Intrusion Detection with Genetic Algorithms and Fuzzy Logic

Emma Ireland

Division of Science and Mathematics
University of Minnesota, Morris
Morris, Minnesota, USA

December 7, 2013
UMM CSci Senior Seminar Conference

The Big Picture

- Computer lab gets large numbers of login attempts that are attempts at intrusion.
  - Trying to gain root access to the system
  - Delete files of users and change user passwords.

- An attempt is an attack if there are more than n number of attempts within t time interval.
- Number of login attempts (for failed passwords or for users that don't exist) over period of 6 days (12/1 - 12/6):
  - normal lab box (avenger): 1,834 attacks
  - normal box, more recently added than avenger (kenshiro): 1,887 attacks

The Big Picture

- With intrusion detection system (IDS): classify attempts.
- Intrusion detection systems provide a way of detecting attacks by monitoring network activities for malicious or abnormal behaviors then producing reports, alerts, actions.
- Training an IDS: use a fuzzy genetic algorithm.

Outline

Outline

Types of Networking Attacks

- Denial of Service (DoS) - makes machine inaccessible to user by making it too busy to serve legitimate requests.
  - Systems lockout user from account after failed login attempts.
  - Use this to prevent users from logging in, by failing to log in enough times to lock account.
- Probe - examines machine to collect info about weaknesses, could be used to compromise system.
  - Trying to determine version of software is being run, if it has known issue it allows attacker to attempt to attack that.

Detection Methodologies

- Signature-based detection: compares well-known patterns of attacks that are already known to IDS against captured events in order to identify possible attacks.
  - Simple and effective way to detect known attacks, ineffective against new kinds of unknown attacks.
- Anomaly-based detection: looks for patterns of activity that are rare and uncommon.
  - Harder to do than signature-based detection, can be an effective way to detect new, unknown attacks.

KDD99

- Generated by simulating a military network environment in 1999.
- Has long been a standard data set for intrusion detection.
- Data was processed into 5 million *records*.
  - A record is a sequence of TCP packets, between which data flows to and from a source IP address to a target IP address.
- Each record: classified as either normal or attack.

Features of KDD99

- KDD99 uses 41 *features* - properties of record that are used to describe activity, help to distinguish normal connections from attacks.

- duration: length of the record in seconds.
- num_failed_logins: number of failed login attempts.
- root_shell: returns 1 if root shell is obtained, else returns 0.

RLD09

- RLD09: created because KDD99 was 10 years old, newer attack types not in KDD99 because of age.
- Data was captured from university in Bangkok, Thailand.
- Has normal network activity, and 17 different types of attacks

Rules

- A commonly used approach for detecting intrusions is to use rules.
- If-Then format: If (*condition*) then (*consequence*).
  - Condition: one or more features
  - Consequence: says if it is an intrusion or not.
  - If *duration* $\leq$ *4* then *intrusion*.

Training and Testing Sets

- Algorithm used runs risk of memorizing the data in training set, so important to keep some data separate, as unseen data for testing.

- Divide data set into 2 subsets: *training set* and *test set*.
- The given algorithm is trained on the training set to look for patterns.
- These patterns are then verified using the test set.

Determining the Accuracy of an Algorithm

	Predicted	
Actual	Not Attack	Attack
Not Attack	True Negative (TN)	False Positive (FP)
Attack	False Negative (FN)	True Positive (TP)

Detection rate (DR): percentage of normal and attack activity correctly classified from the total number of data records.

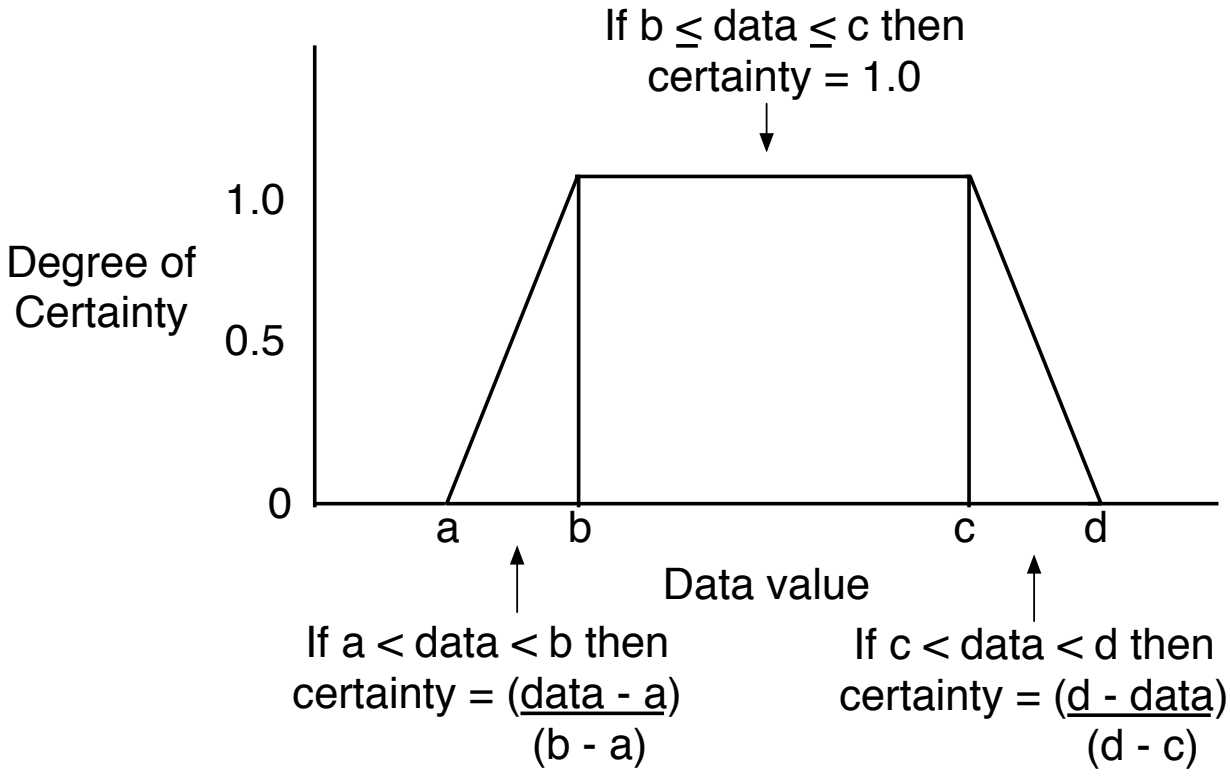
Outline

Fuzzy Logic

- Fuzzy logic: used in intrusion detection systems to find degree of certainty of record being attack.
  - If it's not clear if activity is an attack, fuzzy logic says where on a spectrum it is and how certain it is of being an attack.
- Fuzzy logic rules: similar to rules described before, except that consequence is certainty factor.
  - If (*duration* = 6.2) then (*the degree of certainty of the record being an attack is 0.8*).

Trapezoidal Shape

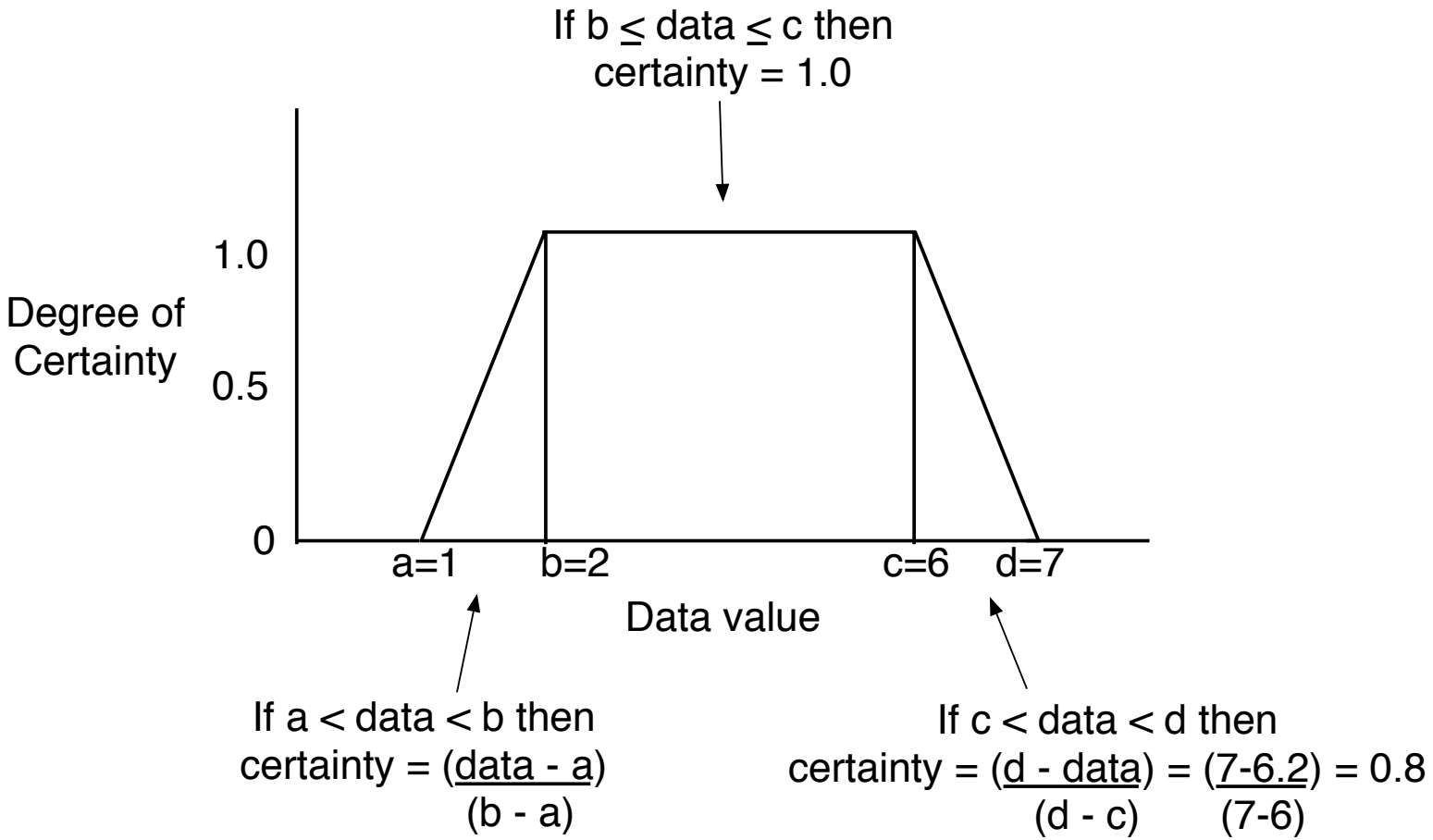
- Used to decide how certain a record is of being an attack.
- Described with 4 numbers that are used to determine what the trapezoid looks like.



- Certain in middle, not as certain in triangle areas.

Finding the Degree of Certainty of a Record Being an Attack

Suppose that the feature is duration, and it is 6.2 seconds. Then data=6.2.



Encoding of Features and Rules

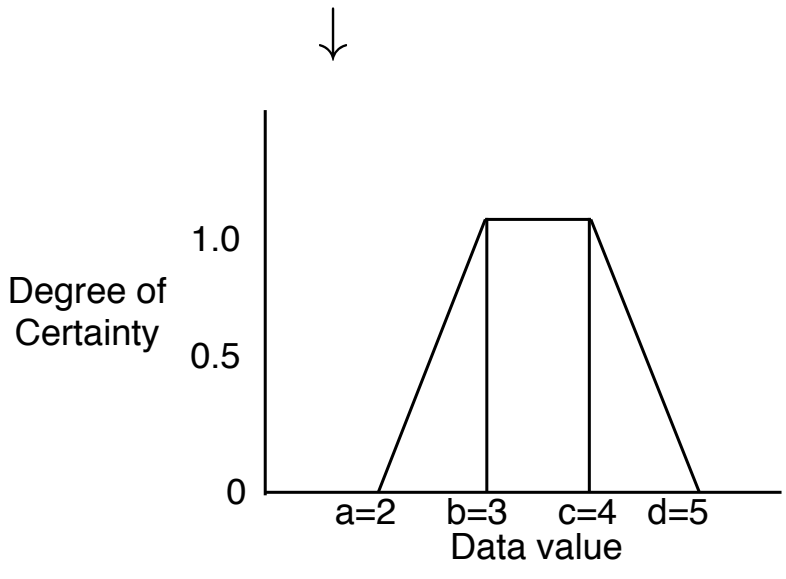
- Four parameters are encoded into blocks. Each block is feature with values 0-7.
- Rule has 1 block for each of 12 features followed at end by marker indicating type of attack.

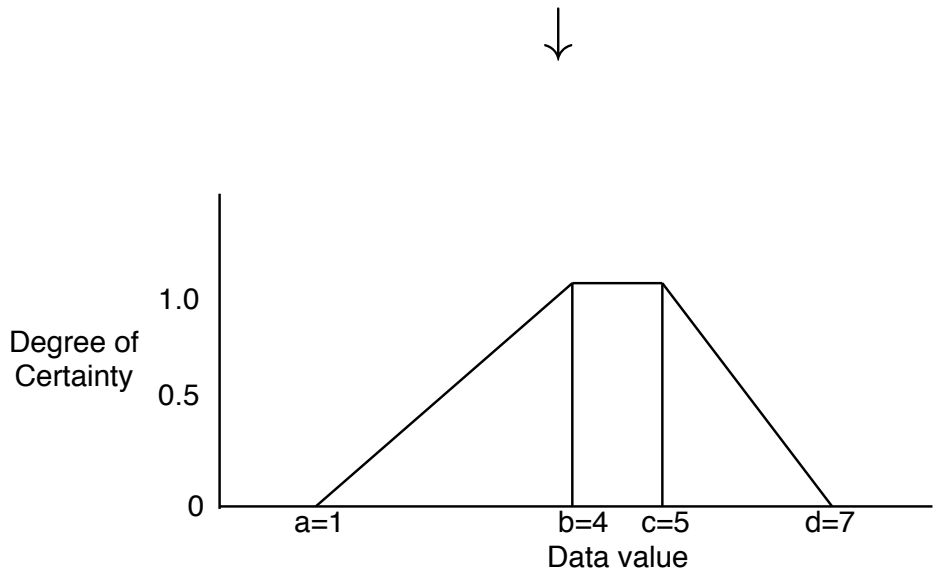
010	011	100	101	...	001	100	101	111	Attack
a=2	b=3	c=4	d=5	...	a=1	b=4	c=5	d=7	
		Block 1				Block 12			Type

Figure : Based on [Jongsuebsuk *et al.*, 2013]

Encoding of Features and Rules

010	011	100	101	...	001	100	101	111	Attack
a=2	b=3	c=4	d=5	...	a=1	b=4	c=5	d=7	
		Block 1				Block 12			Type





Degree of certainty is computed for each of 12 blocks, if sum of those is greater than a threshold, declared as attack.

Outline

Genetic Algorithms

- GAs: search technique used to find solutions to problems.
- Possible solutions to problems: represented in a variety of problem dependent ways.
  - IDS rules are represented as bit strings.
- A randomly generated population of potential solutions is created. Mutation, crossover, selection applied to each generation until acceptable solution is found or time limit is exceeded.

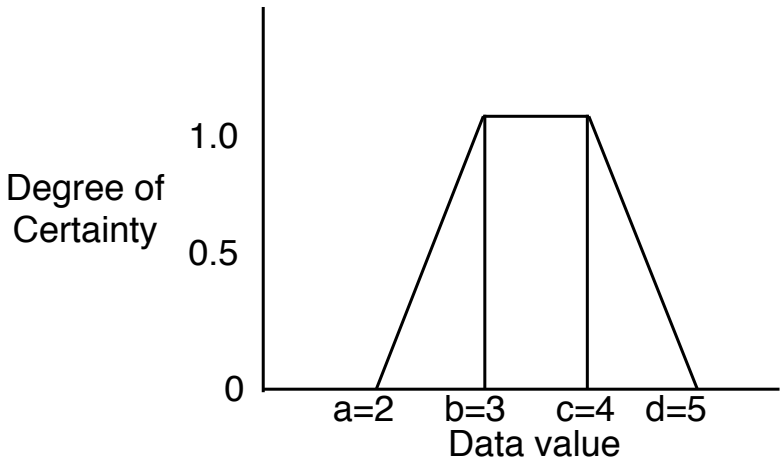
Mutation

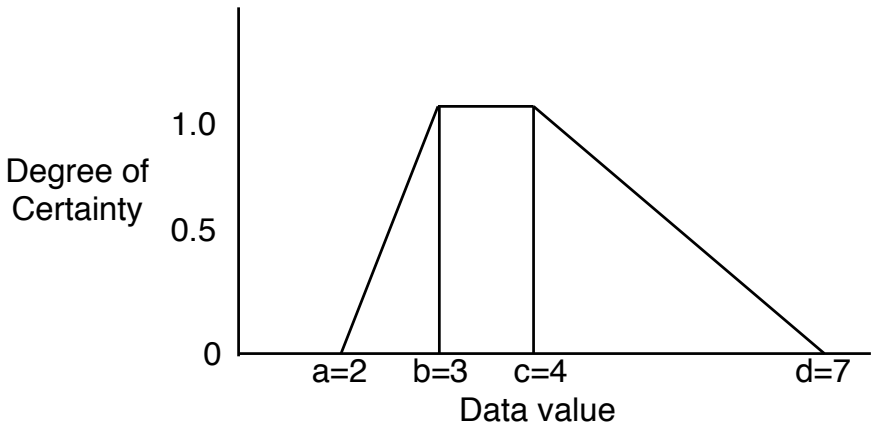
Mutation: random bits in an individual, or possible solution, are randomly changed. Mutation takes bits of rule and changes them to form slightly different rule.

010	011	100	**101**
a=2	b=3	c=4	**d=5**

$\rightarrow$

010	011	100	**111**
a=2	b=3	c=4	**d=7**





After mutation: transition from c to d is more gradual.

Crossover

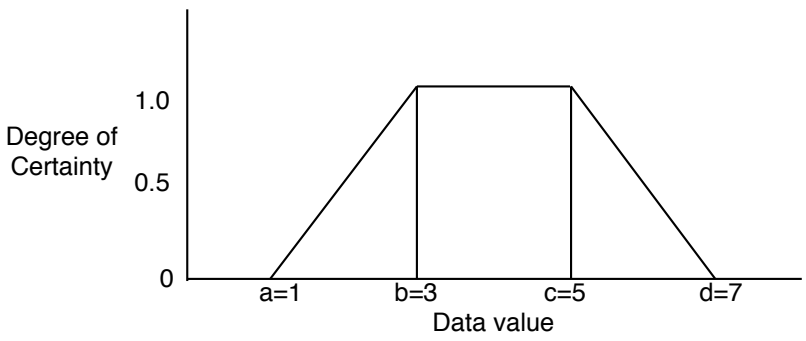
- Crossover: two individuals swap sequences of bits to form two new individuals.
- In IDS: crossover takes 2 rules and creates new rules by swapping bits of old rules.

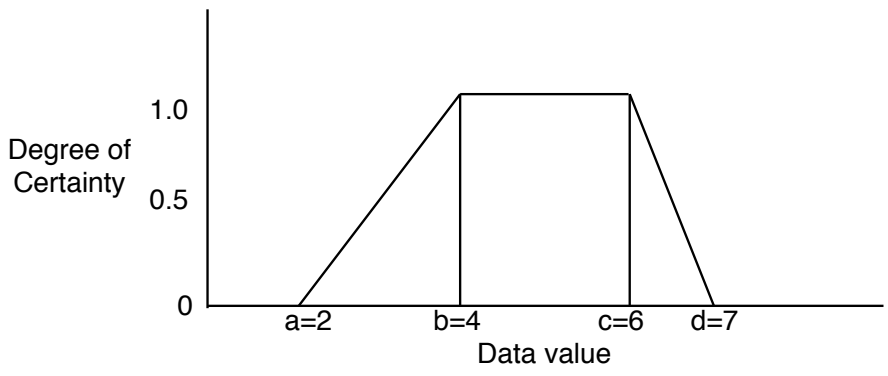
Crossover

Before

001	**011**	101	111
a=1	**b=3**	c=5	d=7

010	**100**	110	111
a=2	**b=4**	c=6	d=7

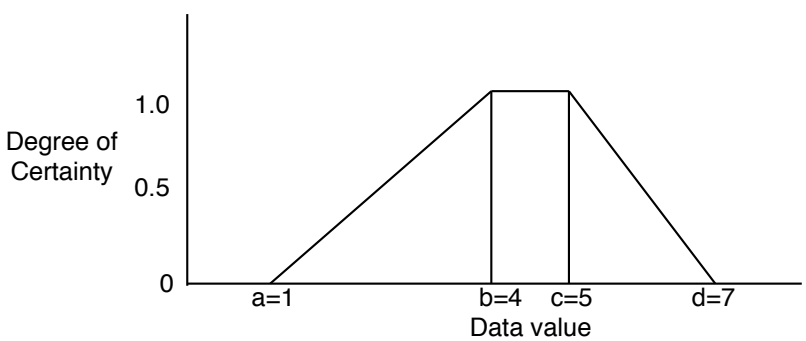


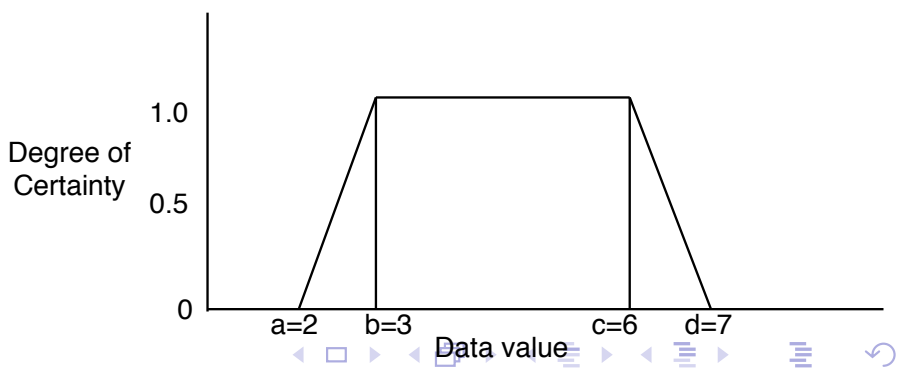


After

001	**100**	101	111
a=1	**b=4**	c=5	d=7

010	**011**	110	111
a=2	**b=3**	c=6	d=7





Selection and Fitness

- Selection: individuals that have better fitness are chosen to be parents.
- Fitness of individual is specified by fitness function, which determines quality of particular individual.

- In an IDS: fitness measures how well a rule classifies records as either attacks or normal activity. Selection combined with fitness function directs search towards effective solution.

Fitness function

The fitness function to be maximized is:

$$\frac{\alpha}{A} - \frac{\beta}{B}$$

α: # of attack records correctly identified as attack.
A: # of attack records.
β: # of normal records incorrectly classified as attack.
B: # of normal records.

Best possible value of β is 0. It's good if $\alpha = A$.
Best possible fitness value is 1.

Outline

Experiments Using Only RLD09

Experiment 1

- Fuzzy GA was used to create DoS and probe detection rules.
- Both rules were then used together in testing process to identify attacks from testing data set.
- If record is classified as either DoS rule or Probe rule, it is classified as attack; else normal.
- Training set: 10,000 records.
  Test set: 26,500 records.

Experiments Using Only RLD09

Experiment 1 Results

	Attack	Normal	Total	FP(%)	FN(%)	DR(%)
DoS Training	1499	8501	10000	1.46	47.50	91.64
Probe Training	2496	7504	10000	1.83	15.38	94.79
Testing	10500	16000	26500	1.13	4.10	97.92

Testing has:

- Higher DR: IDS is more likely to classify attacks because it can match either attack type.
- Lower FN: IDS is less likely to predict that it's not an attack when it really is.

Experiments Using Only RLD09

Experiment 2

- Attacks pulled out of training set, kept for unknown data testing, to test that fuzzy GA could detect unknown attacks.
- Fuzzy GA and decision tree algorithm, which is another common algorithm for classification problems.
- 7 tests were run. Each test case: 13 attack types plus normal activity that were in training set.
  3 attack types used for unknown testing data set.
- Anomaly-based detection

Experiments Using Only RLD09

Experiment 2 Results (7 tests were run in total, 5 are shown here.)

Test Case	Unknown Attacks	Decision Tree DR (%)	Fuzzy Genetic DR (%)
1	Adv Port Scan (Probe) Ack Scan (Probe) Xmas Tree (Probe)	Avg = 98.33	Avg = 100
2	UDP Flood (DoS) Host Scan (Probe) UDP Scan (Probe)	Avg = 46.65	Avg = 99.80
3	Jping (DoS) Syn Scan (Probe) Fin Scan (Probe)	Avg = 99.70	Avg = 98.75
4	UDP Flood (DoS) RCP Scan (Probe) Fin Scan (Probe)	Avg = 70.35	Avg = 98.15
5	Http Flood (DoS) RCP Scan (Probe) Fin Scan (Probe)	Avg = 99.94	Avg = 97.50

Experiments Using Both RLD09 and KDD99

Three experiments used both RLD09 and KDD99.

Experiment 1 - Used fuzzy GA to classify normal activity and attacks from KDD99 and RLD09.

Data set	Attack	Normal	FP (%)	FN (%)	DR (%)
KDD99	160,117	39,337	0.13	1.55	98.72
RLD09	10,500	16,000	1.14	3.39	97.97

Experiments Using Both RLD09 and KDD99

Experiment 2

- Used the fuzzy GA to classify types of attacks in KDD99.
- 10 tests were run in total, 5 are shown here.

Test	Attack	Type	FP (%)	FN (%)	DR (%)
1	Back	DoS	85.33	0.00	16.56
2	PoD	DoS	84.66	0.00	15.58
3	Smurf	DoS	0.76	0.10	99.73
4	Portsweep	Probe	6.40	0.00	93.66
5	Satan	Probe	0.74	3.75	99.22

- 8 test cases had DR greater than 93%. Only 2 cases had low DR, (cases 1 and 2).

Experiments Using Both RLD09 and KDD99

Experiment 3

- Used the fuzzy GA to classify types of attacks in RLD09.
- 17 tests were run in total, 6 are shown here.

Test	Attack	Type	FP (%)	FN (%)	DR (%)
1	HTTP Flood	DoS	0.36	3.5	99.46
2	Smurf	DoS	0.02	0	99.98
3	UDP Flood	DoS	11.06	0	89.59
4	Fin Scan	Probe	2.58	0	97.50
5	IP Scan	Probe	13.01	16.4	86.89
6	Syn Scan	Probe	0.65	4.2	99.24

- 15 cases had DR greater than 97%. 2 cases had lower DR, (cases 3 and 5).

Outline

Conclusions

- The fuzzy genetic algorithm had a higher detection rate than a decision tree algorithm in most cases.
- Fuzzy genetic algorithms are good at detecting unknown attacks.
  - Fuzzy GA DR: 99.8%, Decision Tree DR: 46.7%
- The use of fuzzy genetic algorithms in intrusion detection is an effective way of detecting attacks - DR in all experiments was in the high 90s.

Thanks!

Thank you for your time and attention!

Questions?

References

Jongsuebsuk, P. and Wattanapongsakorn, N. and Charnsripinyo, C.
Network intrusion detection with Fuzzy Genetic Algorithm for unknown attacks.
In *2013 International Conference on Information Networking (ICOIN)*, pages 1-5, 2013.

Jongsuebsuk, P. and Wattanapongsakorn, N. and Charnsripinyo, C.
Real-time intrusion detection with fuzzy genetic algorithm.
In *2013 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, pages 1-6, 2013.

See my Senior Seminar paper for additional references.

DoS Attacks

- Back: Attacker submits requests with URL's containing many front slashes. As server tries to process these requests it will slow down, becomes unable to process other requests.
- PoD: involves sending a malformed/malicious ping to computer. Historically, many systems could not handle a ping packet larger than the maximum IPv4 packet size (65,535 bytes). Sending a ping of this size could crash the target computer.

Features of KDD99

- src_bytes: number of bytes sent from source to destination. Source is user who may or may not be attacker, destination is server being potentially attacked.

- serror_rate: percentage of connections that have “SYN" errors. When client attempts to connect to server, it first sends a SYN (synchronize) message to server. The server then acknowledges the request by sending a SYN-ACK to client. The connection is established when client sends an ACK back to server. A SYN error is a failure to get an ACK back.