

# Commit Acts of Steganography Before it's too late

Gabriel Kaptchuk

Real World Cryptography 2022

Based on **Meteor: Cryptographically Secure Steganography for Realistic Distributions (CCS'21)**

joint work with Tushar Jois, Matthew Green, and Avi Rubin

# Commit Acts of Steganography Before it's too late

Gabriel Kaptchuk

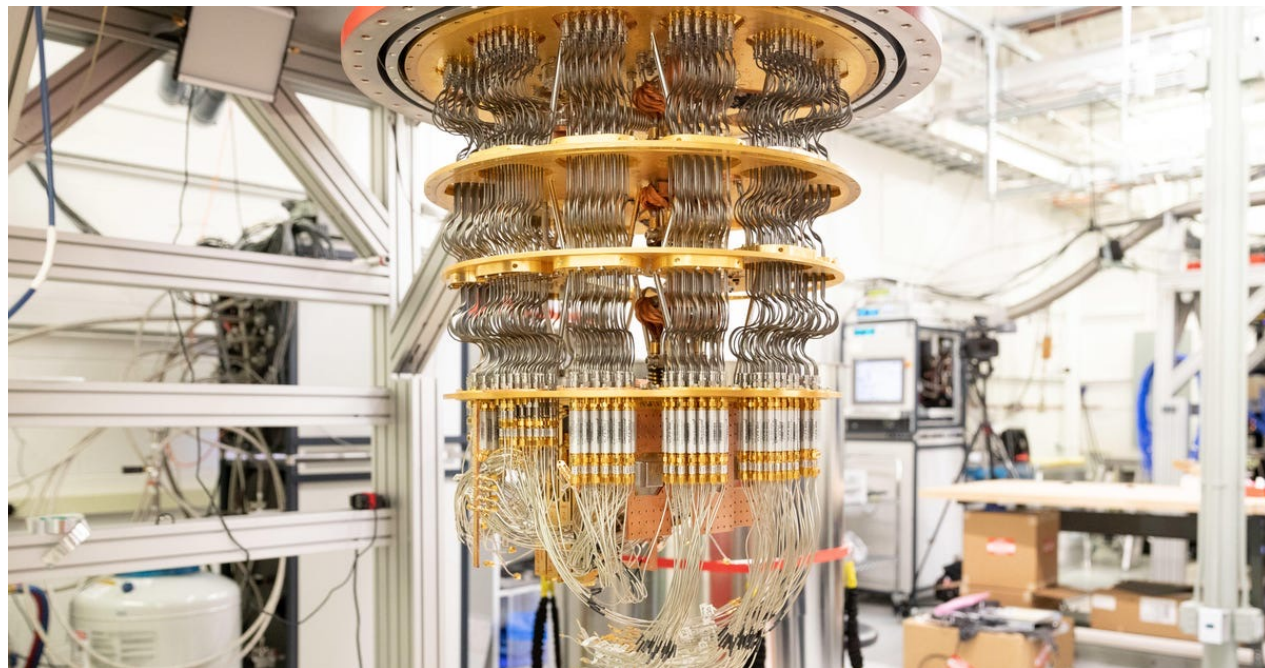
Real World Steganography 2022

Based on **Meteor: Cryptographically Secure Steganography for Realistic Distributions (CCS'21)**

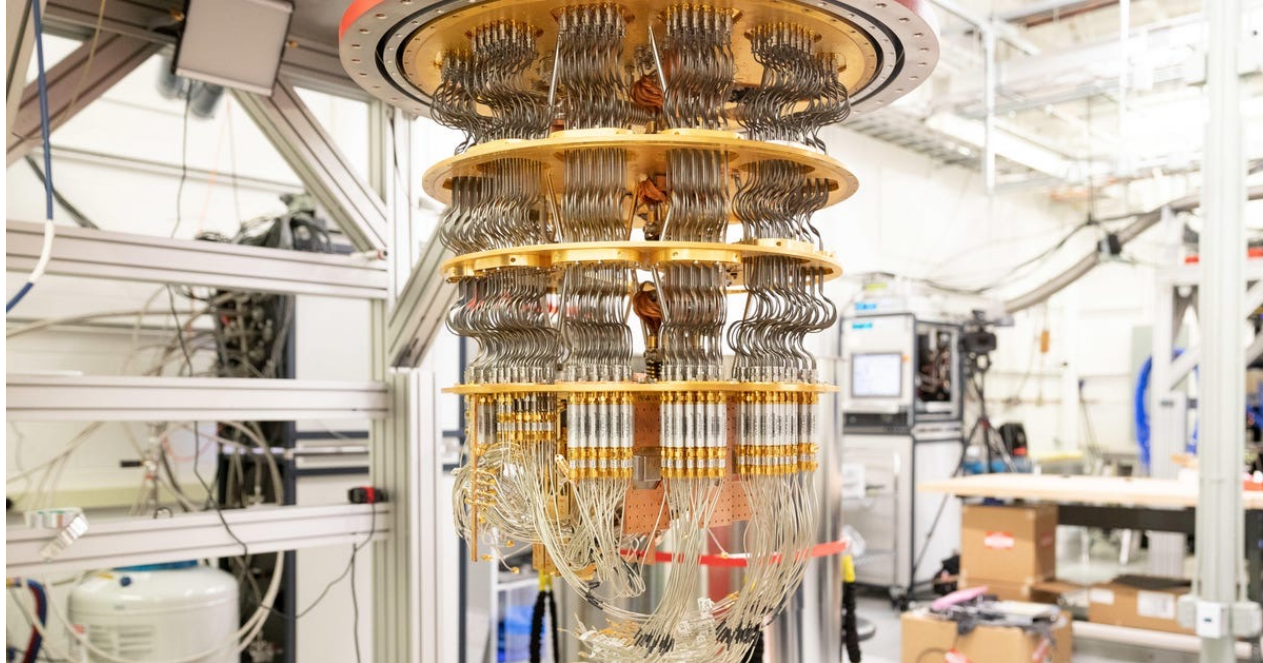
joint work with Tushar Jois, Matthew Green, and Avi Rubin

# Big Threats to Crypto

# Big Threats to Crypto

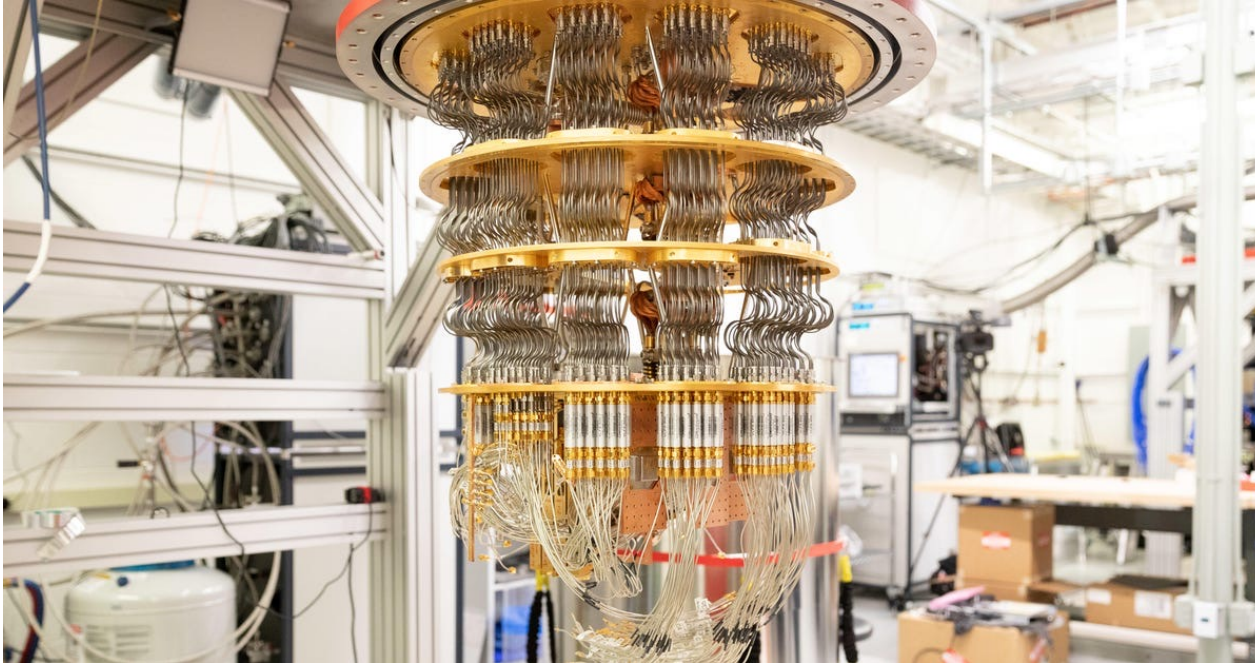


# Big Threats to Crypto



See Friday 9am Session

# Big Threats to Crypto



## A BILL

To establish a National Commission on Online Child Sexual Exploitation Prevention, and for other purposes.

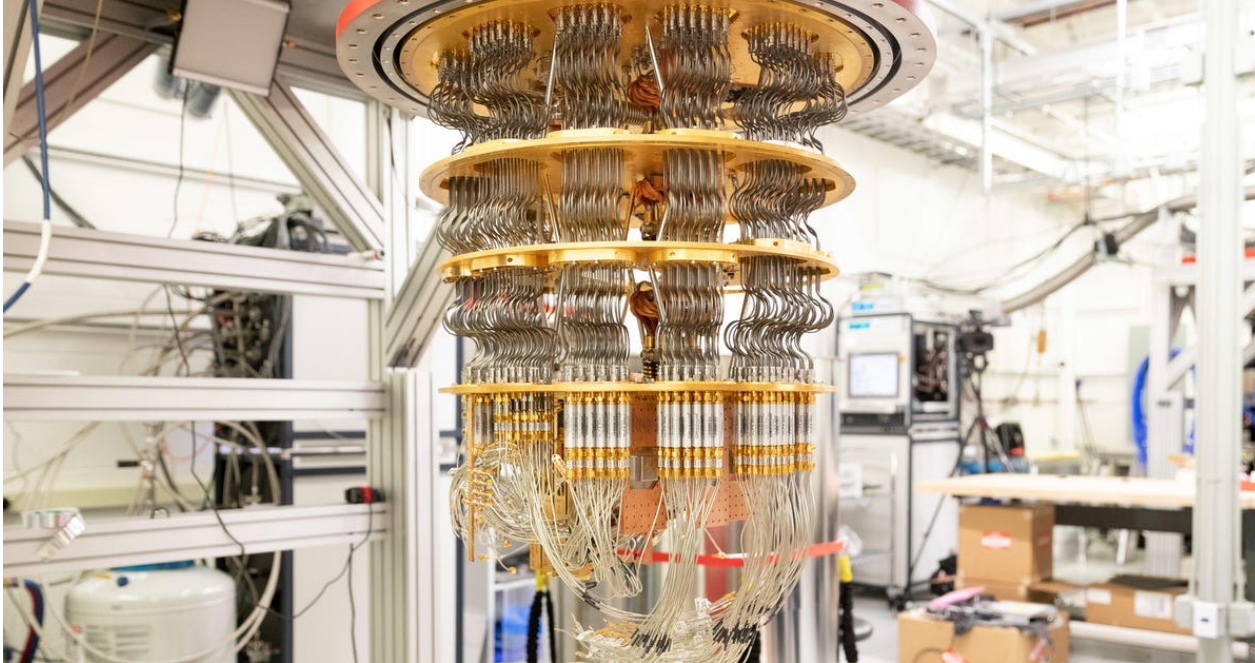
1 *Be it enacted by the Senate and House of Representa-*  
2 *tives of the United States of America in Congress assembled,*

3 **SECTION 1. SHORT TITLE.**

4 This Act may be cited as the “Eliminating Abusive  
5 and Rampant Neglect of Interactive Technologies Act of  
6 2022” or the “EARN IT Act of 2022”.

See Friday 9am Session

# Big Threats to Crypto



See Friday 9am Session

## A BILL

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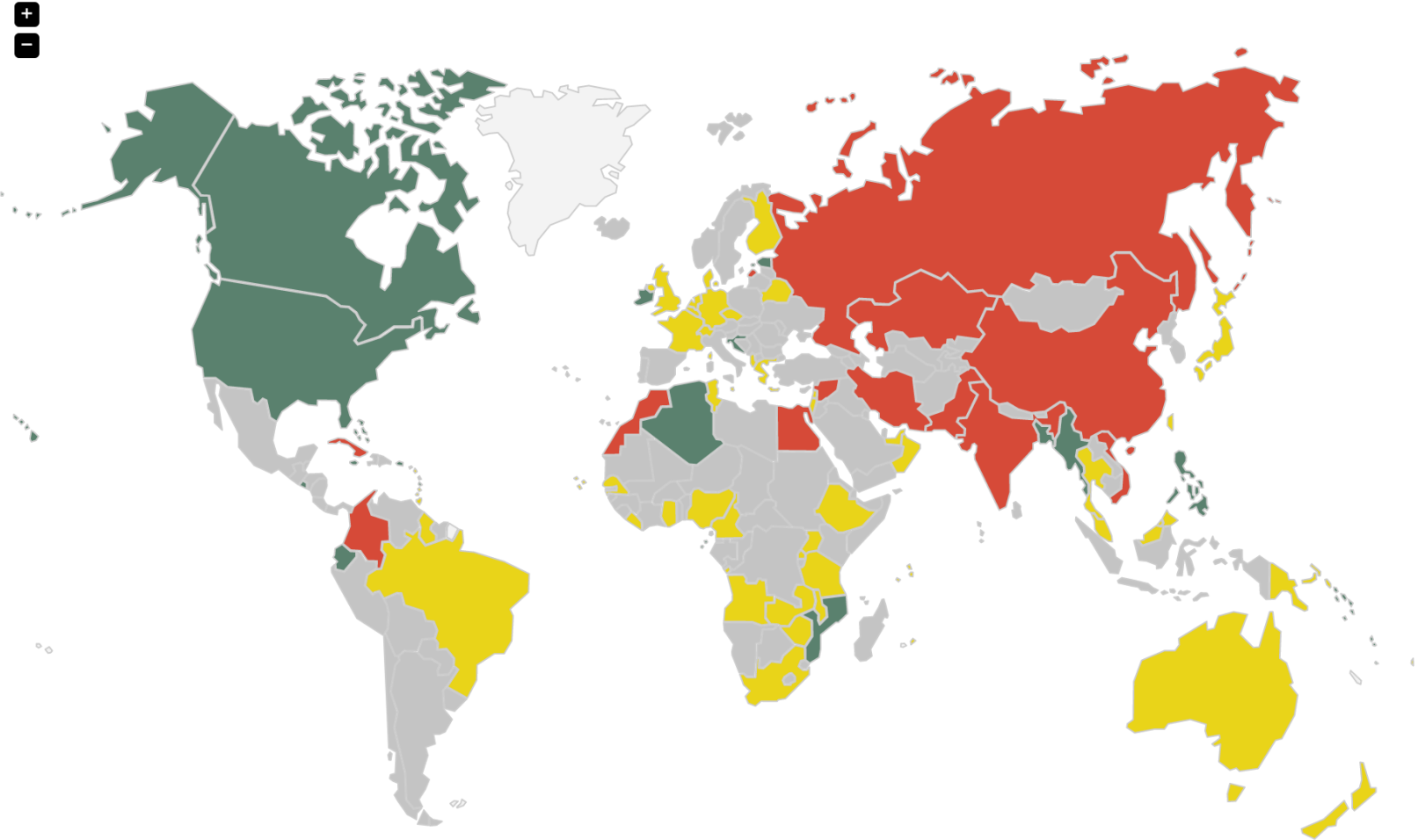
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See Mallory Knodel’s Talk

# Encryption Doomsday Prepping

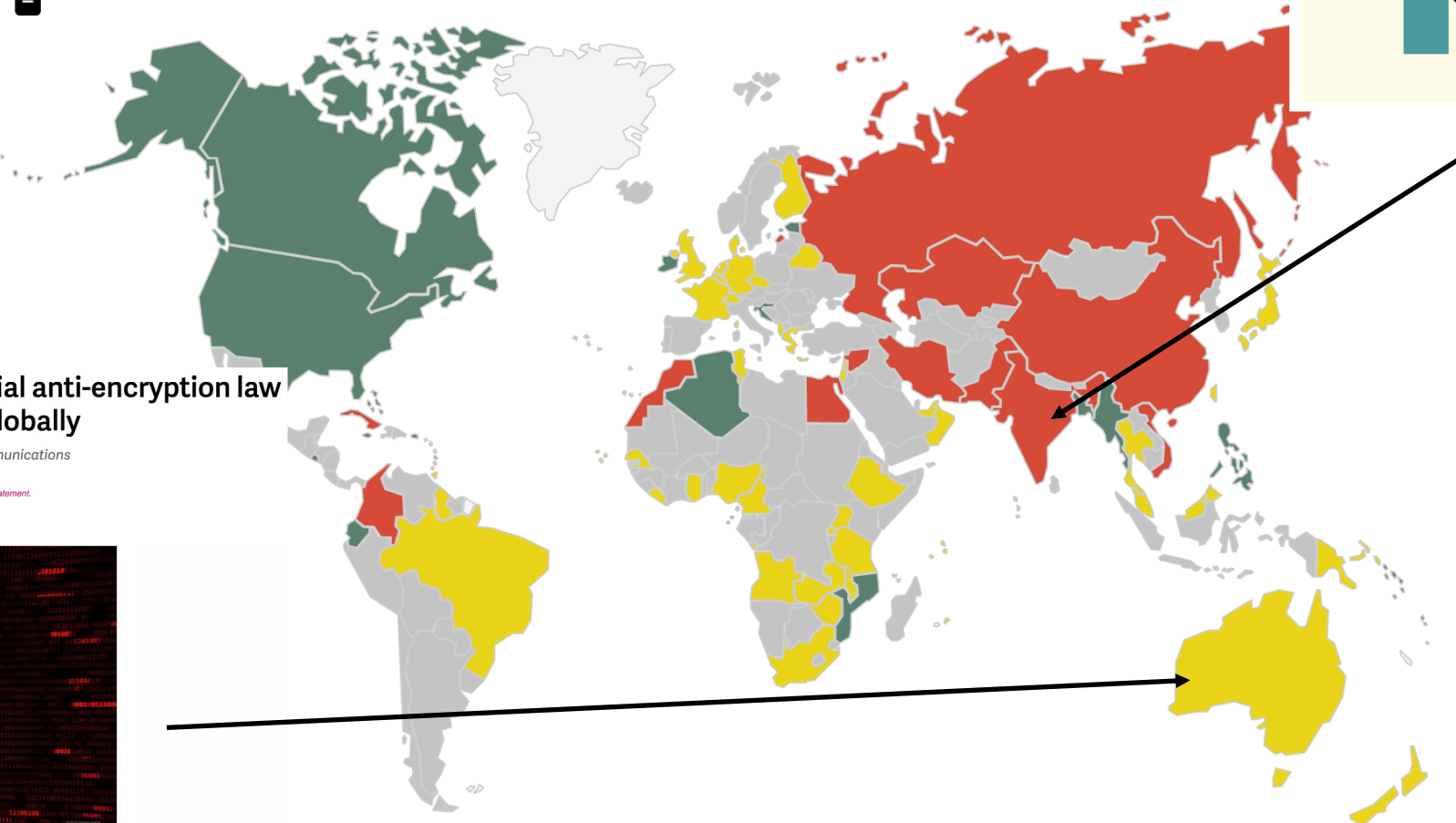
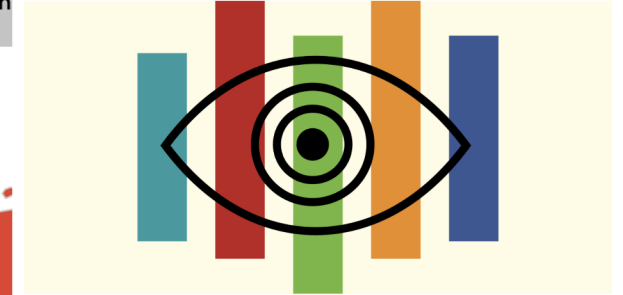




# Encryption Doomsday Prepping

## India's Draconian Rules for Internet Platforms Threaten User Privacy and Undermine Encryption

BY KATITZA RODRIGUEZ AND KURT OPSAHL | JULY 20, 2021



## Australia passes controversial anti-encryption law that could weaken privacy globally

Companies are required to give access to encrypted communications

By Jon Porter | @JonPorty | Dec 7, 2018, 8:38am EST

If you buy something from a Verge link, Vox Media may earn a commission. See our ethics statement.

f t SHARE

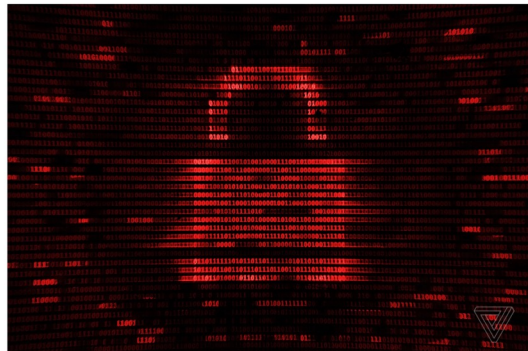
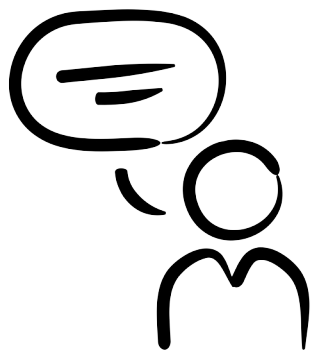


Illustration by Alex Castro / The Verge

# Steganography: The Solution?

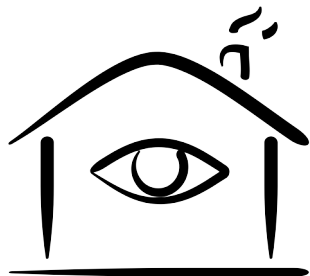
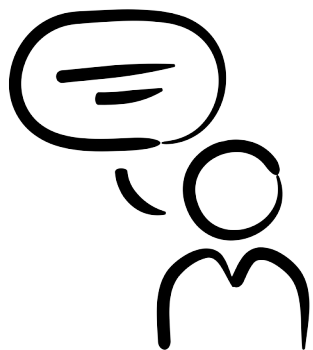


“Let’s engage in civil disobedience to protest  
Putin’s invasion of Ukraine”

---



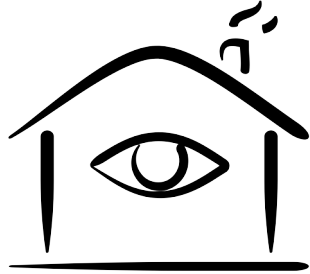
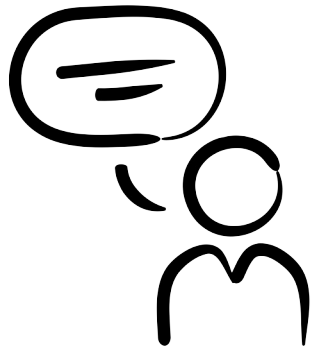
# Steganography: The Solution?



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# Steganography: The Solution?

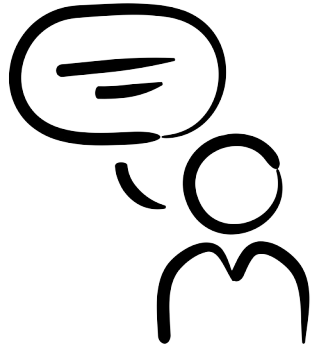
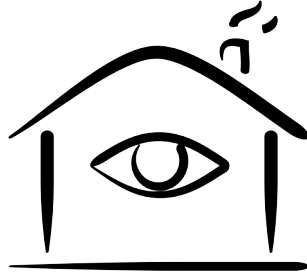


“Let’s engage in civil ~~dis~~obedience to protest  
Putin’s invasion of Ukraine”



“Hey! Sorry I haven’t texted in a hot sec...  
How is your grandmother doing?”

# Steganography: The Solution?



“Let’s engage in civil ~~dis~~obedience to protest  
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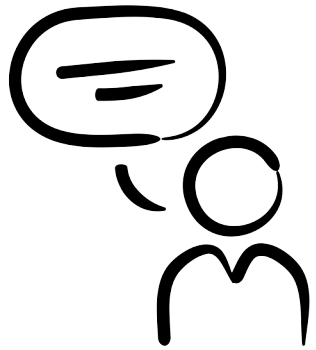


“Hey! Sorry I haven’t texted in a hot sec...  
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## Format Transforming Encryption

[LDJ+14, DCRS13b, DCS15, OYZ+20]

# Steganography: The Solution?



“Let’s engage in civil ~~dis~~obedience to protest  
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“Hey! Sorry I haven’t texted in a hot sec...  
How is your grandmother doing?”

## Format Transforming Encryption

[LDJ+14, DCRS13b, DCS15, OYZ+20]

## Tor Pluggable Transport

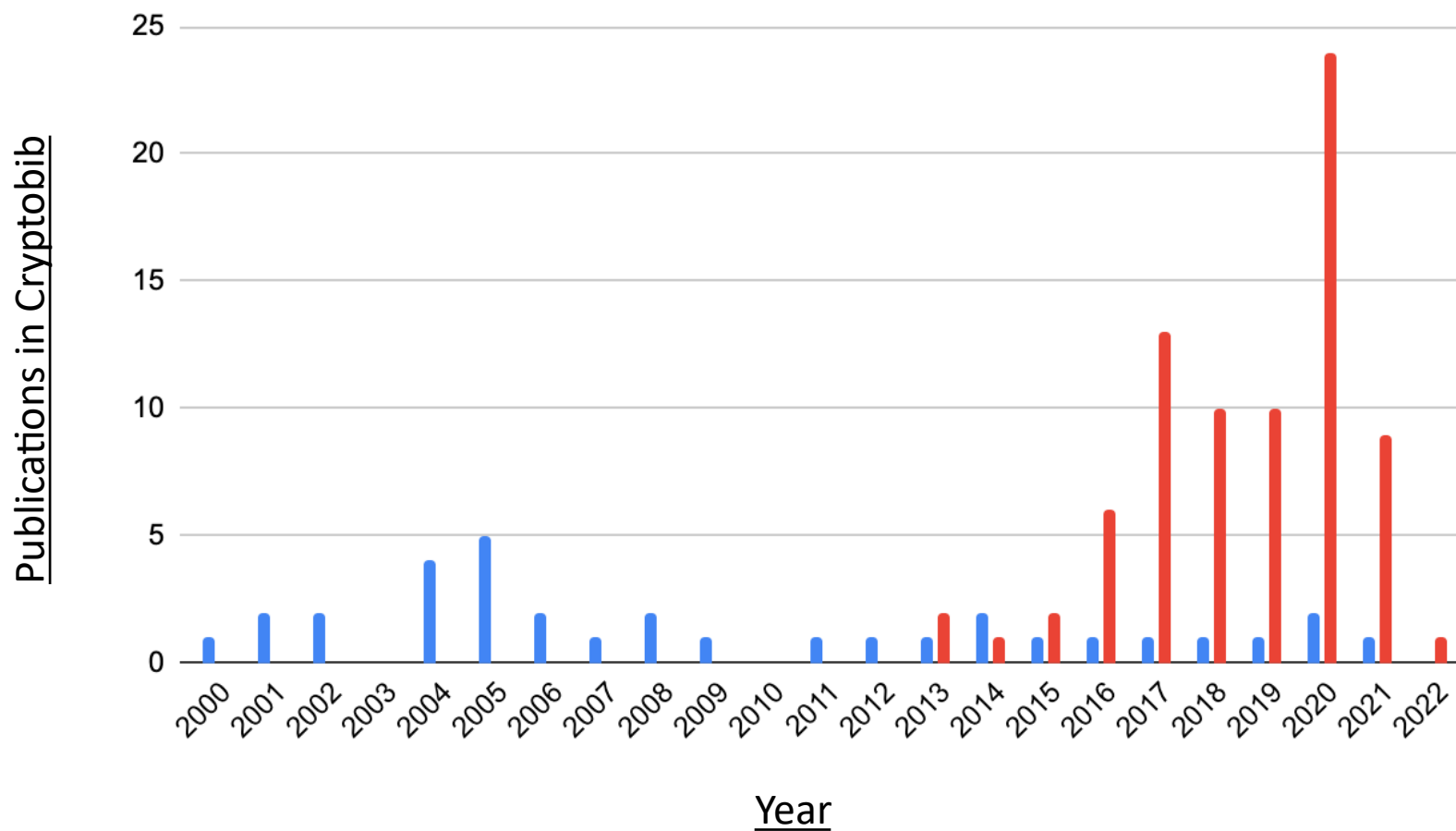
[MLDG12] [WWY+12] [WGN+12] [HRBS13]  
[DCRS13a] [WPF13] [FLH+15]

# Encryption Doomsday Prepping

Are we ready for pseudorandomness to be considered suspicious?

# Where is OUR effort?

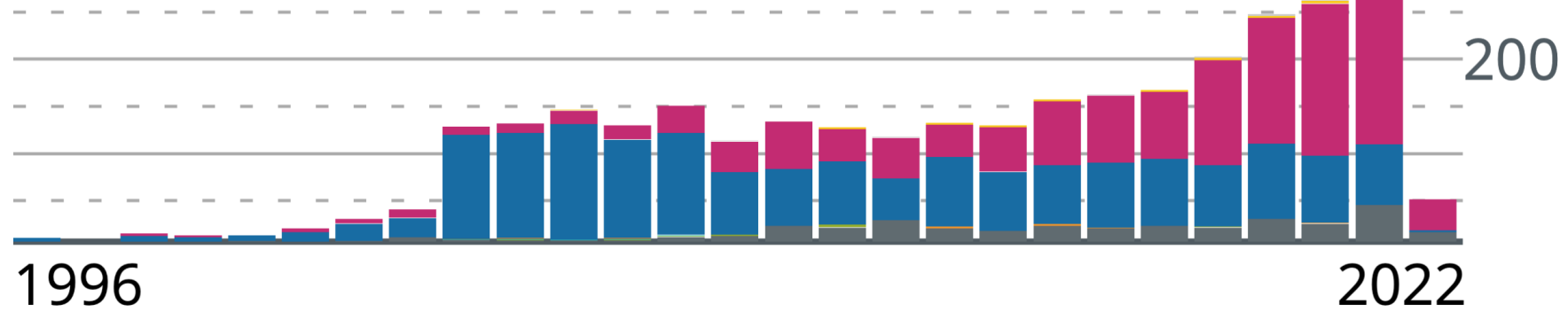
■ Steganography Publications ■ PQC Publications





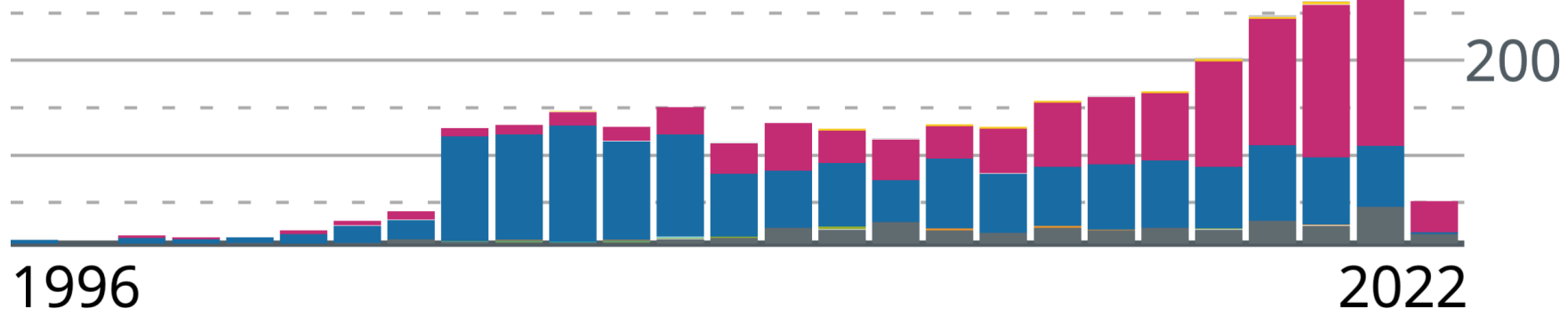
# Where is the effort?

The Good News: **Steganography** Publications by Year (source: DBLP)

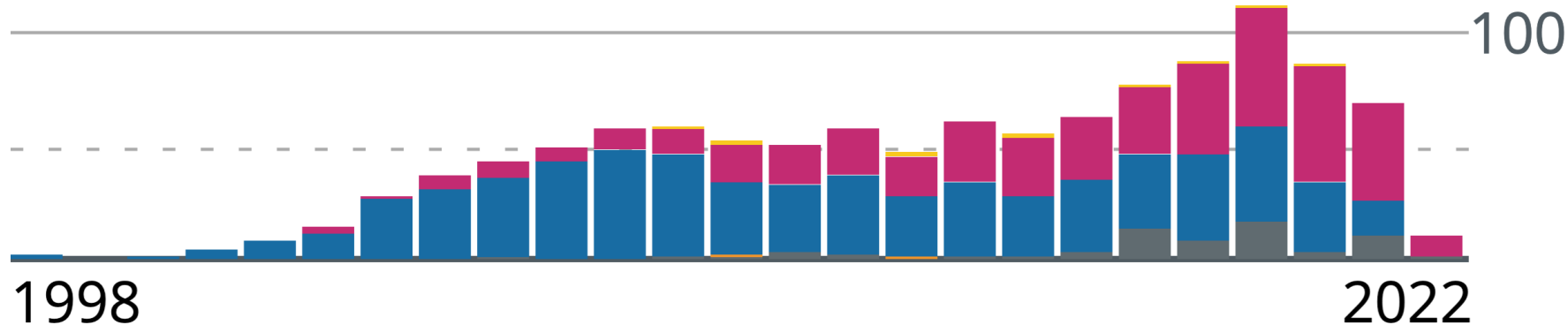


# Where is the effort?

The Good News: **Steganography** Publications by Year (source: DBLP)



The Bad News: **Steganalysis** Publications by Year (source: DBLP)



# Universal Steganography Refresher

1. Pick a covertext channel (communication to blend in with)

# Universal Steganography Refresher

## 1. Pick a covert channel (communication to blend in with)

### Bible Verses

*“And there was evening and there was morning, a third day”*

*“Now there arose a new king over Egypt, who knew not Joseph.”*

*“Then shall there be presented with the bullock a meal-offering of three tenth parts of ...”*

# Universal Steganography Refresher

## 1. Pick a covertext channel (communication to blend in with)

### Bible Verses

*“And there was evening and there was morning, a third day”*

*“Now there arose a new king over Egypt, who knew not Joseph.”*

*“Then shall there be presented with the bullock a meal-offering of three tenth parts of ...”*

### Pro-Putin Posters



# Universal Steganography Refresher

## 1. Pick a covert channel (communication to blend in with)

### Bible Verses

*“And there was evening and there was morning, a third day”*

*“Now there arose a new king over Egypt, who knew not Joseph.”*

*“Then shall there be presented with the bullock a meal-offering of three tenth parts of ...”*

### Pro-Putin Posters



### Emoji



# Universal Steganography Refresher

1. Pick a coverttext channel (communication to blend in with)

Emoji



# Universal Steganography Refresher

## 2. Encode your message:

Emoji





# Universal Steganography Refresher

## 2. Encode your message:

Plaintext: “Crypto means Cryptography”

### Emoji



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Emoji



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

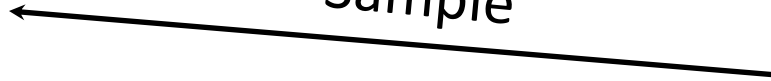
Ciphertext: 110110000001110100000010...



Emoji



Sample



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

$$\text{Hash}(\text{🐉}) = 1$$

Emoji



Sample



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

$$\text{Hash}(\text{Dragon}) = 1$$

Perfectly Unbiased



Sample

Emoji

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

$$\text{Hash}(\text{Dragon}) = 1$$

Perfectly Unbiased

Emoji



Sample

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

$$\text{Hash}(\text{🐉}) = 1$$

Perfectly Unbiased

Covertext: 🐉

Emoji



Sample

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Hash( ) =

Perfectly Unbiased

Covertext:



Emoji



Sample



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Hash(  ) =

Perfectly Unbiased

Covertext: 

Emoji



Sample

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"  
Ciphertext: 110110000001110100000010...

$$\text{Hash}(\text{🥑}) = 0$$

Perfectly Unbiased

Covertext: 🐉

Emoji



Sample

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Hash(  ) = 0

Perfectly Unbiased

Covertext:



Emoji



Sample

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"  
Ciphertext: 110110000001110100000010...

Hash( ) =

Perfectly Unbiased

Covertext:



Emoji



Sample

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"  
Ciphertext: 110110000001110100000010...

Hash( 🍌 ) =

Perfectly Unbiased

Covertext: 🐉



Emoji

Sample

# Universal Steganography Refresher

## 2. Encode your message:

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Pseudorandom Ciphertext

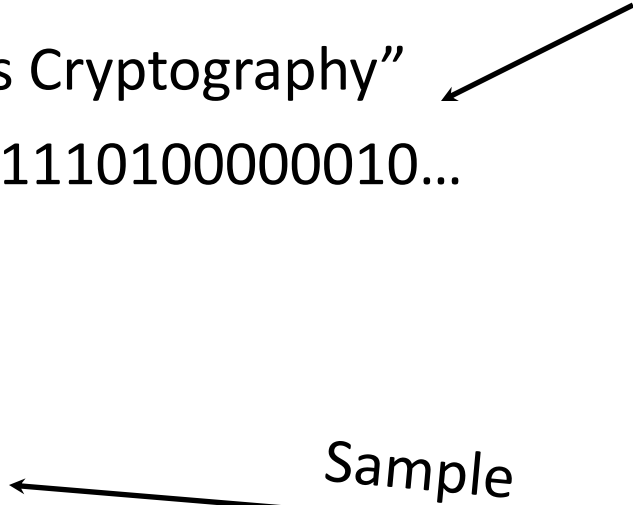
$$\text{Hash}(\text{🍌}) = 1$$

Perfectly Unbiased

Covertext: 🐉



Sample



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"  
Ciphertext: 110110000001110100000010...

$$\text{Hash}(\text{🍌}) = 1$$

Perfectly Unbiased

Covertext: 🐉 🍌



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Hash( ) =

Perfectly Unbiased

Sample

Emoji

Covertext:





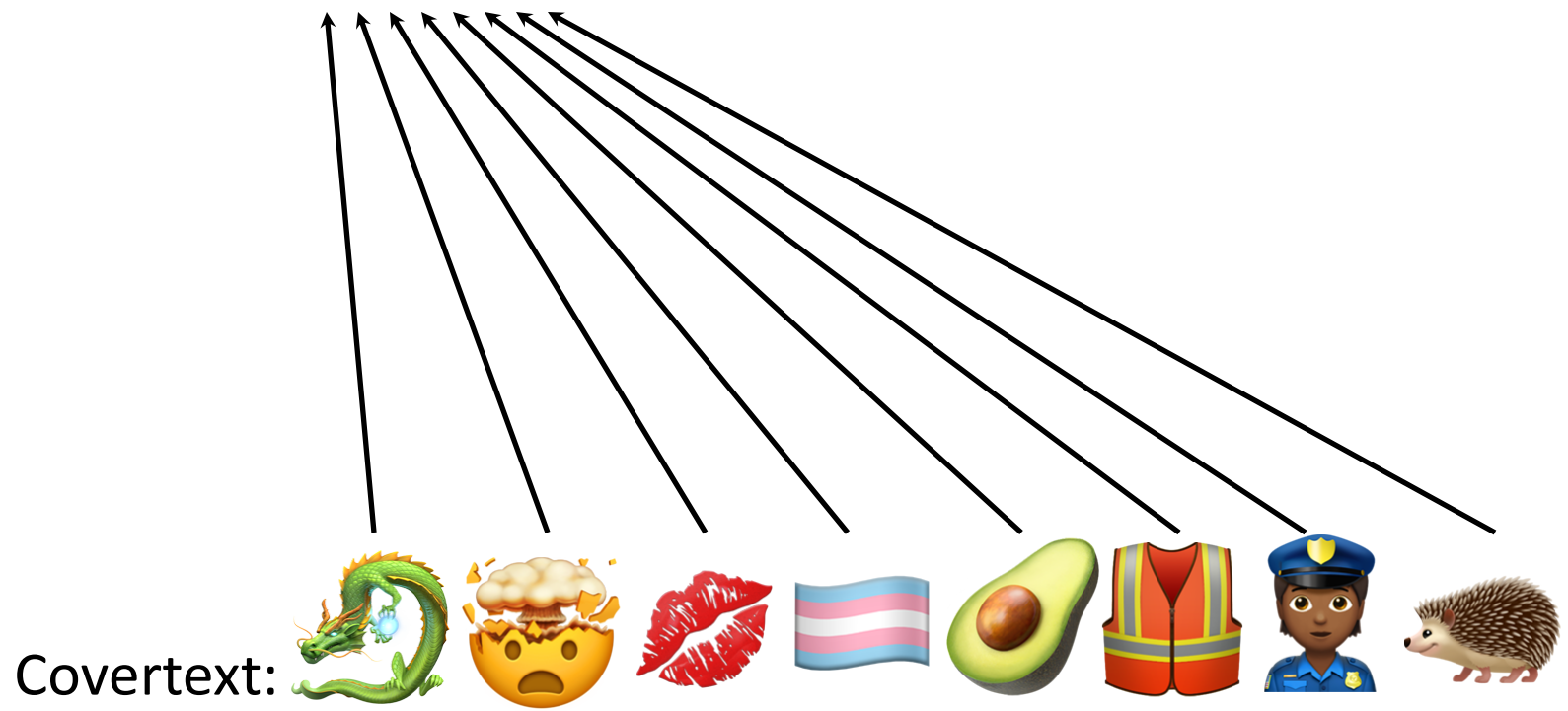
# Universal Steganography Refresher

Pseudorandom Ciphertext

## 3. Decode your message:

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Hash( ) =

Perfectly Unbiased

Sample

Emoji

Covertext:



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom Ciphertext

Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Emoji

Hash( ) =

Perfectly Unbiased

Sample

Natural Human Language

Covertext:



# Universal Steganography Refresher

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Plaintext: "Crypto means Cryptography"

Ciphertext: 110110000001110100000010...

Pseudorandom Ciphertext

Emoji

Hash( ) =

Perfectly Unbiased

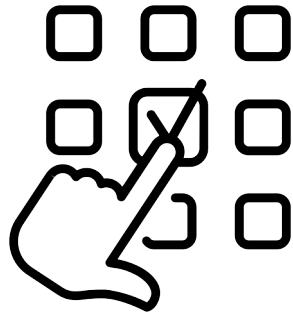
Sample

Natural Human Language

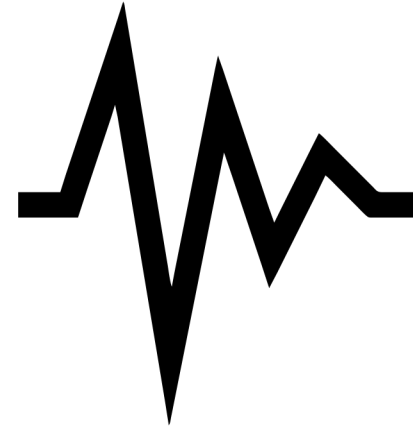
Coverttext: "Hey! Sorry I haven't texted in a hot sec..."

How is your grandmother doing?"

# Barriers to Deploying Universal Steganography



**Appropriate Samplers**

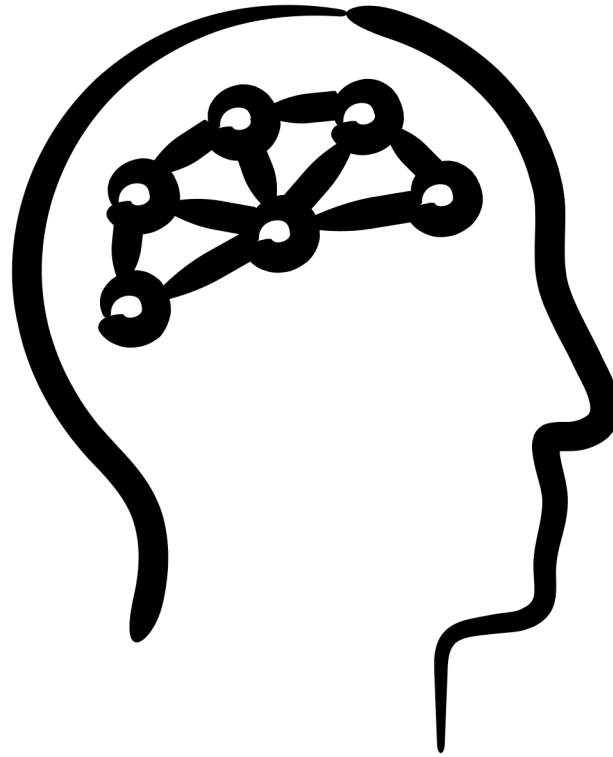


**Minimum Entropy  
Requirements**

# Generative Models and Samplers

## Context:

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”

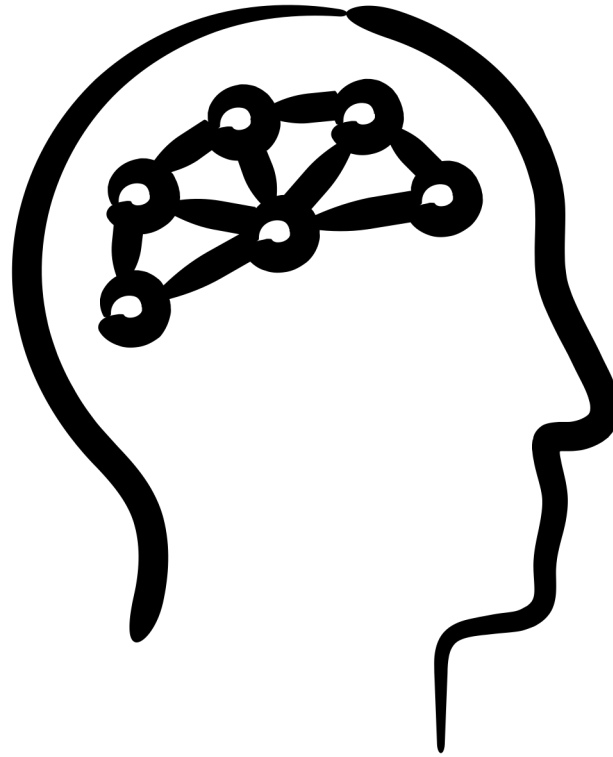


Generative Models

# Generative Models and Samplers

## Context:

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”



## Next Word Prediction:

- 32% - “An”
- 17% - “The”
- 12% - “A”
- 23% - “However”
- 15% - “Since”
- 1% - Other Options

Generative Models

# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom (random looking)

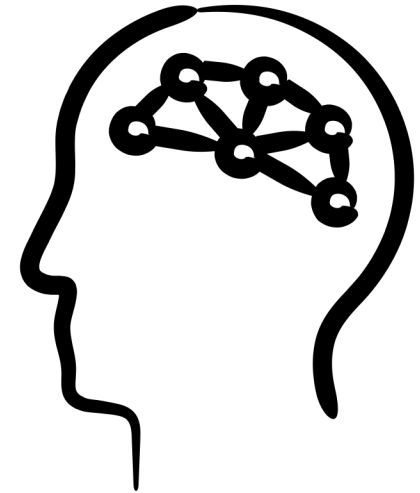
Plaintext: "Attack@Dawn"

Ciphertext: 110110000001110100000010...

Hash

Perfectly Unbiased

Sample



Coverttext: "Hey! Sorry I haven't texted in a hot sec...  
How is your grandmother doing?"



# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom (random looking)

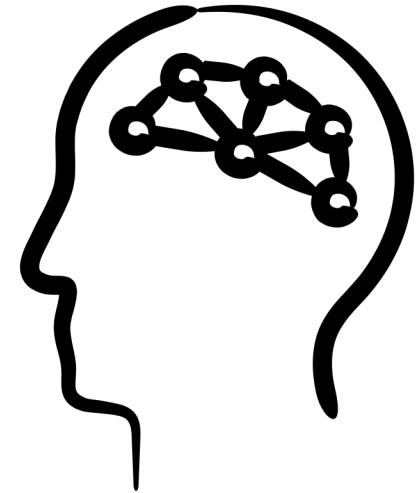
Plaintext: "Attack@Dawn"

Ciphertext: 110110000001110100000010...

Hash

Perfectly Unbiased

100% Failure Rate



Coverttext: "Hey! Sorry I haven't texted in a hot sec...

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# Universal Steganography Refresher

## 2. Encode your message:

Pseudorandom (random looking)

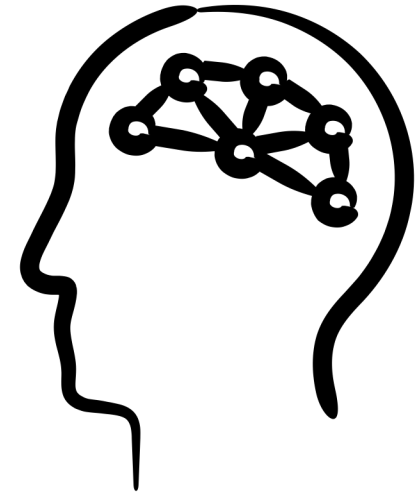
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100% Failure Rate



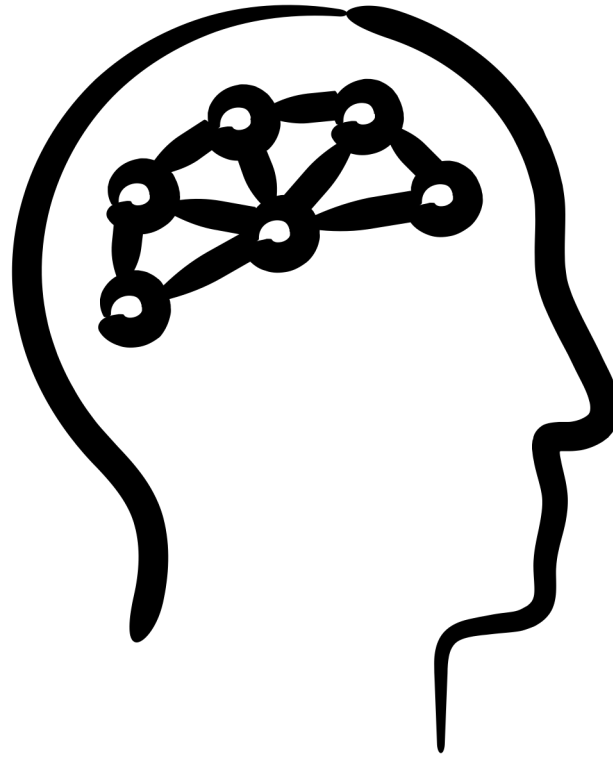
Coverttext: "Hey! Sorry I haven't texted in a hot sec...

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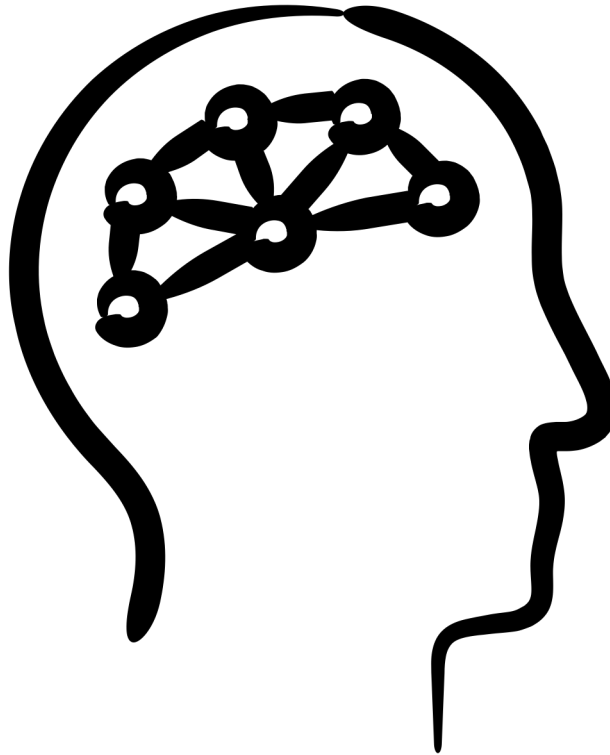
# Generative Models

## **Context:**

“The largest carnivore of the Cretaceous period was the Tyrannosaurus”



# Generative Models



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“The largest carnivore of the Cretaceous period was the Tyrannosaurus”

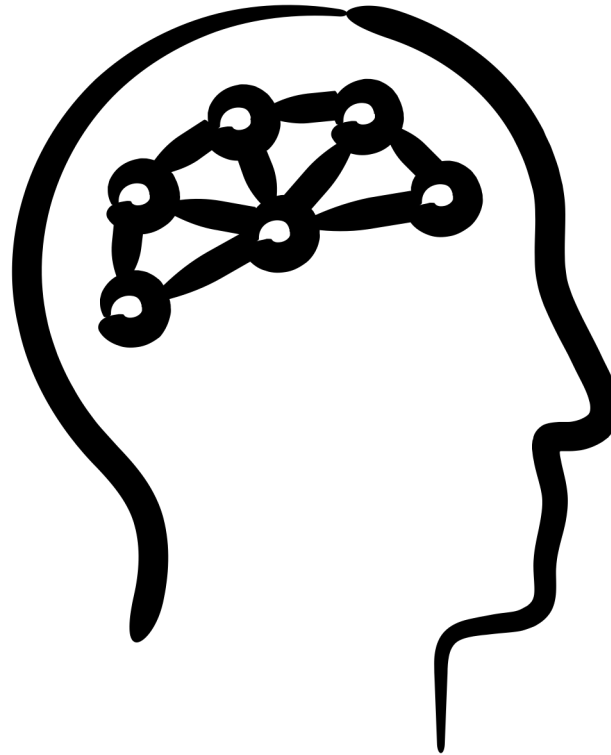
## **Next Word Prediction:**

98% - “Rex”

1% - “Spinosaurus”

1% - “Giganotosaurus”

# Generative Models



## **Context:**

“The largest carnivore of the Cretaceous period was the Tyrannosaurus”

## **Next Word Prediction:**

98% - “Rex”

1% - “Spinosaurus”

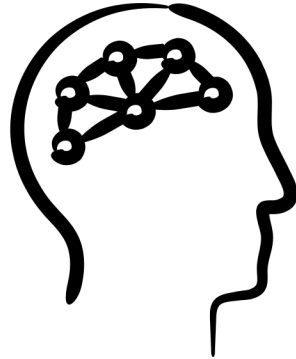
1% - “Giganotosaurus”

**A Perfectly Unbiased Hash Function Does Not Exist!**

# Meteor Intuition

## Context:

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”



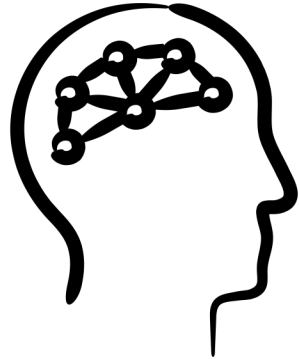
## Next Word Prediction:

- 32% - “An”
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- 23% - “However”
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## Context:

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## Next Word Prediction:

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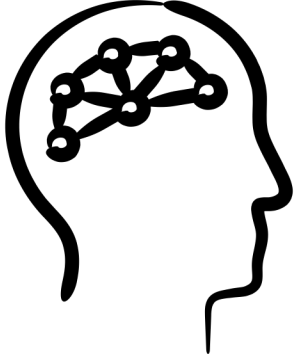
## Encrypted Message (as bits)

“The”

# Meteor Intuition

**Context:**

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”



**Next Word Prediction:**

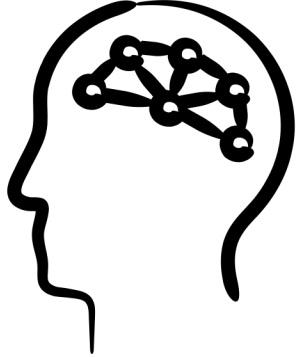
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**Encrypted Message  
(as bits)**

“The”

**Context:**

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”



**Next Word Prediction:**

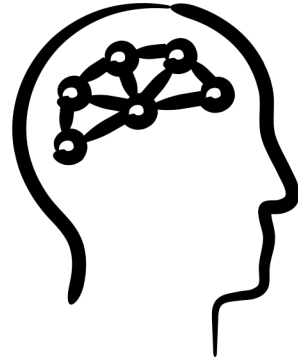
- 32% - “An”
- 17% - “The”
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- 23% - “However”
- 15% - “Since”
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# Meteor Intuition

## Context:

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”



## Next Word Prediction:

- 32% - “An”
- 17% - “The”
- 12% - “A”
- 23% - “However”
- 15% - “Since”
- 1% - Other Options

## Encrypted Message (as bits)

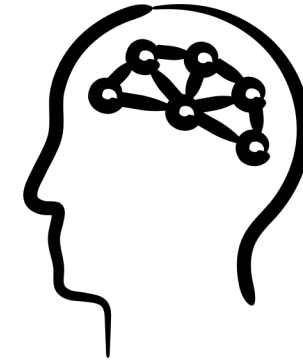
“The”

“The”

## Next Word Prediction:

- 32% - “An”
- 17% - “The”
- 12% - “A”
- 23% - “However”
- 15% - “Since”
- 1% - Other Options

First few bits of encrypted message  
(as bits)



## Context:

“Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.”

# Meteor Protocol

## 2. Encode your message:

Plaintext: "010000010111010001110100..."

# Meteor Protocol

## 2. Encode your message:

Plaintext: "010000010111010001110100..."

Mask: 000110000001110100000010... +

# Meteor Protocol

## 2. Encode your message:

Plaintext: "010000010111010001110100..."

Mask:       000110000001110100000010... +

---

Random:    010110010110100101110110...

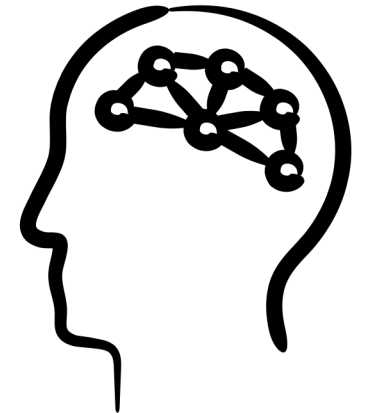
# Meteor Protocol

## 2. Encode your message:

Plaintext: "010000010111010001110100...  
Mask: 000110000001110100000010... +  
-----  
Random: 010110010110100101110110..."

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."



# Meteor Protocol

## 2. Encode your message:

Plaintext: "010000010111010001110100..."

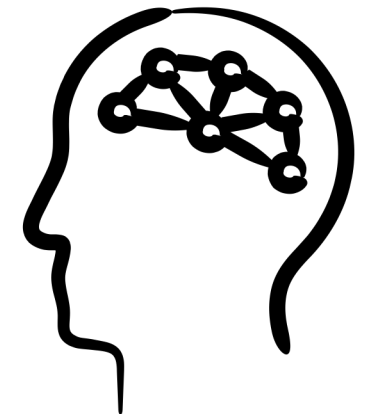
Mask: 000110000001110100000010... +

Random: 010110010110100101110110...



### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."



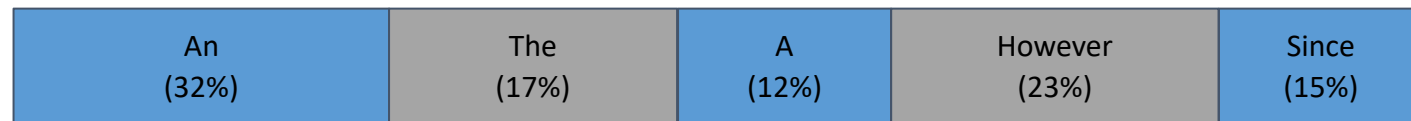
# Meteor Protocol

## 2. Encode your message:

Plaintext: "010000010111010001110100..."

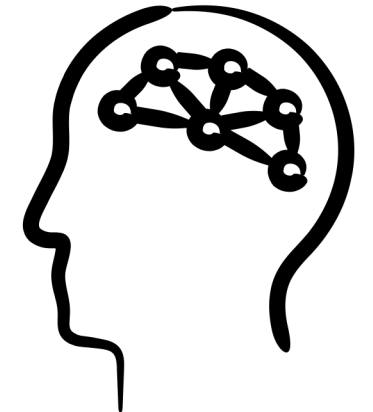
Mask: 000110000001110100000010... +

Random: 010110010110100101110110...



### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."



# Meteor Protocol

## 2. Encode your message:

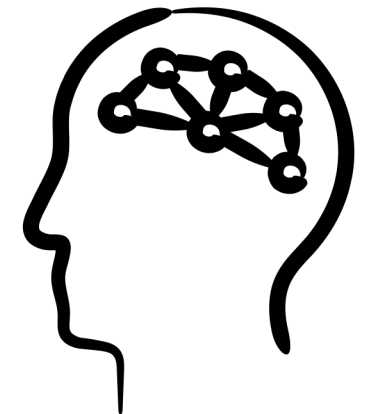
Plaintext: "010000010111010001110100...  
Mask: 000110000001110100000010... +  
-----  
Random: 010110010110100101110110..."



Covertext: The

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."

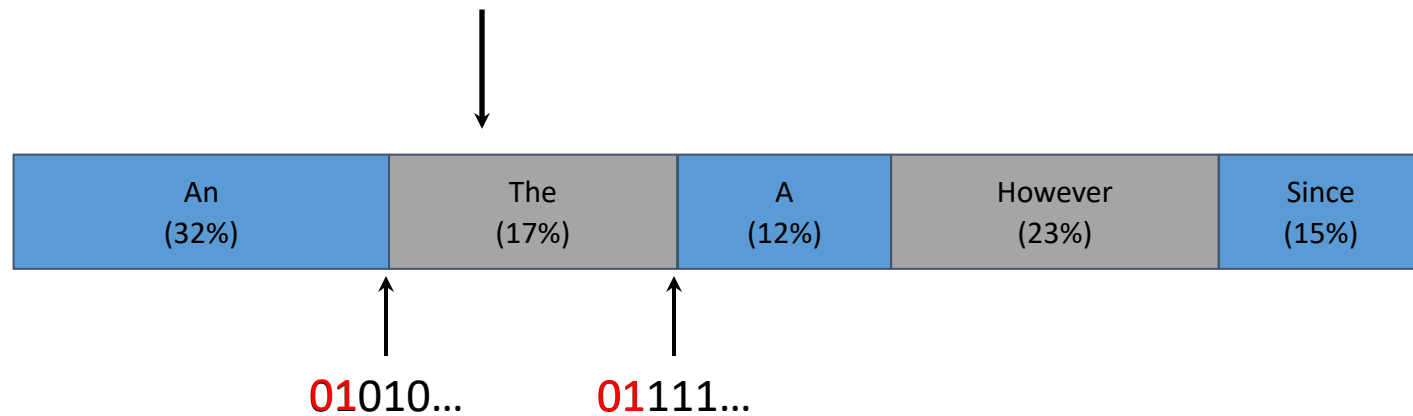




# Meteor Protocol

## 2. Encode your message:

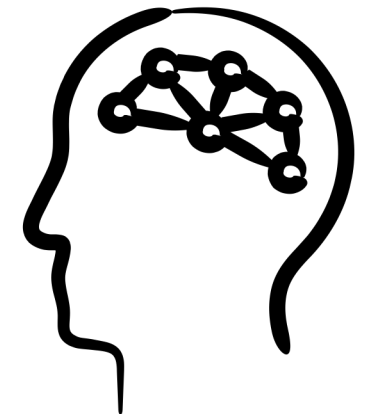
Plaintext: "010000010111010001110100..."  
Mask: 000110000001110100000010... +  
-----  
Random: 010110010110100101110110...



Covertext: The

### Context:

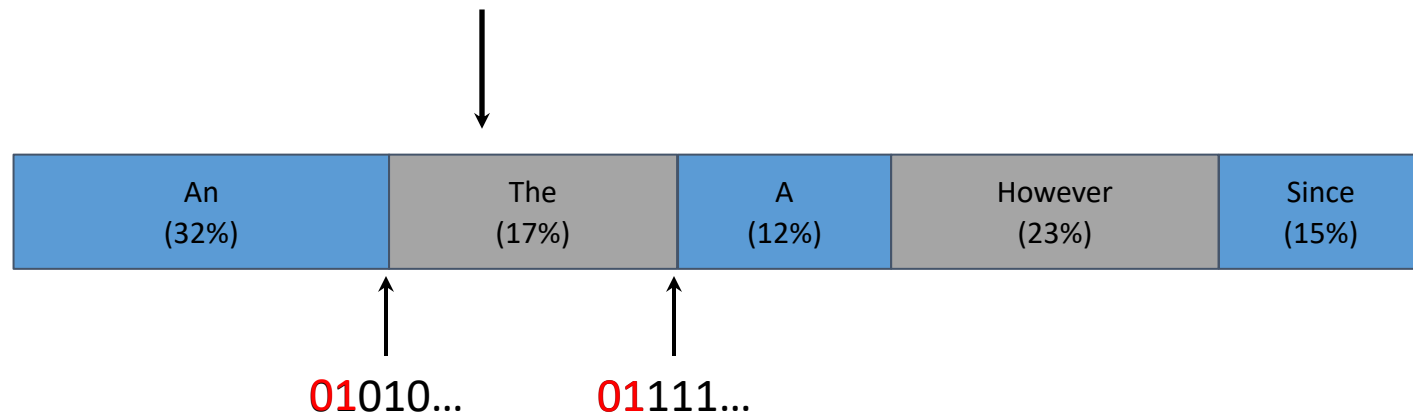
"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."



# Meteor Protocol

## 2. Encode your message:

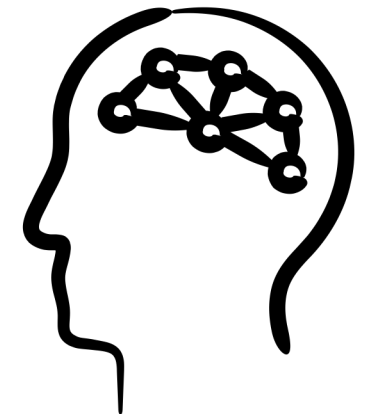
Plaintext: "010000010111010001110100..."  
Mask: 000110000001110100000010... +  
-----  
Random: 010110010110100101110110...



Covertext: The

### Context:

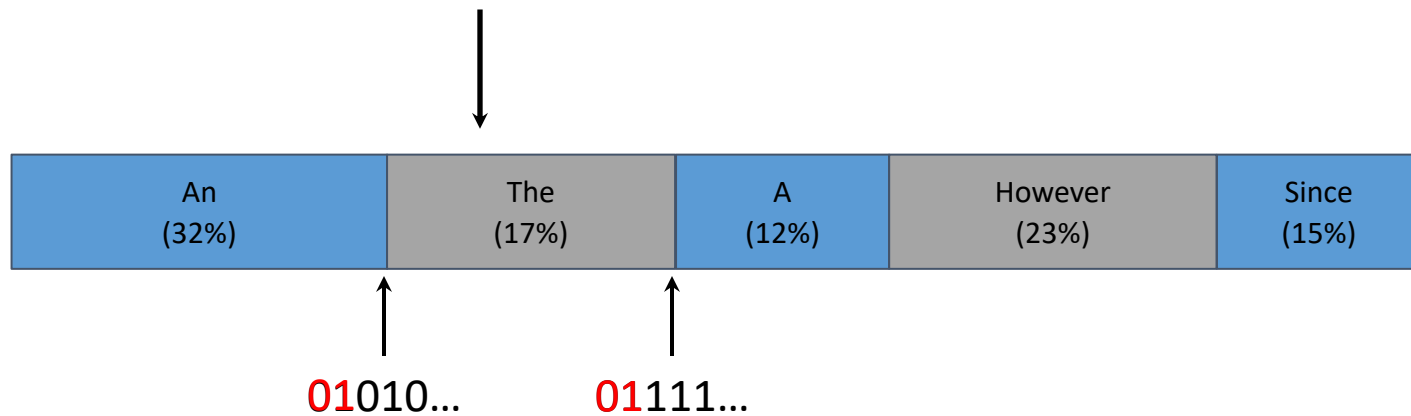
"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."



# Meteor Protocol

## 2. Encode your message:

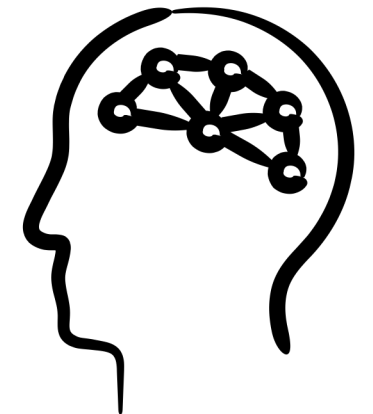
Plaintext: "010000010111010001110100...  
Mask: 000110000001110100000010... +  
Random: 010110010110100101110110..."



Covertext: The

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico."



# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100..."

Mask: \_\_\_\_\_ +

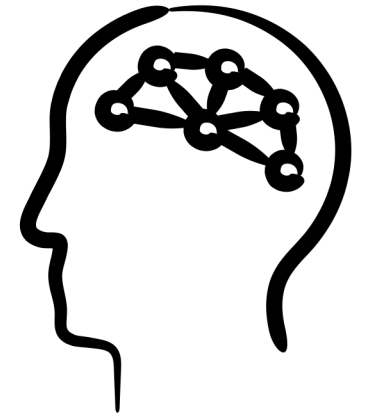
Random:

Covertext: The

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

The



# Meteor Protocol

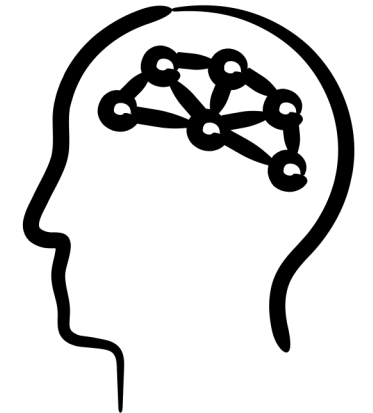
## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
-----  
Random: 1011100010100100100110..."

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

The



Coverttext: The

# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
-----  
Random: 1011100010100100100110..."

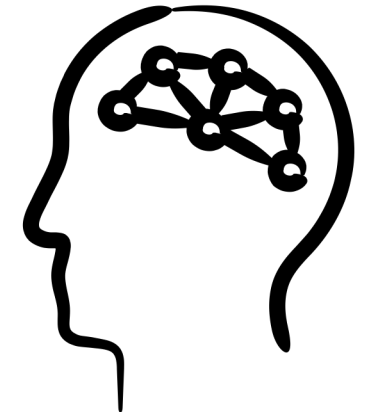


Covertext: The

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

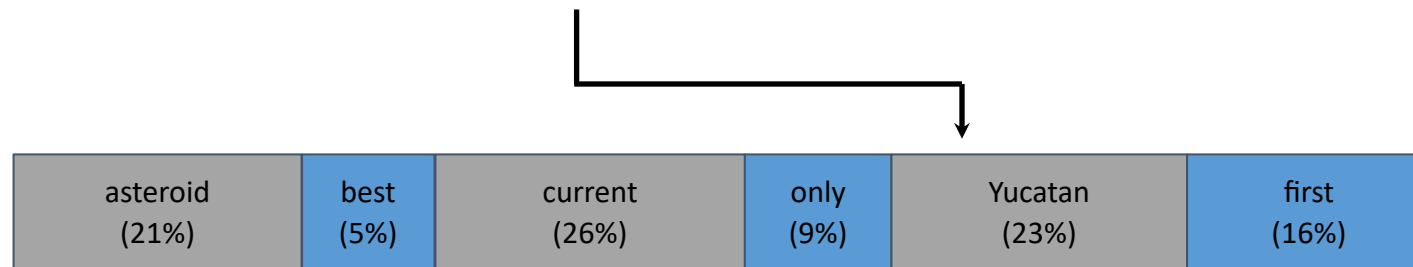
The



# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
-----  
Random: 1011100010100100100110..."

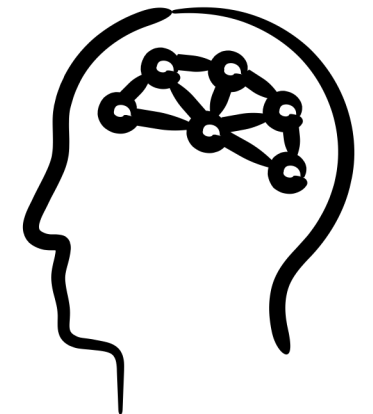


Covertext: The

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

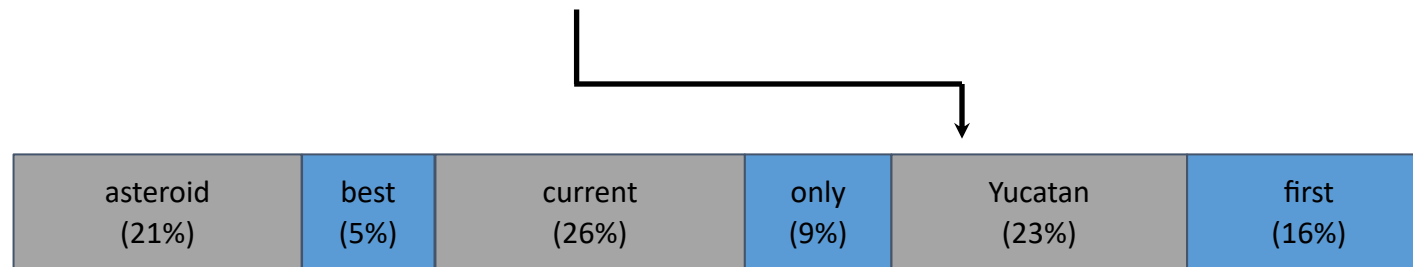
The



# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
-----  
Random: 1011100010100100100110..."

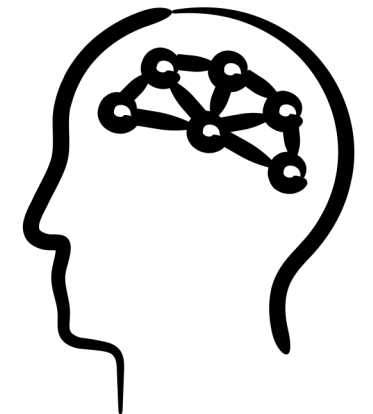


Covertext: The Yucatan

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

The

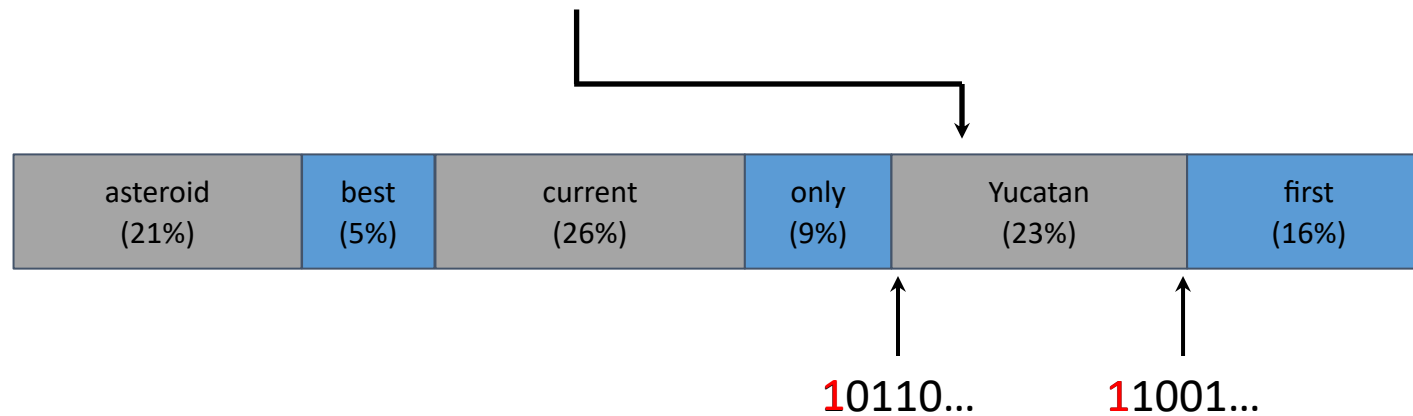




# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
-----  
Random: 1011100010100100100110..."

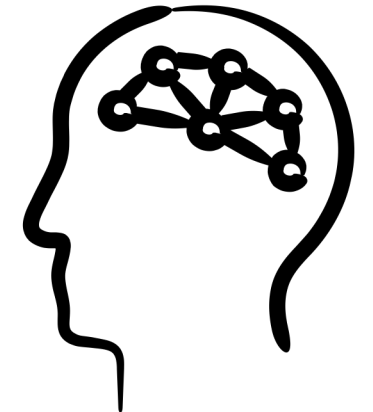


Covertext: The Yucatan

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

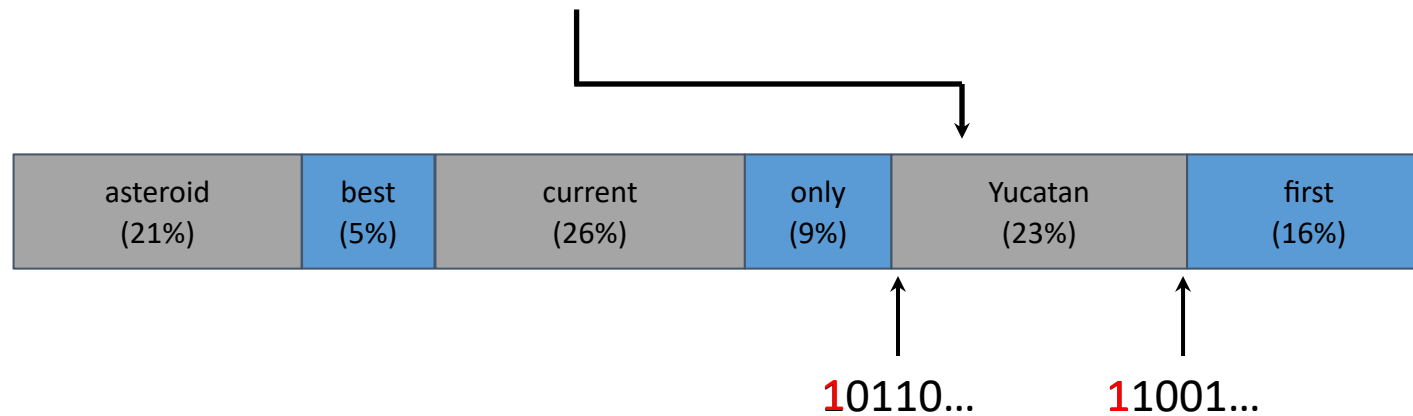
The



# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
Random: 1011100010100100100110..."

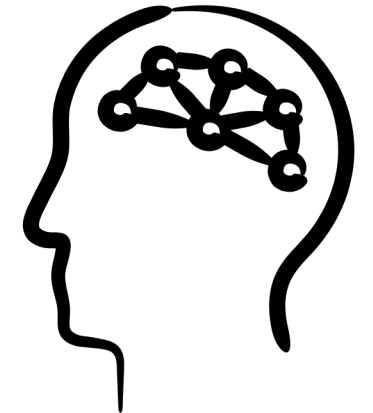


Covertext: The Yucatan

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

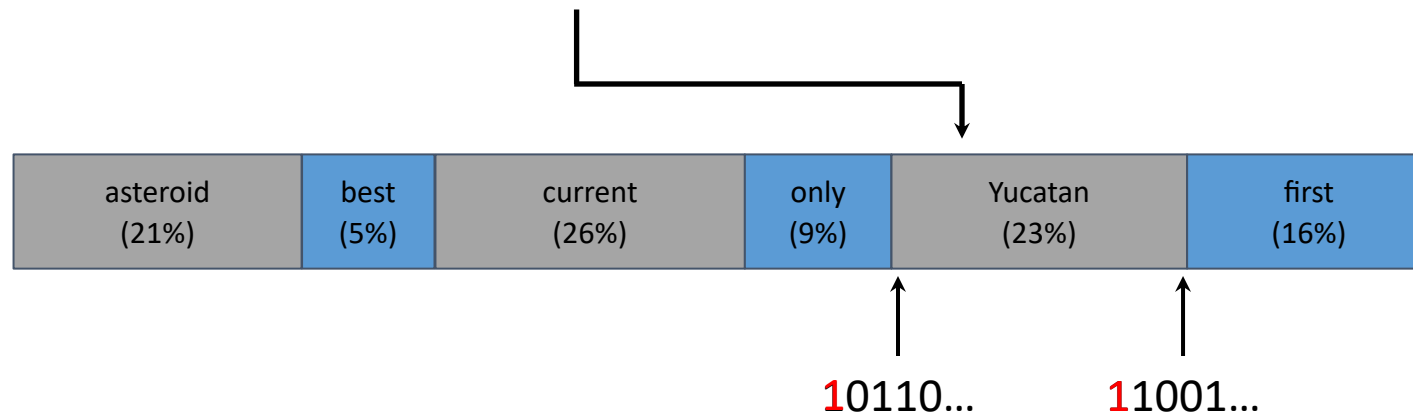
The



# Meteor Protocol

## 2. Encode your message:

Plaintext: "0000010111010001110100...  
Mask: 1011110100100101000010... +  
-----  
Random: 1011100010100100100110..."

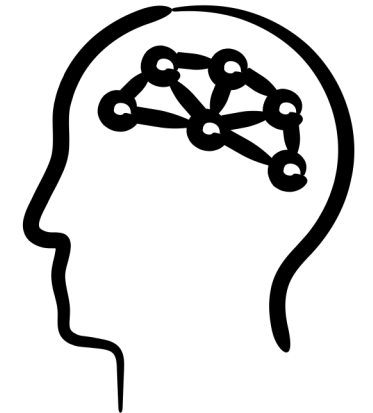


Covertext: The Yucatan

### Context:

"Evidence indicates that the asteroid fell in the Yucatan Peninsula, at Chicxulub, Mexico.

The



# A “Demo”

**Meteor**



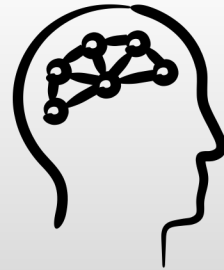
**GPT-2**

# A "Demo"

"Crypto means cryptography"



**Meteor**



**GPT-2**

# A "Demo"



"Crypto means cryptography"



**Meteor**



**GPT-2**

# A "Demo"



**Matthew Green** @matthew\_d\_green · Apr 6

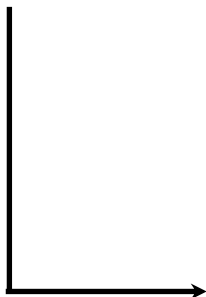
Restaurants continue to bring Tabasco in response to clearly-articulated requests for "hot sauce" and this needs to change.



**Matthew Green** @matthew\_d\_green · Apr 6  
Restaurants continue to bring Tabasco in response to clearly-articulated requests for "hot sauce" and this needs to change.

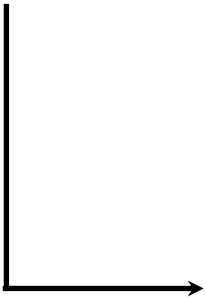


28 8 142



28 8 142

# A "Demo"



"Crypto means cryptography"



**Meteor**



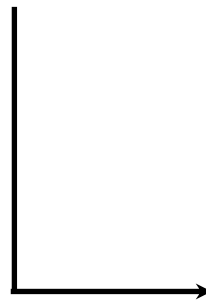
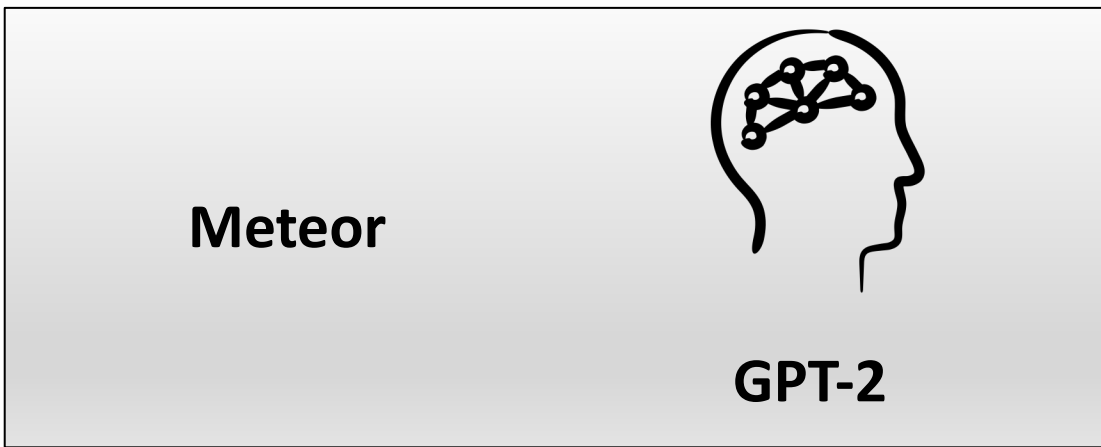
**GPT-2**



# A "Demo"



"Crypto means cryptography"



# A "Demo"



28

8

142



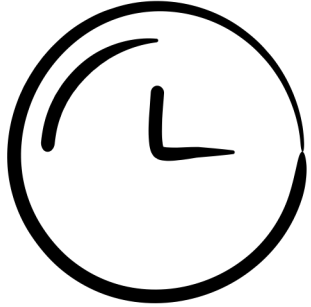
**Gabe Kaptchuk**  
@gkaptchuk



Replying to [@matthew\\_d\\_green](#)

I know this Spring that the process has gone fairly smoothly, but I think the hot sauce space needs to be more transparent and less afraid to be underestimated by restaurants. I'd rather have really [#anythingelse](#)

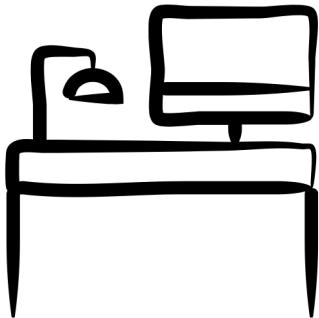
# Meteor Performance



~.1 sec to encode an ASCII Character on GPU,  
5x slower on CPU, 50x slower on mobile

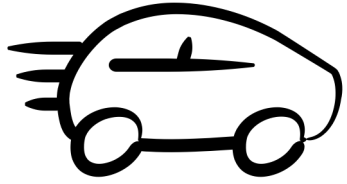


Provable indistinguishability from model output (CPA-like security)



Code conveniently pre-loaded into a Google Codelab

# Lots Left To Do



Increasing Efficiency



Porting Over E2E Security  
Lessons



Understanding Deployment  
Considerations

# Thank You!

For paper, demo, and blog: <https://meteorfrom.space/>

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Tushar Jois -- [jois@cs.jhu.edu](mailto:jois@cs.jhu.edu) Twitter: @tusharjois

Matt Green -- [mgreen@cs.jhu.edu](mailto:mgreen@cs.jhu.edu) Twitter: (let's be honest, you already follow him)

Avi Rubin -- [rubin@cs.jhu.edu](mailto:rubin@cs.jhu.edu) Twitter: @avirubin

## Performance Using Solutions Proposed in Theory Literature

Parameters	Samples (Tokens)	Time (Sec)	Stegotext Len. (KiB)	Overhead (Length)
$H_p = k = 16$	502.8	42.69	2.3	149.4x
$H_p = k = 32$	880.4	128.41	4.1	261.8x
$H_p = k = 64$	1645.0	361.28	7.5	482.1x
$H_p = k = 128$	2994.6	765.40	13.6	870.7x

**Input Length: 16 bytes**

## Meteor Performance

Device	Load	Encode	Decode	Overhead (time)
GPU	5.867	6.899	6.095	1×
CPU	5.234	41.221	40.334	4.6×
Mobile	1.830	473.58	457.57	49.5×

Input Length: 160 bytes