Flow-based network traffic generation using Generative Adversarial Networks*

Markus Ring, Daniel Schlör, Dieter Landes and Andreas Hotho

* M. Ring, D. Schlör, D. Landes, A. Hotho: Flow-Based Network Traffic Generation Using Generative Adversarial Networks. In *Computers and Security 82,* 2019, 156-172.

1.) Motivation

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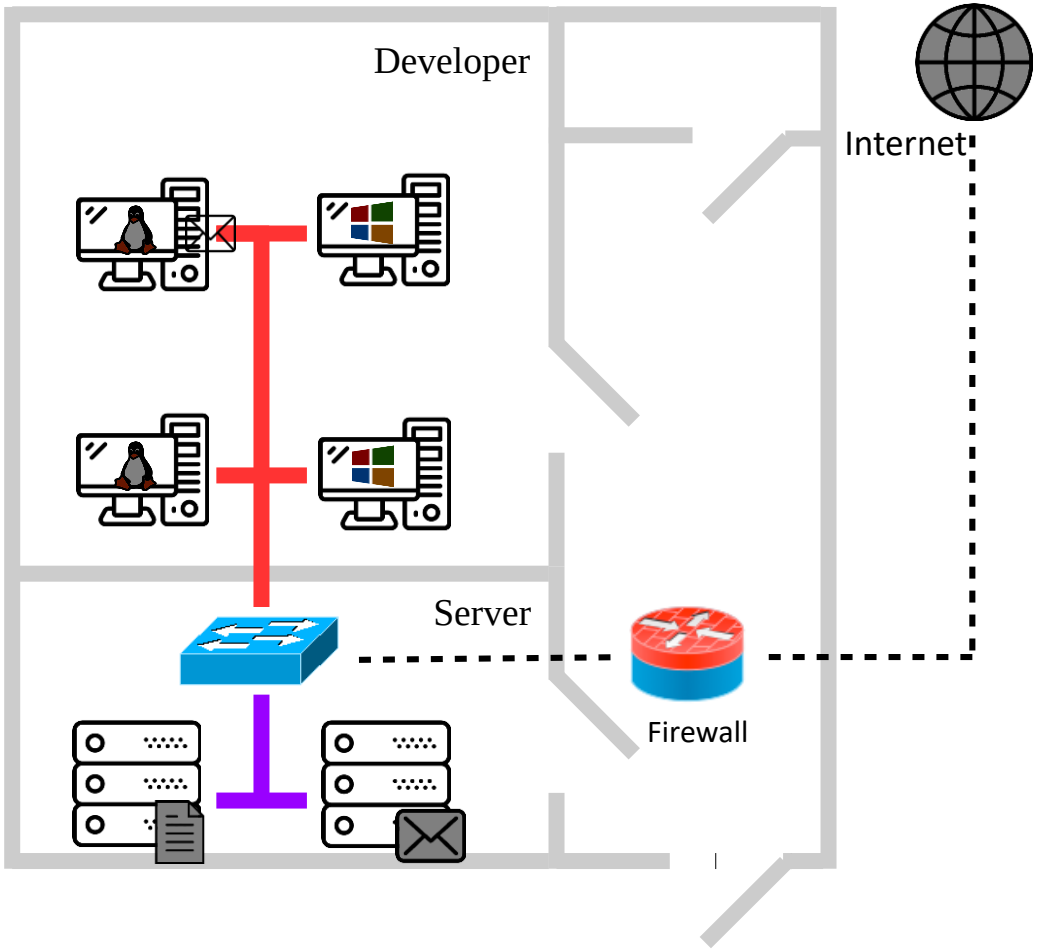
Company network



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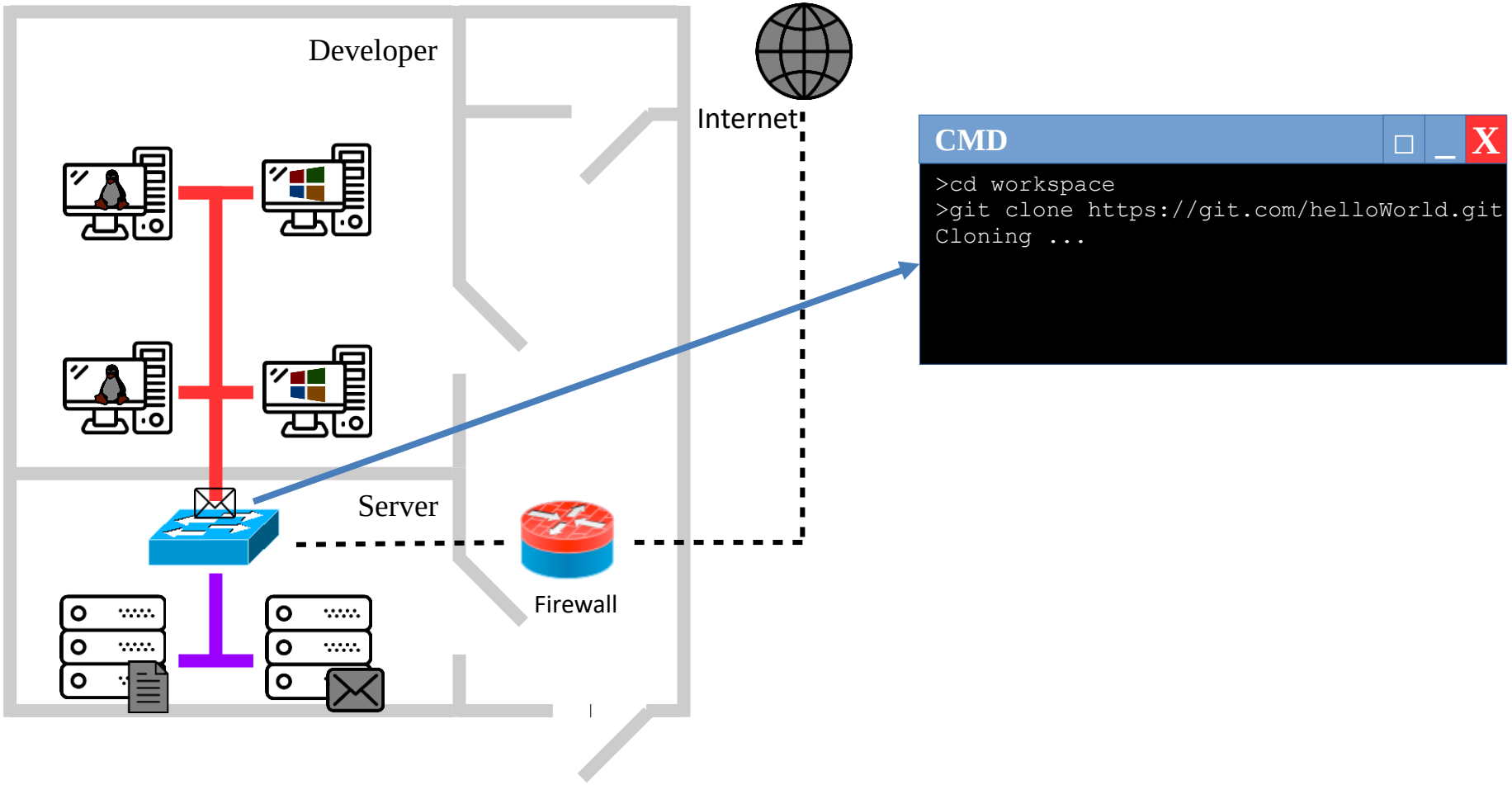

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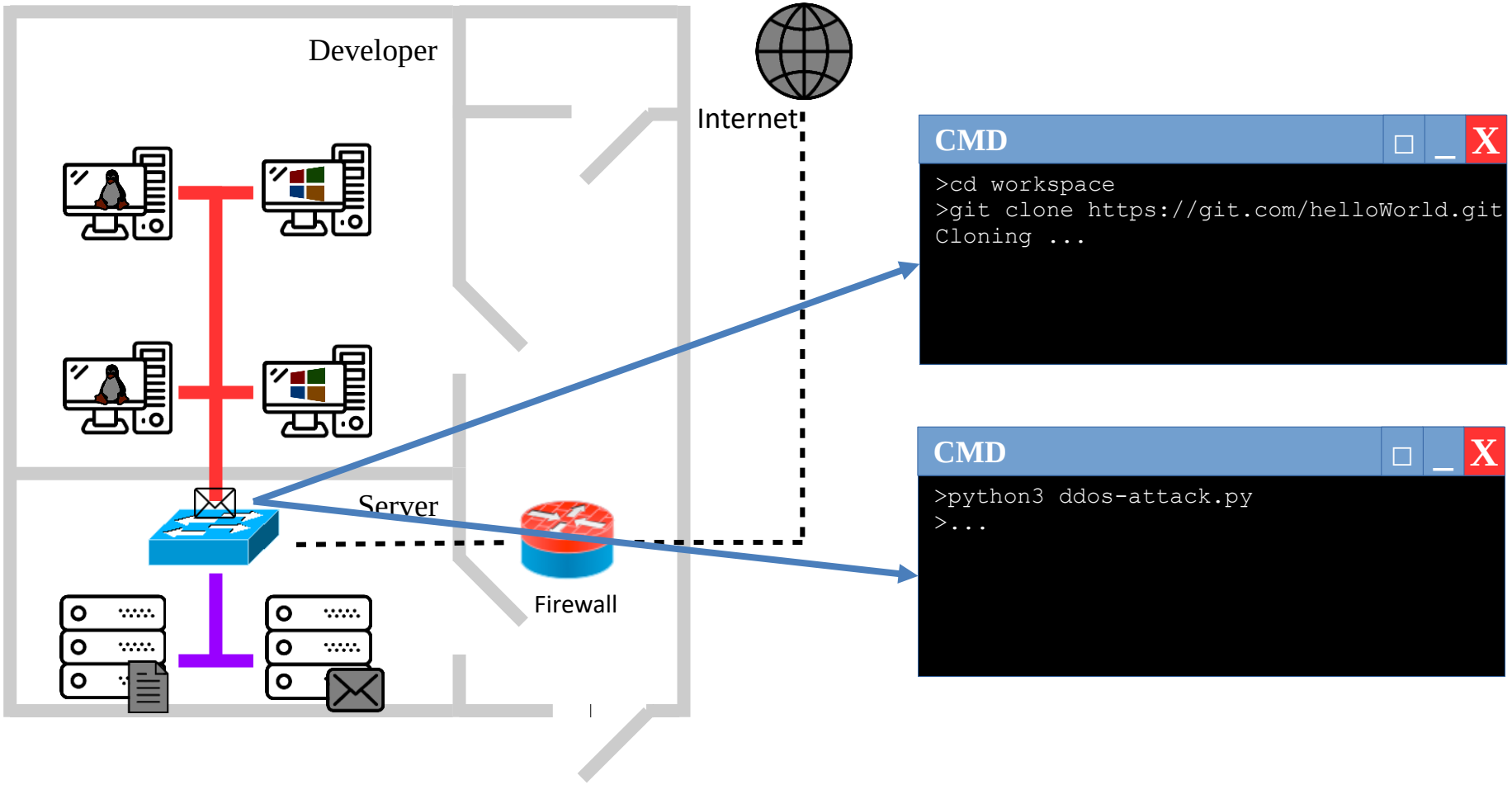

1) Motivation

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- **Target:** Generate synthetic network traffic to enrich existing data sources
- **Focus:** Network traffic in flow-based format
  - Flows describe network connections between endpoint devices using meta data

```
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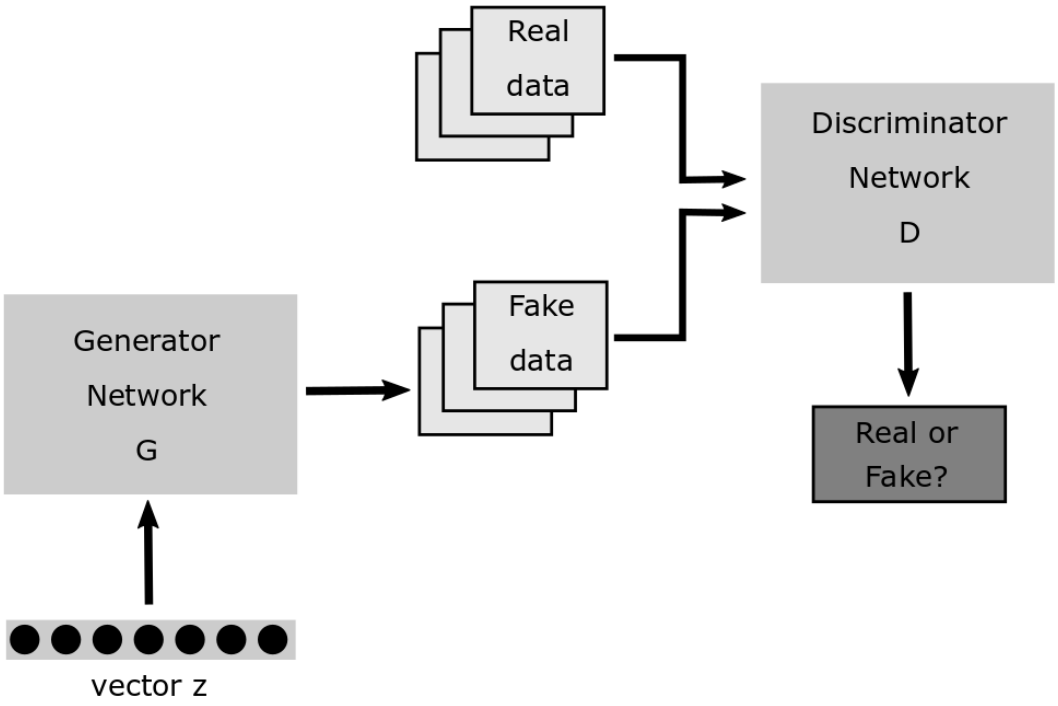
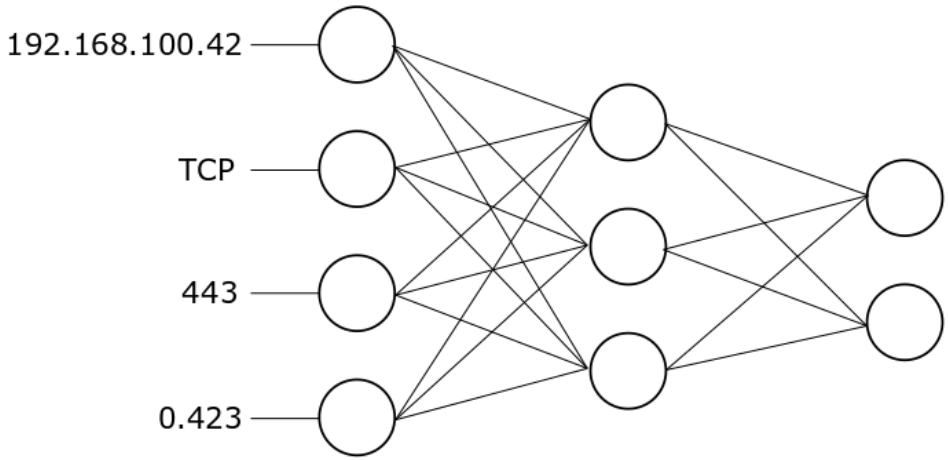
2) Approach
2.1) Generative Adversarial Networks

- Use GANs for creating flow-based network traffic



2) Approach
2.2) Challenges

GANs can only process continuous data but flow-based network traffic contains also categorical attributes like IP Addresses



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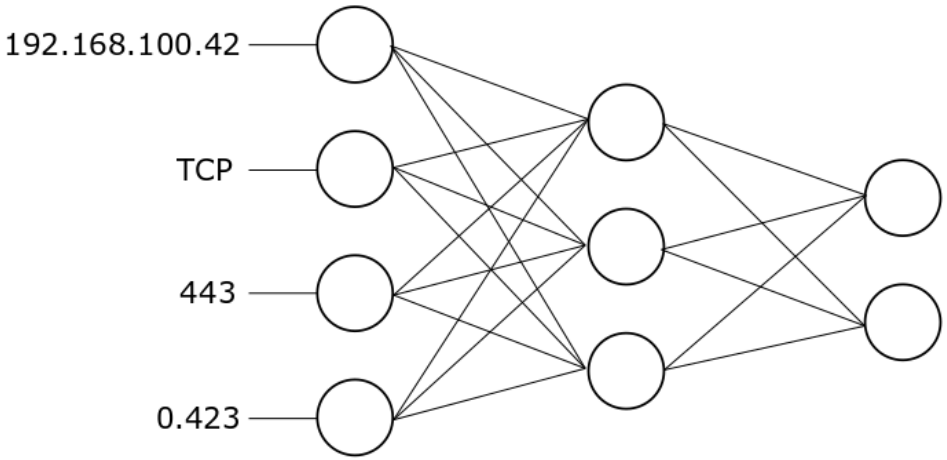

– Improved Wasserstein GANs* with the two time scale update rule from Heusel et al.+)

* Gulrajani, Ishaan ; Ahmed, Faruk ; Arjovsky, Martin ; Dumoulin, Vincent ; Courville, Aaron C.: Improved Training of Wasserstein GAN. In: Advances in Neural Information Processing Systems (NIPS), 2017, S. 57695779

+ Heusel, Martin ; Ramsauer, Hubert ; Unterthiner, Thomas ; Nessler, Bernhard ; Hochreiter, Sepp: GANs Trained by a Two Time-Scale Update Rule Converge to a Local Nash Equilibrium. In: Advances in Neural Information Processing Systems (NIPS), 2017, S. 66296640

2) Approach

2.3) Representation of flow-based network traffic

- Flows describe meta information about network connections between endpoint devices

#	Timestamp	Dur.	Proto	Source IP	Source Port	Dest. IP	Dest. Port	Bytes	Pkt.	TCP Flags
1	2019-03-07 13:41:41	0.000	UDP	192.168.220.16	48297	192.129.29.8	53	66	1	.....
2	2019-03-07 13:41:41	0.000	UDP	192.129.29.8	53	192.168.220.16	48297	66	1	.....
3	2019-03-07 13:41:42	4.199	TCP	192.168.220.16	53333	192.168.100.5	80	180	3	.A..SF
4	2019-03-07 13:41:42	4.324	TCP	192.168.100.5	80	192.168.220.16	53321	932	4	.A..SF

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- Three approaches
  1. Numeric Approach: Convert categorical attributes to numbers
  2. Binary Approach: Create binary attributes from categorical attributes
  3. Embedding Approach: Learn embeddings for categorical attributes
- Baseline
  1. Draw from the empirical probability distribution

2) Approach
2.3) Representation of flow-based network traffic

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- WGAN Approaches
  1. Numeric approach – Converting categorical values to numbers

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transform *daytime* into seconds [0…86400) and normalize to the interval [0,1]

normalize *Duration* to interval [0,1]

create 3 binary attributes (isTCP, isUDP, isICMP)

normalize each octet of an *IP Address*

normalize *Ports* to interval [0,1]

$$\frac{80}{65536} = 0{,}001\ldots$$

normalize *Bytes* to interval [0,1]

normalize *Packets* to interval [0,1]

create 6 binary attributes (isSYN,…)

$$192.168.210.5 \rightarrow \frac{192}{255} = 0{,}75\ldots, \frac{168}{255} = 0{,}65\ldots \frac{210}{255} = 0{,}82\ldots \frac{5}{255} = 0{,}01\ldots$$

2) Approach
2.3) Representation of flow-based network traffic

- WGAN Approaches
  2. Binary approach – Extracting binary attributes from categorical values

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1	2019-03-07 13:41:41	0.000	UDP	192.168.220.16	48297	192.129.29.8	53	66	1	.....
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transform *daytime* into seconds [0…86400) and normalize to the interval [0,1]

normalize *Duration* to interval [0,1]

create 3 binary attributes (isTCP,…)

interpret *IP Addresses* as 32 Bit Integer

192.168.210.5 → 11000000 10101000 ….

interpret *Ports* as 16 Bit Integer

80 → 00000000 01010000

interpret *Bytes* as 32 Bit Integer

interpret *Packets* as 32 Bit Integer

create 6 binary attributes (isSYN,…)

2) Approach
2.3) Representation of flow-based network traffic

- WGAN Approaches
  3. Embedding approach – Learning embeddings using IP2Vec*

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4	2019-03-07 13:41:42	4.324	TCP	192.168.100.5	80	192.168.220.16	53321	932	4	.A..SF

transform *daytime* into seconds [0…86400) and normalize to the interval [0,1]

replace *Duration* with embedding

create 3 binary attributes (isTCP,…)

replace *IP Adresses* with embedding

replace *Ports* with embedding

replace *Byte* with embedding

replace *Packets* with embedding

create 6 binary attributes (isSYN,…)

* M. Ring, A. Dallmann, D. Landes, A. Hotho: **IP2Vec**: Learning Similarities between IP Adresses. In Proc. Workshop on Data Mining for Cyber Security (DMCS), International Conference on Data Mining (ICDM 2017), New Orleans, USA, 2017, 657-666.

3) Experiments and Results
3.1) Overview

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- Experimental Evaluation
  - Create flow-based network traffic on the CIDDS-001* data set
  - Split the four weeks of the CIDDS-001 data set in two parts
    - week1 (reference data)
    - week2-4 (training data)

- Evaluation of generative models
  - Use different approaches for evaluation
    1. Temporal progression of the generated traffic
    2. Visualization of diversity and inter-attribute relationships
    3. Similarity calculations of value distributions
    4. **Intrinsic evaluation using domain knowledge checks**

* Ring, Markus ; Wunderlich, Sarah ; Grüdl, Dominik ; Landes, Dieter ; Hotho, Andreas: Flow-based benchmark data sets for intrusion detection. In: European Conference on Cyber Warfare and Security (ECCWS). ACPI, 2017, S. 361369

3) Experiments and Results

3.3) Intrinsic evaluation: Domain knowledge checks

accuracy in percent

	Baseline	Numeric	Binary	Embedding
Test 1	14.08	96.46	97.88	**99.77**
Test 2	81.26	0.61	98.90	**99.98**
Test 3	86.90	95.45	**99.97**	**99.97**
Test 4	15.08	7.14	**99.90**	99.84
Test 5	**100.0**	25.79	47.13	99.80
Test 6	0.07	0.00	40.19	**92.57**
Test 7	71.26	**100.0**	85.32	99.49

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Test 1: If transport protocol is UDP, then the flow must not have any TCP Flags

3) Experiments and Results

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the baseline does not consider inter-attribute relationships

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Test 2: At least one IP address of each flow must be internal
(starting with 192.168.XXX.XXX)

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Test 2: At least one IP address of each flow must be internal
(starting with 192.168.XXX.XXX)

Numeric approach often generates IP addresses like
191.168.103.78
192.167.103.78

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Test 6: If the flow represents a netbios message (destination port is 137 or 138),
the source IP address must be internal (192.168.XXX.XXX) and
the destination IP address must be an internal broadcast (192.168.XXX.255)

4) Summary

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GANs are suitable for creating synthetic flow-based network traffic, if a good representation is chosen

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Advantages

- Enrich existing data sets with synthetic data
- Trained models may be passed on
- Can be trained on different data sets to combine them

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Advantages

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Next Steps

- Handle sequences of flows

Thanks for your Attention!

Questions?

- GANs are able to create realistic flow-based network traffic
- How to create sequences of flows?
- Further information about network-based data

  https://www.hs-coburg.de/cidds (own data sets)

  http://www.dmir.uni-wuerzburg.de/datasets/nids-ds (overview of data sets)

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