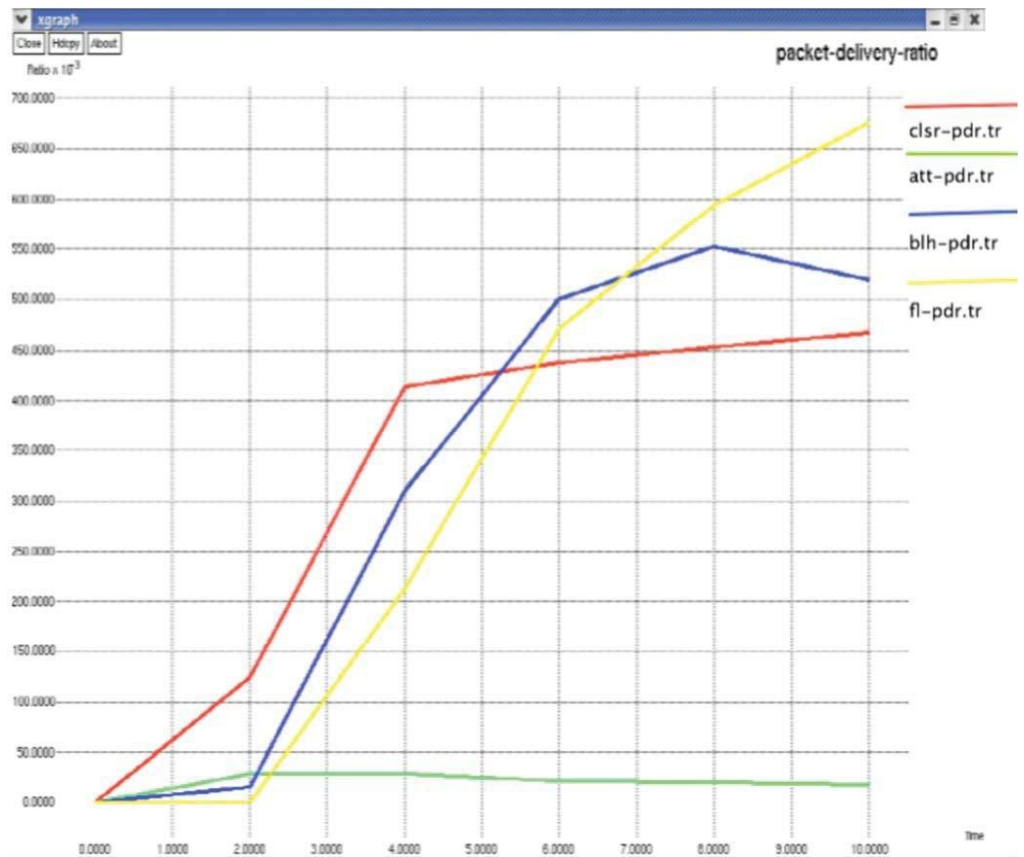
7KHPXOWLOD\HUSHUFHSWURQVHVWDEOLVKHG
IRUHOHYDQWSXUSRVHV DUH WUDLQHGLWZLWK %3
DOJRULWKP UHVSHFWLYHO\ WKURXJK WKH
VHOHFWHGWUDLQLQJHVW
,QRUGHUWRHVWDEOLVKDIDLUVWUDUWXSVDW
HIRU%3EDVHG
SHUFHSWURQVWKHWUDLQLQJSURFHVHVHVRI%3ED
VHGSHUFHSWURQV DOZD\VVWUDUW ZLWK UDQGRP
VROXWLRQ SDUDPHWULF JUDGXDOO\
DWHPHPSWLRQJWRJHWDWRSWLPDOUHVXOWIRU%3
EDVHGSHUFHSWURQV
VXF3HYROXWLRQWLPH'GLUHFWO\HTXDOVWKH
WLPHVRIWVXSGDWHG
LWHUDWLRQV7KHLPSOHPHQWDWLRQLVGRQHIRU
H[SHULPHQWVIRU
'DWD6HWGLYLGHGWRWUDLQLQJHVWDQGWHVWL
QJHVHE\
UHVSHFWLYHO\,WVREYLRXVWKDWH[SHULPHQW
LVPXFKEHWWHUWKDQ
RWKHUVGXHWRWKHPLQLPDOUURUFUHFWRU
QDQGWKH\$FFXUDF\
/HYHO

Table with 5 columns: (,3, \$/J, 1R, 06(, \$/. Row 1: 7\$(%/(9, %3(3(50(17\$/5(68/76. Row 2: (%3, %3, %3, %3.

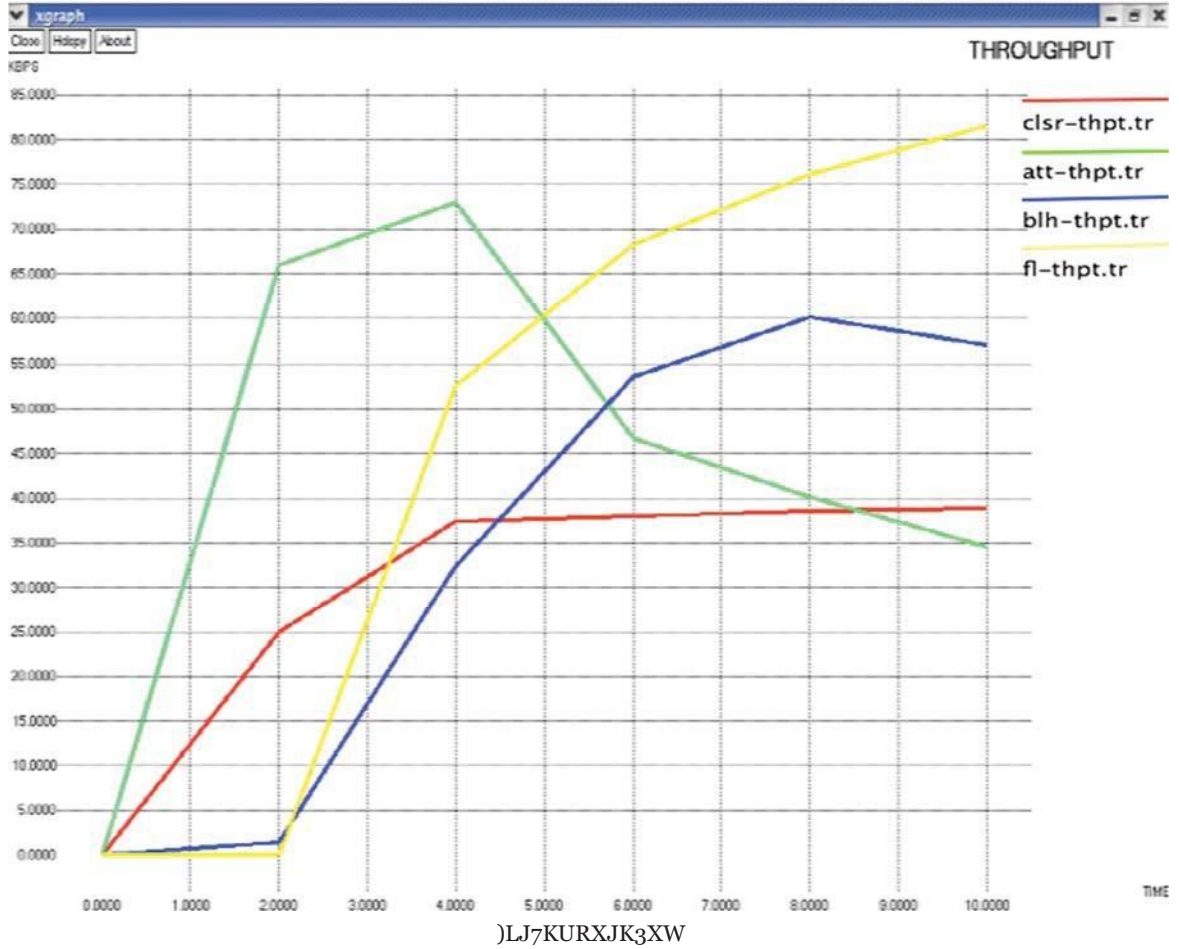


DQGIORRGLQJDWWDFNV ,QIXWXUHWKHIHDWXUHVHOHFWLRQLVHYDOXDWHGZLWKYDULRXV  
\$IWHUWKHFRPSXWHULJHGIRUPDQGIHDWXUHVHOHFWLRQWHFKQLTXH  
H[FOXVLYHFODVVLILHUVLWZLOOEHFPELQHGWSURGXFDHGHVLUHG  
LVDSSOLHGUVSHFWLYO\VLQFHWKH%3DOJRULWKPLVXVHG7KH  
UHVXOWIRUGLIHUUHQWW\SHRIDWWDFNV  
VHOHFWHGIHDWXUHVDUHXVHGGXULQJWKHGLVFRYHU\SURFHVVWKH

International Science Index. Computer and Information Engineering Vol:11, No:6, 2017 waset.org/Publication/1000792



)LJ3DFNHW'HOLYHU\5DWLR



)LJ\$YHUDJH'HOD\

&RPSXWHU6FLHQFHDQG1HWZRUN6HFXULW\92/1R1RYH  
PEHU >@ 2 'HSUHQ o 7RSDOODU ( \$QDULP DQG o N &LOL] <sup>3</sup>An  
*Intelligent intrusion detection system (IDS) for anomaly and misuse  
detection in computer networks,*([SHUW6\VW\$SSOYROQRSS

&LWHGRQSDJHVDQG

KWWSZHEKRPHFVXYLFFDaZNXLUHVHDUFK,'6SGI

YROQRSS&LWHGRQSDJH

>@ o+DOODQG\*+ROPHV"*Benchmarking attribute selection  
techniques for discrete class data mining," IEEE Transaction on  
Knowledge and Data Engineering, vol. 15, no.6, pp.1437-1447,  
2003. Cited on page 88 and 93.*