

UNSUPERVISED CIPHER CRACKING USING DISCRETE GANS

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AAU CPH - SW9

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1. Introduction



1. Introduction

Premise of this paper

Can a neural network be trained to deduce withheld ciphers from unaligned text, without the supplementation of preexisting human knowledge?

Historical context

- Decryption was human-guided

Unsupervised learning

- Unpaired bank of ciphertext/plaintext
- No knowledge of vocab frequencies or cipher keys
- Large vocab (200 elements)

2. Key Concepts

2.1 Caesar Shift

PLAIN: a b c d e f g h i j k l m n o p q r s t u v w x y z

3-SHIFTED: d e f g h i j k l m n o p q r s t u v w x y z a b c

Example: hello world → khoor zruog

2.1 Caesar Shift

PLAIN: a b c d e f g h i j k l m n o p q r s t u v w x y z

3-SHIFTED: d e f g h i j k l m n o p q r s t u v w x y z a b c

Example: hello world → khoor zruog

Weakness

- Trivial to solve with frequency analysis

2.2 Vigenère

PLAIN: hello world

KEY: soda

KEYSTREAM: sodas odaso

ENCRYPTED: zsolg krrdr

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

2.2 Vigenère

PLAIN: hello world

KEY: soda

KEYSTREAM: sodas odaso

ENCRYPTED: zsolg krrdr

$(h, s) \rightarrow z$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

2.2 Vigenère

PLAIN: hello world

KEY: soda

KEYSTREAM: sodas odaso

ENCRYPTED: zsolg krrdr

$(h, s) \rightarrow z$

$(e, o) \rightarrow s$

And so on...

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

2.2 Vigenère

PLAIN: hello world

KEY: soda

KEYSTREAM: sodas odaso

ENCRYPTED: zsolg krrdr

$(h, s) \rightarrow z$

$(e, o) \rightarrow s$

And so on...

Increased difficulty

- Frequencies are scrambled

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

Generator

- Attempts to produce convincing samples from data distribution
- Denoted as F

Discriminator

- Tries to distinguish between true and synthetic samples
- Denoted as G

$$D^* = \arg \max_D E_{x \sim \mathcal{X}} [\log D(x)] - E_{z \sim \mathcal{Z}} [\log(1 - D(F(z)))]$$

2.3 GAN

$$D^* = \arg \max_D E_{x \sim \mathcal{X}} [\log D(x)] - E_{z \sim \mathcal{Z}} [\log(1 - D(F(z)))]$$

D^*

- optimal discriminator

$\arg \max_D$

- parameters causing highest possible score

$E_{x \sim \mathcal{X}}$

- Real data

$D(x)$

- Assigned probability
- (e.g. 1 = real, 0 = fake)

$F(z)$

- Generator creating fake text

$1 - D(F(z))$

- Chance of correctly identifying fakes

2.3 GAN

$$D^* = \arg \max_D E_{x \sim \mathcal{X}} [\log D(x)] - E_{z \sim \mathcal{Z}} [\log(1 - D(F(z)))]$$

D^*

- optimal discriminator

$\arg \max_D$

- parameters causing highest possible score

$E_{x \sim \mathcal{X}}$

- Real data

$D(x)$

- Assigned probability
- (e.g. 1 = real, 0 = fake)

$F(z)$

- Generator creating fake text

$1 - D(F(z))$

- Chance of correctly identifying fakes

Vulnerable to mode collapse

- Generator loses diversity - distribution collapses



Figure 2: Discriminators trained on the toy example of recognizing the bottom-right corner of a simplex as true data. From left to right the discriminators were regularized using: nothing; WGAN Jacobian norm regularization; and, the relaxed sampling technique.

Original GAN can be too strict

- No helpful feedback

Used by this paper

- Wasserstein Jacobian norm
- Relaxation Sampling

3. Related Work

3.1 CycleGAN

Two distributions

- \mathcal{X} & \mathcal{Y}

Two generators

- $F : \mathcal{X} \rightarrow \mathcal{Y}$
- $G : \mathcal{Y} \rightarrow \mathcal{X}$

Two discriminators

- $D_{\mathcal{X}} : \mathcal{X} \rightarrow [0, 1]$
- $D_{\mathcal{Y}} : \mathcal{Y} \rightarrow [0, 1]$

Cycle loss

- L1 Norm - original text vs. round-trip text
- Forces model to be one-to-one

$$\mathcal{L}_{\text{cyc}}(F, G, \mathcal{X}, \mathcal{Y}) =$$

$$E_{x \sim X}[\|G(F(x)) - x\|_1] + E_{y \sim Y}[\|F(G(y)) - y\|_1]$$

3.1 CycleGAN

Consider the losses together

$$\mathcal{L}(F, G, D_y, D_x, \mathcal{X}, \mathcal{Y}) = \underbrace{\mathcal{L}_{\text{GAN}}(F, D_y, \mathcal{X}, \mathcal{Y})}_{\text{forward pass}} + \underbrace{L_{\text{GAN}}(G, D_x, \mathcal{Y}, \mathcal{X})}_{\text{backward pass}} + \lambda * \mathcal{L}_{\text{cyc}}(F, G, \mathcal{X}, \mathcal{Y})$$

Forward pass

- Generator F: Plaintext to ciphertext for discriminator D_y

Backward pass

- Generator G: Ciphertext to plaintext for discriminator D_x

λ

- Hyperparameter - good translator vs good detective

Cycle

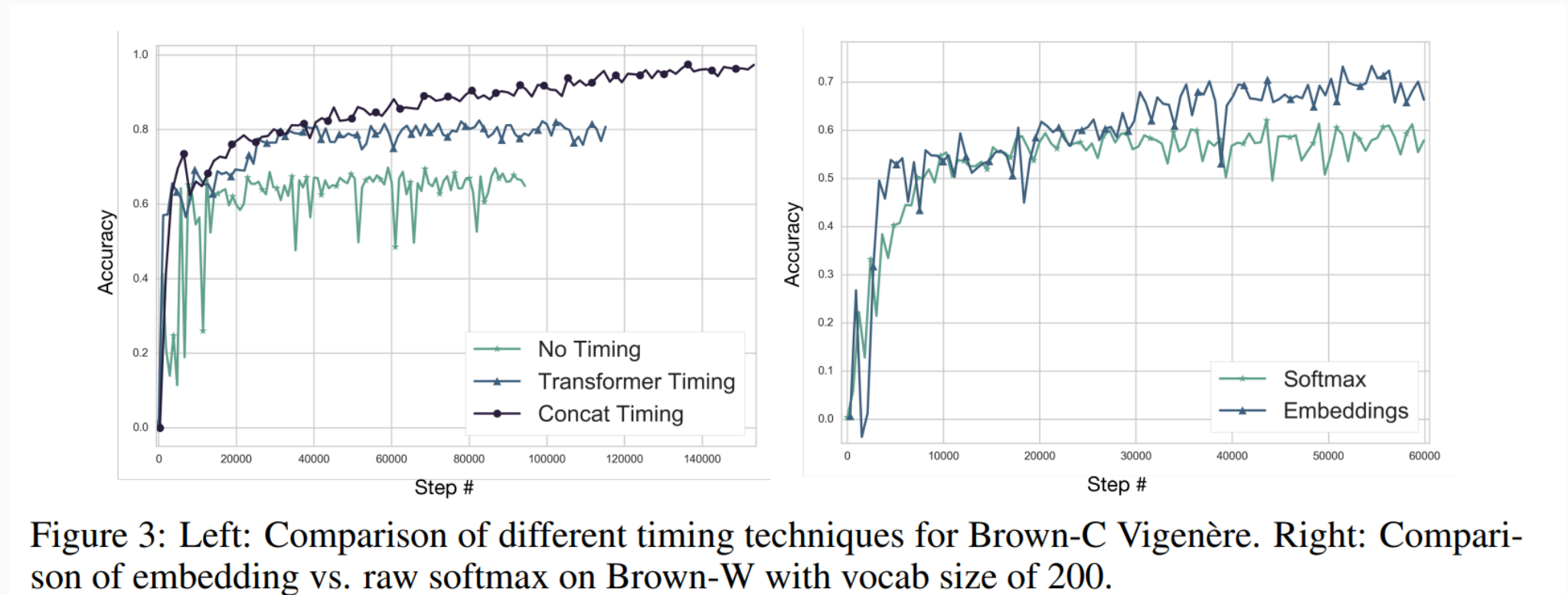
- Ensures diversity - avoid mode collapse

4. Ideas & Results

4.1 CipherGAN

Words in embedding space

- Discrete choices do not produce gradients



4.1 CipherGAN

WGAN-GP (Jacobian Norm)

- Limit learning rate of discriminator
- Smooth training signal for generator

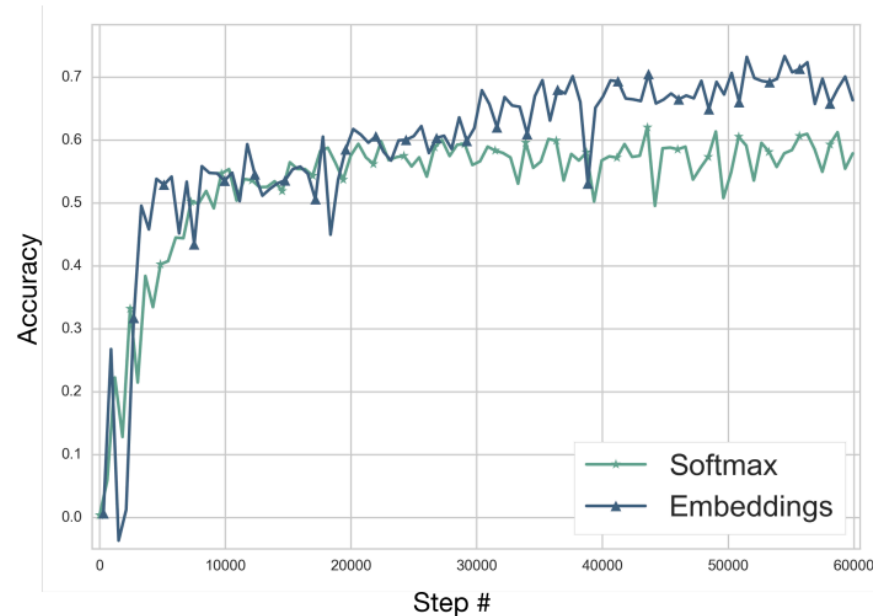
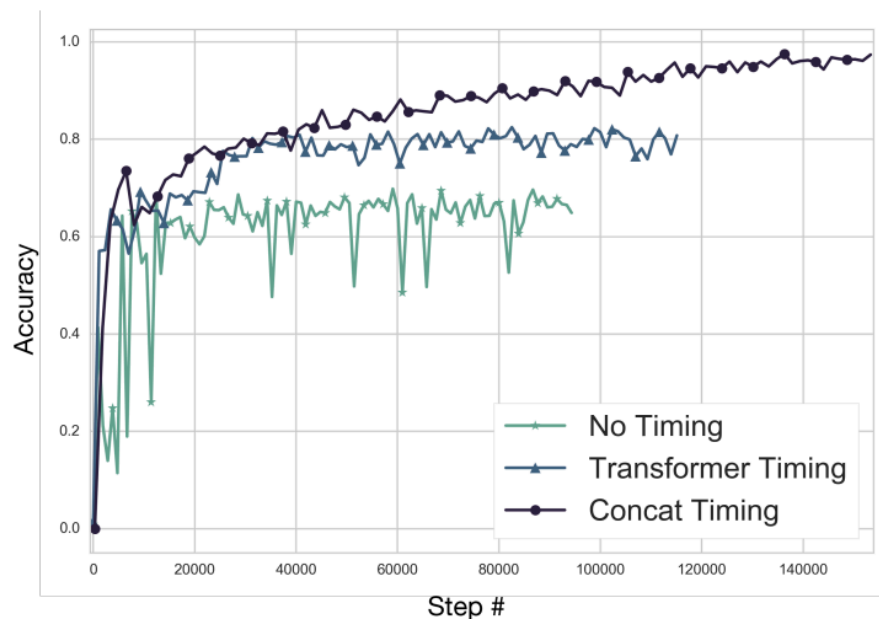


Figure 3: Left: Comparison of different timing techniques for Brown-C Vigenère. Right: Comparison of embedding vs. raw softmax on Brown-W with vocab size of 200.

4.1 CipherGAN

Positional embedding (Timing)

- Vigenère relies on positioning
- Tag each letter with position index

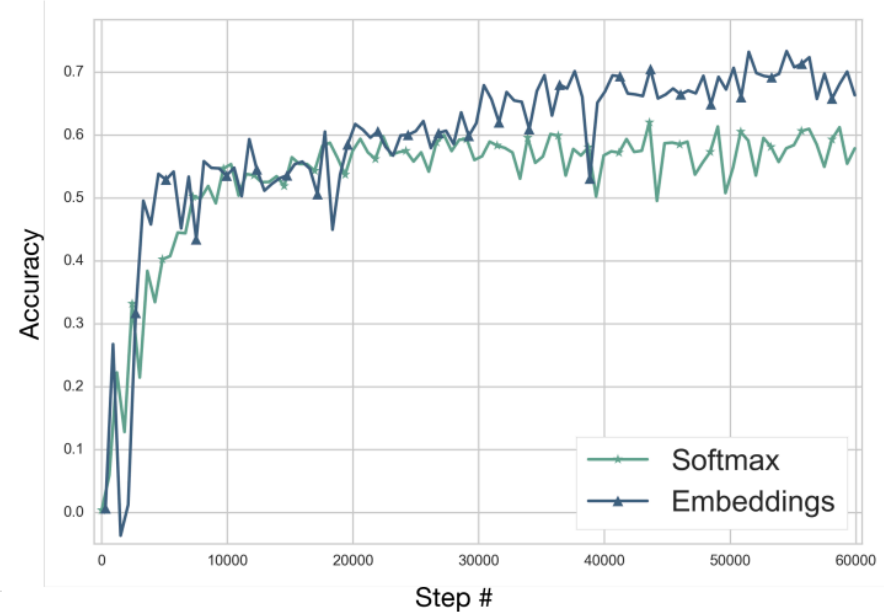
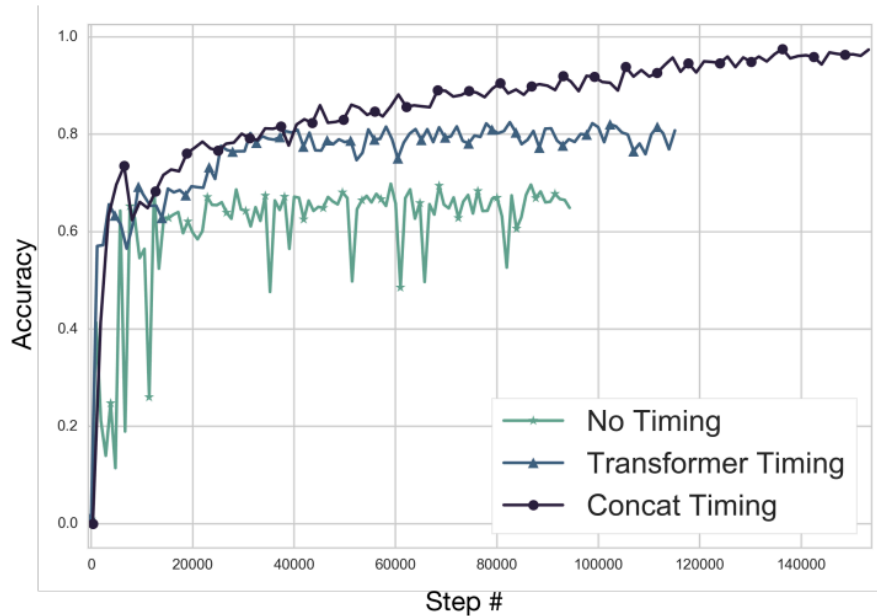


Figure 3: Left: Comparison of different timing techniques for Brown-C Vigenère. Right: Comparison of embedding vs. raw softmax on Brown-W with vocab size of 200.

Brown English text dataset

- 1st half as CycleGAN \mathcal{X} distribution
- 2nd half as ciphers in \mathcal{Y} distribution

Brown English-Language corpus

- Natural language plaintext
- Over 1 mil. words
- Both word-level and char-level

Brown-W

- Top 200 most frequent words
- Rest is blank

4.3 Results

Data	Brown-W	Brown-W	Brown-C	Freq. Analysis (With Key)	
Vocab size	10	200	58	58	200
Cipher	Shift/Permutation				
Acc.	100%	98.7%	99.8%	80.9%	44.5%
Cipher	Vigenère (Key: “345”)				
Acc.	99.7%	75.7%	99.0%	9.6% (78.1%)	<0.1% (44.3%)

Table 2: Average proportion of characters correctly mapped in a given sequence. The “Freq. Analysis” column is simple frequency analysis applied to the same corpus our model observes. For Vigenère we also show the score if the key were known (note: the key is left unknown to our model).

4.3 Results

Work	Ciphertext Length	Accuracy
Hasinoff (2003)	500	~ 97%
Forsyth & Safavi-Naini (1993)	5000	~ 100%
Ramesh et al. (1993)	160	~ 78.5%
Verma et al. (2007)	1000	~ 87%

Table 1: Previous results on automated shift cipher cracking with limited ciphertext length.

5. Criticism

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Why not test on a real cipher?

- The real Caesar cipher
- Civil War Vigenere cipher

Sequence length bottleneck

- 200 chars is short!
- Concat timing limited to training length
- GANs are likely to become unstable

Why only compare against non-neural approaches?

- Maybe compare with LSTM, etc?

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Current better models - (like CausalLM)

- We know this because we are from the future 😊

6. Relevance to my project

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Homophonic Substitution Ciphers

- 1-to-many mappings
- English
- Only lowercase letters
- No spaces

Comparative Study

- Embeddings
- Heuristics
- Seq-2-Seq

Increase sequence length with CausalLM

- Linear attention?
- Flash attention?

Decipherment as Regression: Solving Historical Substitution Ciphers by Learning Symbol Recurrence Relations

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Abstract

Solving substitution ciphers involves mapping sequences of cipher symbols to fluent text in a target language. This has conventionally been formulated as a search problem, to find the decipherment key using a character-level language model to constrain the search space. This work instead frames decipherment as a sequence prediction task, using a Transformer-based causal language model to learn recurrences between

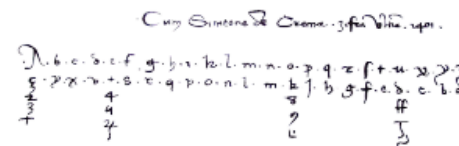


Figure 1: The homophonic substitution key for the *Simeone de Crema* written in Mantua in 1401 AD. The top line maps each character in the alphabet to its reversed-alphabet equivalent; each vowel is substituted by three additional symbols.