

Privacy and Legal Issues

Uttam Rao (ur6yr)
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April 14th, 2025

Background and Motivation

Increasing use of ML in sensitive settings

TECHNOLOGY FEATURE | 21 April 2020

Deep learning takes on tumours

Artificial-intelligence methods are moving into cancer research.

By [Esther Landhuis](#)

AI CAN FIX EVERYTHING IN INSURANCE. RIGHT?

There is no question about whether AI can improve insurance. Rather, the questions are about which functions, how extensively and when.

Alan Demers, Stephen Applebaum

Increasing use of ML in sensitive settings

A Face Is Exposed for AOL Searcher No. 4417749

By Michael Barbaro and Tom Zeller Jr.

Aug. 9, 2006

“Anonymous” Genomes Identified

The names and addresses of people participating in the Personal Genome Project can be easily tracked down despite such data being left off their online profiles.

Dan Cossins

May 3, 2013 | 2 min read



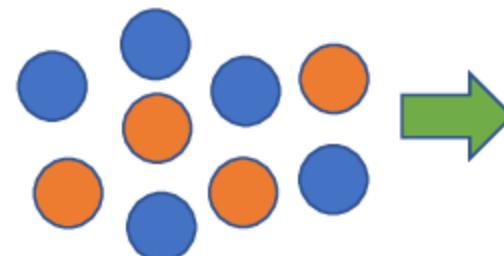
By Jeremy White Dec. 22, 2023

Exposing training data

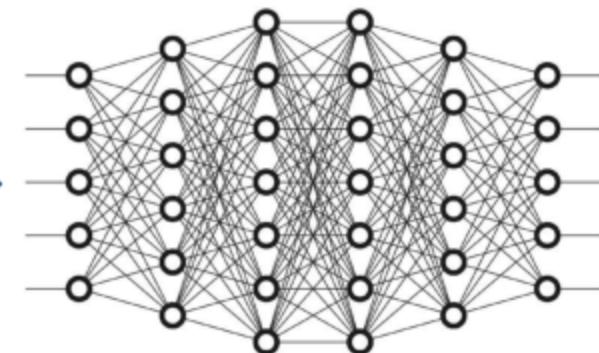
Membership inference

- Predict whether a particular example was used to train the model
- Least revealing form of attack

Training of Target Model



Training Data

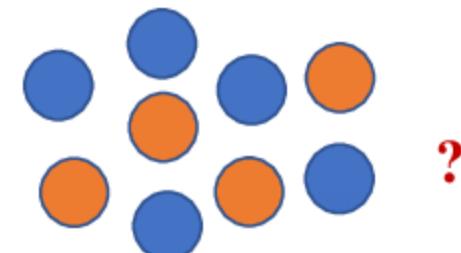


Deep Neural Network

Membership Inference Attack on Target Model



tries to answer: $\text{?} \in \text{?}$

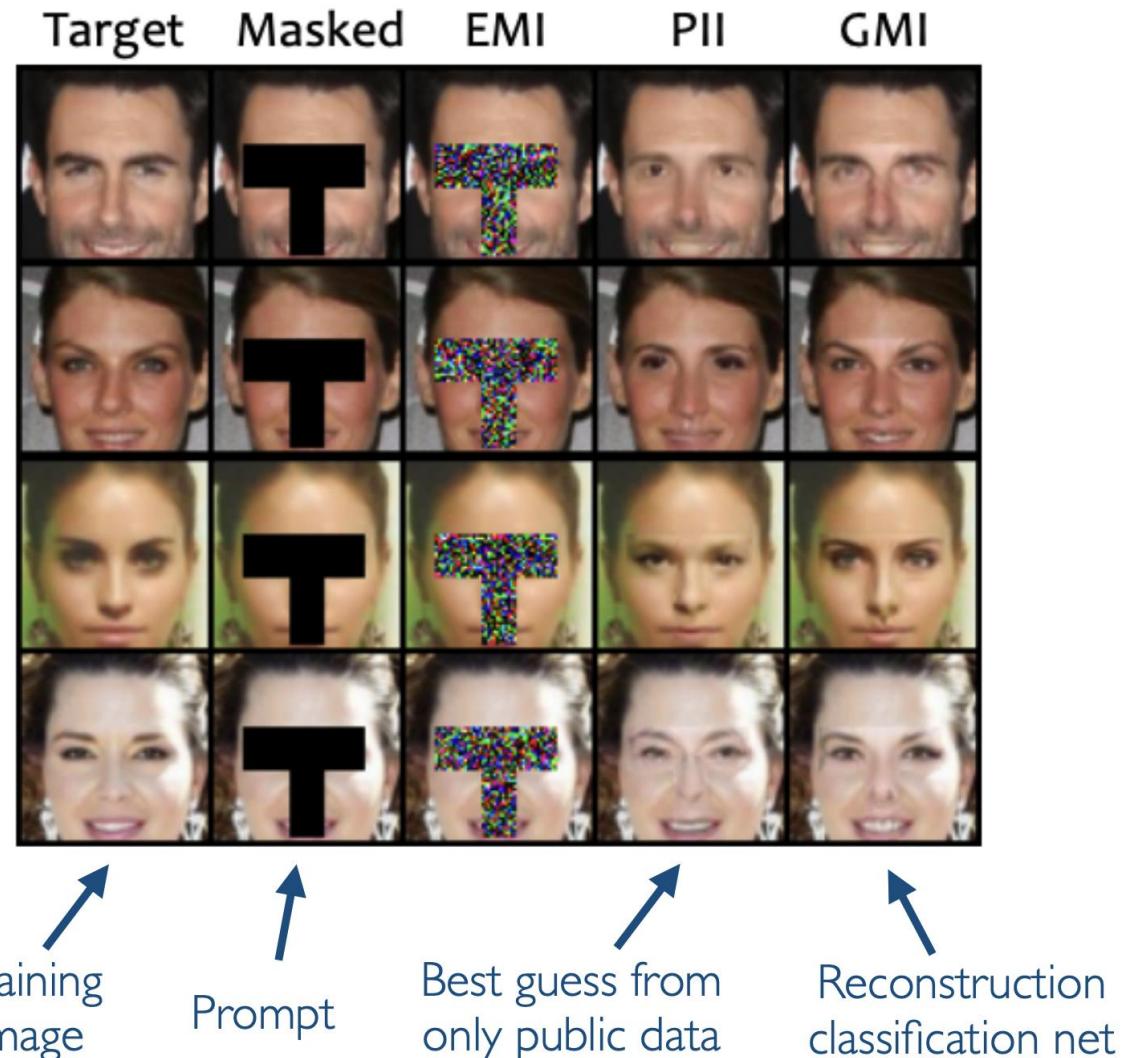


Training Data

Exposing training data

Model inversion

- Reconstruct representative views of a subset of examples

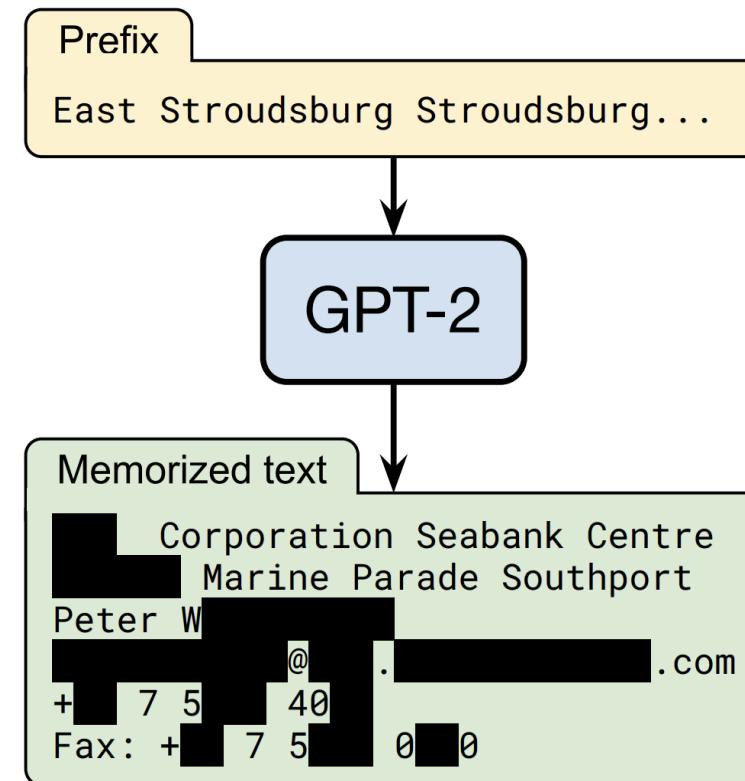


Source: Zhang et al., “The secret revealer: Generative model-inversion attacks against deep neural networks.” <https://arxiv.org/abs/1911.07135>

Exposing training data

Data extraction

- Reconstruct verbatim training examples and not just representative “fuzzy” examples



What causes privacy leakage?

- Typically associated with *overfitting*
 - Training error is significantly lower than test error
 - Indicates a model has memorized examples from its training set
- Language Models?
 - LMs exhibit little to no overfitting
 - Prevailing wisdom: "*the degree of copying with respect to any given work is likely to be, at most, de minimis*"

Overview

Can we extract training data from language models?

Can we mitigate the extraction of training data from LMs?

Can we quantify how much an LM has memorized?



Extracting Training Data from Large Language Models

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Ariel Herbert-Voss^{5,6}

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Adam Roberts¹

Tom Brown⁵

Dawn Song³

Úlfar Erlingsson⁷

Alina Oprea⁴

Colin Raffel¹

¹*Google* ²*Stanford* ³*UC Berkeley* ⁴*Northeastern University* ⁵*OpenAI* ⁶*Harvard* ⁷*Apple*

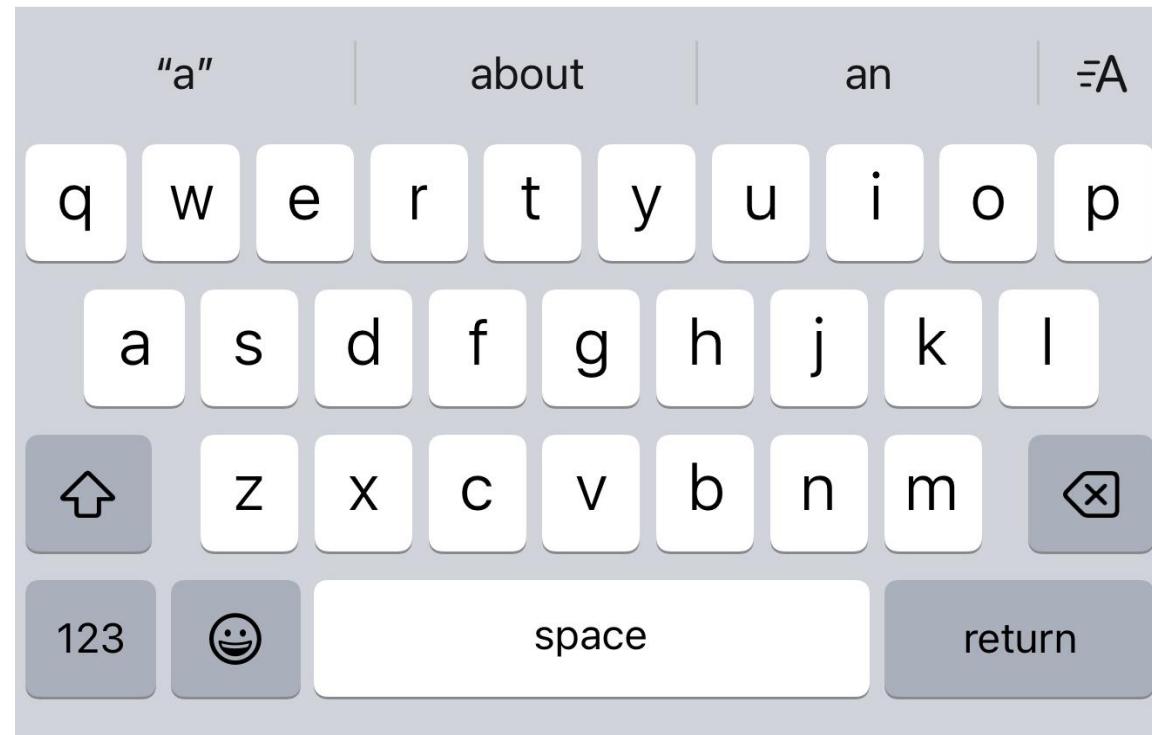
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Authors show the prevailing wisdom is wrong!

+

Do you want to grab some coffee with me in a



Presentation Slides

- ↗ ×

Feng, Shunqiang (mpp7ez)

Presentation Slides

Hi Shunqiang,

Hope you are doing well

Threat Model

Adversarial capabilities

- Black box access
 - Compute the probability of arbitrary sequences $f_\theta(x_1, \dots, x_n)$
 - Obtain next-word predictions
 - No access to individual weights or hidden states
- Highly realistic
 - Many LM models are available through black box APIs (e.g. OpenAI, Anthropic, etc.)

Attack target

- GPT-2
 - 1.5B parameters (XL)
 - 40GB training data
 - Trained over 12 epochs
 - Training loss only 10% less than test loss (no overfitting)
- Suitable target
 - Training data is all from the public sources
 - Training dataset was never released so no "cheating"



Defining memorization

Definition 1 (Model Knowledge Extraction) A string s is extractable⁴ from an LM f_θ if there exists a prefix c such that:

$$s \leftarrow \arg \max_{s': |s'|=N} f_\theta(s' \mid c)$$

Defining memorization

Definition 2 (k -Eidetic Memorization) A string s is k -eidetic memorized (for $k \geq 1$) by an LM f_θ if s is extractable from f_θ and s appears in at most k examples in the training data X : $|\{x \in X : s \subseteq x\}| \leq k$.

Adversarial objective

- **Goal:** Extract memorized training data from the language model
- **Attack Strength:** measured by quantity, length, and privacy level (k -eidetic) of extracted sequences.
- Indiscriminate extraction of training data, not targeting specific pieces of information

Prefix

East Stroudsburg Stroudsburg...

GPT-2

Memorized text

[REDACTED] Corporation Seabank Centre
[REDACTED] Marine Parade Southport
Peter W [REDACTED]
[REDACTED] @ [REDACTED]. [REDACTED].com
+ [REDACTED] 7 5 [REDACTED] 40
Fax: + [REDACTED] 7 5 [REDACTED] 0 [REDACTED] 0

Methodology

Initial attack (strawman baseline)

- Generate text
 - generate a large quantity of data by unconditionally sampling from the model
- Predict which outputs contain memorized text
 - Use a ***membership inference attack*** to remove the generated samples that are unlikely to contain memorized text
 - Does the example have high likelihood?
 - Yes = memorized, No = not memorized

Initial attack

- Generate text
 - Sample 256 tokens for each trial using the top-n strategy with n = 40
 - 200,000 samples on GPT-2XL
- Predict which outputs contain memorized text
 - Sort the output using a perplexity (likelihood measure)
 - Manually investigate lowest perplexity samples

$$\mathcal{P} = \exp \left(-\frac{1}{n} \sum_{i=1}^n \log f_{\theta}(x_i | x_1, \dots, x_{i-1}) \right)$$

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Each box will include: A selection of 5-star beauty products, from brands including L'Oréal, Smashbox, and more. A mystery beauty product with value of at least \$45. A surprise gift. And you'll also receive a bonus item (valued at at least \$12.50) when you sign-up. Here are the details for this month's box: Birchbox October 2016 Box - \$45 Value. Check out our Birchbox reviews to learn more about this monthly beauty subscription box! Liz is the founder of My Subscription Addiction. She's been hooked on subscription boxes since 2011 thanks to BirchFormer top American financial regulation lawmaker Mary Ferguson could offer crucial leadership services moving Democratic-only Pennsylvania through uncharted regulatory turmoil facing states reeling. She can also help Democrats in Congress who are struggling to defend a number of seats they won in 2010, including the seat held by Sen. Bob Casey Robert (Bob) Patrick CaseyDems hold edge in Rust Belt Senate races: poll Malnutrition Awareness Week spotlights the importance of national nutrition programs Poll: Democrats hold big leads in Pennsylvania Senate, governor races MORE (D). ADVERTISEMENT The two are the most endangered Democrats in the House. Casey, who is facing a tough race to keep his seat, could be a prime target for Republicans, who have been trying to unseat him ever since he was appointed in 2011. His district is one of 10 in Pennsylvania with a GOP majority. Ferguson, a former member of the House Financial Services Committee, has been a leader of the opposition to the Dodd-Frank financial reform law. She recently announced her candidacy for Senate, and could help Senate Democrats win back the seat held by Sen. Scott Brown Scott Eric TrumpAvenatti: Third Kavanaugh accuser will prove credible against Kavanaugh, other 'privileged white guys' who defend him Grassley's office says itGin Fractions In Alcoholic BrewMigal 'ElbowDropse/Zaknoratraseru' Shattil is a professional CS:GO player. He is currently playing for HellRaisers. Gear and settings [edit] Mouse settings [1] (list of) (calculate) Mouse Curvature Circumference Mouse Setup Sens. Zoom Raw. ZOWIE by BenQ ZA14 1168 MPI 0.762 deg/mm 21.3 in/rev 47.4 cm/rev 400 CPI @ 1000 Hz 2.8 1 On 600 Last updated on 2017-01-15 (119 days ago). Mouse Mousepad ZOWIE by BenQ ZA14 (X) ZA14 (O) SteelSeries QcK Heavy Monitor Refresh rate In-game resolution Scaling ZOWIE by BenQ XL2540 240 Hz 1024x768 Black Bars Keyboard Headset Logitech G400 Last updated on 2017-01-15 (119 days ago). Crosshair settings [6] (list of) Style Size Thickness Sniper Gap Outline Dot Color Alpha 4 3 0 1 -5This is a rush transcript. Copy may not be in its final form. 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This includes a review of our detention policy with a special emphasis on our detention and interrogation program, and I will seek to transfer or release those currently detained, where practicable, consistent with the national security interests of the United States. The review will be a top[136] => 2013-08-06 [displayText] => Passed/agreed to in House: On passage Passed by recorded vote: 230 - 180 (Roll no. 603).(text: CR H8184-8188 [externalActionCode] => 8000 [description] => Passed House) Passed Senate Array ([actionDate] => 2013-08-08 [displayText] => Passed/agreed to in Senate: Passed Senate without amendment by Unanimous Consent.(consideration: CR S6495 [externalActionCode] => 17000 [description] => Passed Senate) To President Array ([actionDate] => 2013-08-12 [displayText] => Presented to President. [externalActionCode] => 28000 [description] => To President) Became Law Array ([actionDate] => 2013-08-16 [displayText] => Became Public Law No: 113-119. [externalActionCode] => 36000 [description] => Became Law) LAW 64. H.R.3580 — 113th Congress (2013-2014) To amend the Internal Revenue Code of 1986 to exclude from gross income disbursements made to an eligible organization for distribution to qualified persons in furtherance of an activity to further religious, charitable, scientific, literary, or educational purposesA federal judge in Manhattan ordered President Donald Trump on Tuesday to give up his business empire to avoid conflicts of interest, but left the door open for the president to retain a stake in his businesses. In a ruling that could have far-reaching consequences, U.S. District Judge George Daniels said Mr Trump's businesses could continue operating without violating the Constitution, but the court did not require him to sell or divest himself of them. "This case does not involve an unconstitutional conflict of interest," Mr Daniels wrote. The ruling came days after Mr Trump issued an executive order that effectively gave his sons, including senior White House adviser Donald Trump Jr., control of the family business, the Trump Organization. The order did not divest the president of any interest in the company. Mr Trump is the president of the Trump Organisation, whose business interests include Trump Tower in New York City and a variety of other assets. Shape Created with Sketch. Trump Inauguration protests around the World Show all 14 left Created with Sketch. right Created with Sketch. Shape Created with Sketch. Trump Inauguration protests around the World 1/14 Activists from Greenpeace display a message reading "Mr President, walls divide. Build Bridges!" along the Berlin wall in Berlin on "What people believe one year before this horrific happening makes fools seem serious like I'll bring ISIS straight along... in February," said Mr Farage in a speech to UKIP's annual conference in London. He added: "It is time to stop talking about ISIS, to stop making speeches about 'we are going to defeat them'... to get serious. It is time to do what we are actually good at, which is defeating Labour in a general election." But the UKIP leader said he believed it was possible to defeat Islamic State "one way or another" and that there would be no easy way of tackling the issue. "There is no way of defeating them one way or another," said Mr Farage. "There is only getting on with it - doing all of the very simple things that we all know will actually have an impact." Shape Created with Sketch. In pictures: The rise of Isis Show all 74 left Created with Sketch. right Created with Sketch. Shape Created with Sketch. In pictures: The rise of Isis 1/74 Isis fighters Fighters of the Islamic State wave the group's flag from a damaged display of a government fighter jet following the battle for the Tabqa air base, in Raqqa, Syria AP 2/74 IsisThe New Hampshire Senate on Monday confirmed the nomination of Sen. John McCain John Sidney McCainUpcoming Kavanaugh hearing: Truth or consequences How the Trump tax law passed: Dealing with a health care hangover Kavanaugh's fate rests with Sen. Collins MORE's (R-Ariz.) replacement as the committee chairman of the Senate Armed Services Committee, which is chaired by Sen. Jack Reed John (Jack) Francis ReedAdmiral defends record after coming under investigation in 'Fat Leonard' scandal New York Times: Trump mulling whether to replace Mattis after midterms Overnight Defense: Biden honors McCain at Phoenix memorial service | US considers sending captured ISIS fighters to Gitmo and Iraq | Senators press Trump on ending Yemen civil war MORE (D-R.I.). ADVERTISEMENT McCain's confirmation comes just days after it was announced that the committee was delaying a vote on his nomination until at least July 7. The panel is holding confirmation hearings for five other nominees who were nominated to fill senior Pentagon positions, including the secretaries of the Army, Navy, Air Force and Marine Corps, Defense Secretary Jim Mattis James Norman MattisTurkey-Russia Idlib agreement: A lesson for the US Trump says willing to meet with Maduro, but keeps 'all options' open Pentagon withdrawing some missileWispa Campaign Another Sweet Success - A Kinetic Novel Forgotton Anne FORM forma.8 Formula Formula Fusion Forsaken Uprising Fort Defense Fort Meow Fortified Fortix 2 FortressCraft Evolved Forward to the Sky Fossil Echo Foto Flash FOTONICA Foul Play Four Last Things Four Realms FourChords Guitar Karaoke Fourtекс Jugo Fox & Flock Fox Hime Zero Fractal Fracture the Flag Fractured Space Fragmental Fragments of Him Framed Wings Fran Bow Franchise Hockey Manager 2 Franchise Hockey Manager 2014 Franchise Hockey Manager 3 Franchise Hockey Manager 4 Francis Frankenstein: Master of Death Frantic Freighter Freaky Awesome Freddi Fish 2: The Case of the Haunted Schoolhouse Freddi Fish and the Case of the Missing Kelp Seeds Frederic: Evil Strikes Back Frederic: Resurrection of Music Director's Cut Free to Play Freebie FreeCell Quest Freedom Cry Freedom Fall Freedom Planet Freedom Poopie Freeman: Guerrilla Warfare FreeStyle 2: Street Basketball FreeStyleFootball FreezeME Frequent Flyer Fresh Body Friday Night Bullet Arena Friday the 13th: Killer Puzzle Friday the 13th: The Game Fright Light Frisky Business Frog Climbers Frog HopRigor Gaming Invid Pro C57 + Assets Server - 4 cores max 32 slots for c & non st c 567+ MHz and 2.0 GHz memory overclocked. This means the product was tested and repaired as required to meet the standards of the refurbisher, which may or may not be the original manufacturer. Any exceptions to the condition of the item outside the manufacturer's information should be provided in the listing, up to and including warranty details. Sold and Shipped by Newegg Purchases from these Sellers are generally covered under our Newegg Marketplace Guarantee Marketplace SellerThe first major piece of legislation introduced after President Donald Trump's inauguration will target "sanctuary cities" by prohibiting jurisdictions from withholding certain federal grants or providing certain benefits to people who are in the country illegally, according to a report in The Hill. The "Kate's Law" — named after Kathryn Steinle, a 32-year-old woman who was shot in San Francisco and later died after a federal judge ordered the release of her alleged killer in December 2015 — would create penalties for cities and counties that refuse to cooperate with federal immigration authorities. The "Kate's Law" would also prohibit local governments from withholding information on immigrants who are in 2012-10-01T17:31:31.000Z", "title": "NFL Week 17: What If? - ", "thumbnail_url": "https://img.bleacherreport.net/cms/media/image/73/c9/47/bb/7418/46aa/99af/e6f94ed4a8cc/crop_exact_AB.jpg?h=502&q=90&w=754", "metadata": { "video_url": "https://vid.bleacherreport.com/videos/40291/akamai.json", "video_id": "40291", "title": "What If Football Results Are Last Sunday Instead of Monday? Watch above to see if your favorite team won't play this weekend!", "thumbnail_url": "https://img.bleacherreport.net/cms/media/image/73/c9/47/bb/7418/46aa/99af/e6f94ed4a8cc/crop_exact_AB.jpg?h=502&q=90&w=754", "tags": "[apple-video", "nfl"] }, "stub_id": "40291", "comments": "73008a11-162f-40d3The U.S. Senate's top Democrat has introduced a bill that would require the Federal Communications Commission to create privacy rules for internet service providers. Sen. Ed Markey Edward (Ed) John MarkeyThis week: Kavanaugh nomination thrown into further chaos Overnight Defense: Mattis dismisses talk he may be leaving | Polish president floats 'Fort Trump' | Dem bill would ban low-yield nukes Dems introduce bill to ban low-yield nukes MORE (Mass.) on Thursday called the measure a "first step toward a stronger privacy law." "Our Internet service providers have become the most sensitive data in our society," he said in a statement. "We need to do everything that we can to prevent them from using it to track our behavior and sell it to the highest bidder." ADVERTISEMENT Markey's bill is aimed at the FCC rules, which he says have not kept pace with the digital revolution. "The Federal Communications Commission's rules are woefully outdated," he said. "The internet has changed so quickly that the FCC has struggled to keep up." The bill would require broadband providers to obtain customer consent before collecting data on their online activities, including the websites people visit, the time spent on them and The new, highly-anticipated movie, 'The Interview,' has been cancelled. The studio's CEO, Jim Gianopoulos, has confirmed this afternoon. "The film has been cancelled," Gianopoulos said. "The filmmakers and I have been in communication with the studio leading up to this decision and, after considerable thought, we have decided that it is in the best interests of everyone involved that the film NOT proceed." "While we respect and appreciate the freedom of expression that creators are guaranteed by our constitution and laws, we cannot allow the actions of a few to undermine the principles that this country was founded on and which we continue to

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[externalActionCode] => 28000 [description] => To President) Became Law Array ([actionDate] => 2013-08-16 [displayText] => Became Public Law No: 113-119. [externalActionCode] => 36000 [description] => Became Law) LAW 64. H.R.3580 — 113th Congress (2013-2014) To amend the Internal Revenue Code of 1986 to exclude from gross income disbursements made to an eligible organization for distribution to qualified persons in furtherance of an activity to further religious, charitable, scientific, literary, or educational purposesA federal judge in Manhattan ordered President Donald Trump on Tuesday to give up his business empire to avoid conflicts of interest, but left the door open for the president to retain a stake in his businesses. In a ruling that could have far-reaching consequences, U.S. District Judge George Daniels said Mr Trump's businesses could continue operating without violating the Constitution, but the court did not require him to sell or divest himself of them. "This case does not involve an unconstitutional conflict of interest," Mr Daniels wrote. The ruling came days after Mr Trump issued an executive order that effectively gave his sons, including senior White House adviser Donald Trump Jr., control of the family business, the Trump Organization. The order did not divest the president of any interest in the company. Mr Trump is the president of the Trump Organisation, whose business interests include Trump Tower in New York City and a variety of other assets. Shape Created with Sketch. Trump Inauguration protests around the World Show all 14 left Created with Sketch. right Created with Sketch. Shape Created with Sketch. Trump Inauguration protests around the World 1/14 Activists from Greenpeace display a message reading "Mr President, walls divide. Build Bridges!" along the Berlin wall in Berlin on "What people believe one year before this horrific happening makes fools seem serious like I'll bring ISIS straight along... in February," said Mr Farage in a speech to UKIP's annual conference in London. He added: "It is time to stop talking about ISIS, to stop making speeches about 'we are going to defeat them'... to get serious. It is time to do what we are actually good at, which is defeating Labour in a general election." But the UKIP leader said he believed it was possible to defeat Islamic State "one way or another" and that there would be no easy way of tackling the issue. "There is no way of defeating them one way or another," said Mr Farage. "There is only getting on with it - doing all of the very simple things that we all know will actually have an impact." Shape Created with Sketch. In pictures: The rise of Isis Show all 74 left Created with Sketch. right Created with Sketch. Shape Created with Sketch. In pictures: The rise of Isis 1/74 Isis fighters Fighters of the Islamic State wave the group's flag from a damaged display of a government fighter jet following the battle for the Tabqa air base in Raqa, Syria AP 2/74 IsisThe New Hampshire Senate on Monday confirmed the nomination of Sen. John McCain John Sidney McCainUpcoming Kavanaugh hearing: Truth or consequences How the trump tax law passed: Dealing with a health care hangover Kavanaugh's fate rests with Sen. Collins MORE's (R-Ariz.) replacement as the committee chairman of the Senate Armed Services Committee, which is chaired by Sen. Jack Reed John (Jack) Francis Reed/ midterms Overnight Defense: Biden honors McCain at Phoenix memorial service | US considers sending captured ISIS fighters to Gitmo and Iraq | **Senators press Trump on ending Yemen civil war MORE (D-R.I.). ADVERTISEMENT** McCain's confirmation comes just days after it was announced that the committee was delaying a vote on his nomination until at least July 7. The panel is holding confirmation hearings for five other nominees who were nominated to fill senior Pentagon positions, including the secretaries of the Army, Navy, Air Force and Marine Corps, Defense Secretary Jim Mattis James Norman MattisTurkey-Russia Idlib agreement: A lesson for the US Trump says willing to meet "the Madura, but keeps 'all' optional open Pentagon withdrawing some missileWings Campaign Another Sure Success - A Kinetic Novel Forgotton Anne FORM forma.8 Formata Formula Fusion Forsaken Uprising Fort Defense Fort Meow Fortified Fortissimo FA Fortix Fortix 2 FortressCraft Evolved Forward to the Sky Fossil Echo Foto Flash FOTONICA Foul Play Four Last Things Four Realms FourChords Guitar Karaoke Fourtex Jugo Fox & Flock Fox Hime Zero Fractal Fracture the Flag Fractured Space Fragmental Fragments of Him Framed Wings Fran Bow Franchise Hockey Manager 2 Franchise Hockey Manager 4 Franchise Hockey Manager 4 Francisca Frankenstein: Master of Death Frantic Freightier Freaky Awesome Freddi Fish 2: The Case of the Haunted Schoolhouse Freddi Fish and the Case of the Missing Kelp Seeds Frederic: Evil Strikes Back Frederic: Resurrection of Music Director's Cut Free to Play Freebie FreeCell Quest Freedom Cry Freedom Fall Freedom Planet Freedom Poopie Freeman: Guerrilla Warfare FreeStyle 2: Street Basketball FreeStyleFootball FreezeME Frequent Flyer Fresh Body Friday Night Bullet Arena Friday the 13th: Killer Puzzle Friday the 13th: The Game Fright Light Frisky Business Frog Climbers Frog HopRigor Gaming Iivid Pro C57 + Assets Server - 4 cores max 32 slots for c & non st c 567+ MHz and 2.0 GHz memory overclocked. This means the product was tested and repaired as required to meet the standards of the refurbisher, which may or may not be the original manufacturer. Any exceptions to the condition of the item outside the manufacturer's information should be provided in the listing, up to and including warranty details. Sold and Shipped by Newegg Purchases from these Sellers are generally covered under our Newegg Marketplace Guarantee Marketplace Seller:The first major piece of legislation introduced after President Donald Trump's inauguration will target "sanctuary cities" by prohibiting jurisdictions from withholding certain federal grants or providing certain benefits to people who are in the country illegally, according to a report in The Hill. The "Kate's Law" — named after Kathryn Steinle, a 32-year-old woman who was shot in San Francisco and later died after a federal judge ordered the release of her alleged killer in December 2015 — would create penalties for cities and counties that refuse to cooperate with federal immigration authorities. The "Kate's Law" would also prohibit local governments from withholding information on immigrants who are in 2012-10-01T17:31:31.000Z", "title": "NFL Week 17: What If?", "thumbnail_url": "https://img.bleacherreport.net/cms/media/image/73/c9/47/bb/7418/46aa/99af/e6f94ed4a8cc/crop_exact_AB.jpg?h=502&q=90&w=754", "metadata": {"video_url": "https://vid.bleacherreport.com/videos/40291/akamai.json", "video_id": "40291", "title": "What If Football Results Are Last Sunday Instead of Monday? 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Initial extraction results

- Wide variety of memorized content
 - Entire text of MIT License and popular twitter handles
- Only k-eidetic memorization for large values of k
 - All memorized content is likely to have appeared many times in the training data
- Low diversity of generated outputs
 - Many duplicate samples
- Large number of false positives
 - Many samples contain "repeated" strings

How do we improve this attack?

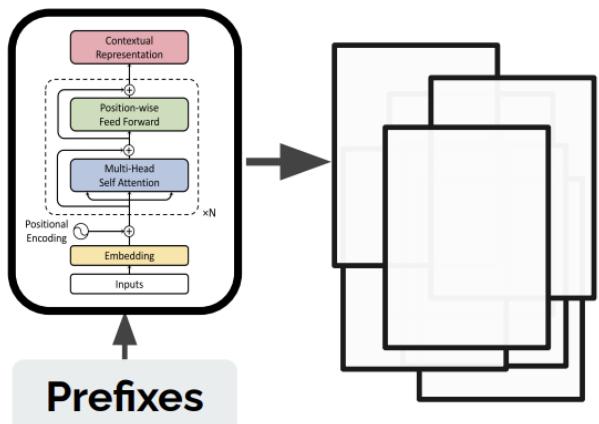
- Improve sampling
 - Top-n (sample naively)
 - Sampling with decaying temperature (control randomness)
 - Conditioning on internet text (seed model with carefully chosen prefixes)
- Improve membership inference (use a second model)
 - Comparing to Other Neural Language Models
 - Comparing to zlib Compression
 - Comparing to Lowercased Text
 - Perplexity on a Sliding Window

6 membership inference metrics

- *Perplexity*: the perplexity of the largest GPT-2 model.
- *Small*: the ratio of log-perplexities of the largest GPT-2 model and the Small GPT-2 model.
- *Medium*: the ratio as above, but for the Medium GPT-2.
- *zlib*: the ratio of the (log) of the GPT-2 perplexity and the zlib entropy (as computed by compressing the text).
- *Lowercase*: the ratio of perplexities of the GPT-2 model on the original sample and on the lowercased sample.
- *Window*: the minimum perplexity of the largest GPT-2 model across any sliding window of 50 tokens.

Training Data Extraction Attack

LM (GPT-2)
200,000 LM
Generations



Sorted
Generations
(using one of 6 metrics)

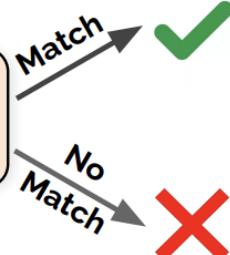
Deduplicate

Choose
Top-100

Evaluation

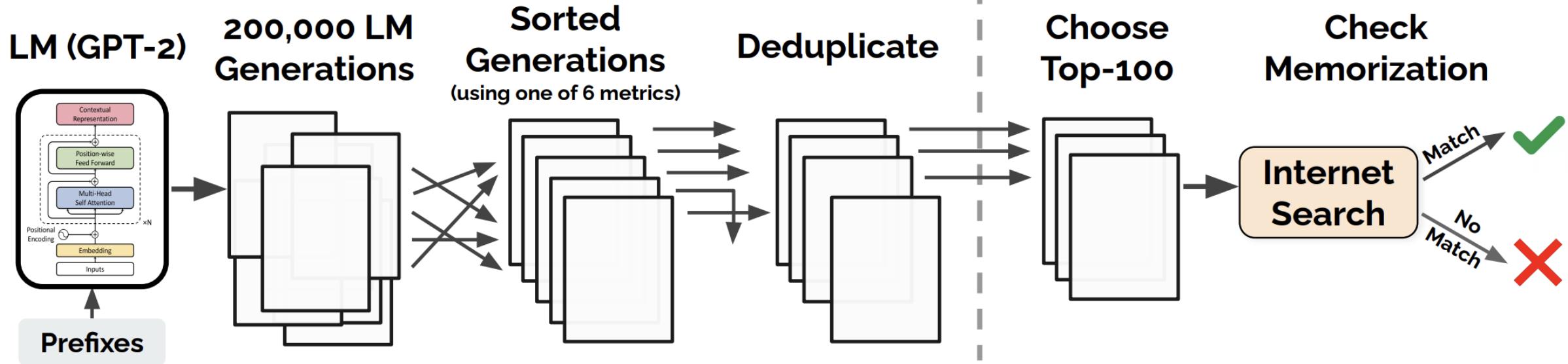
Check
Memorization

Internet
Search



Training Data Extraction Attack

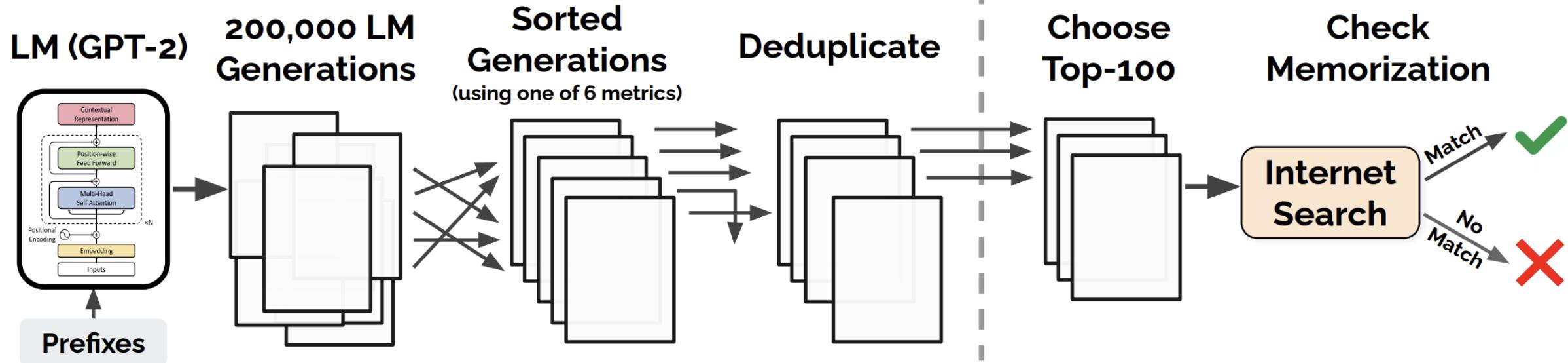
Evaluation



- Manually reviewed 1,800 samples for memorization using Internet searches
- Sample is marked as memorized if a non-trivial substring yields an exact match via Google

Training Data Extraction Attack

Evaluation



- GPT-2 authors performed fuzzy 3-gram matching on 1,800 samples to confirm memorization, minimizing false negatives
- Exact match counts were obtained via a separate grep over the training data

Results

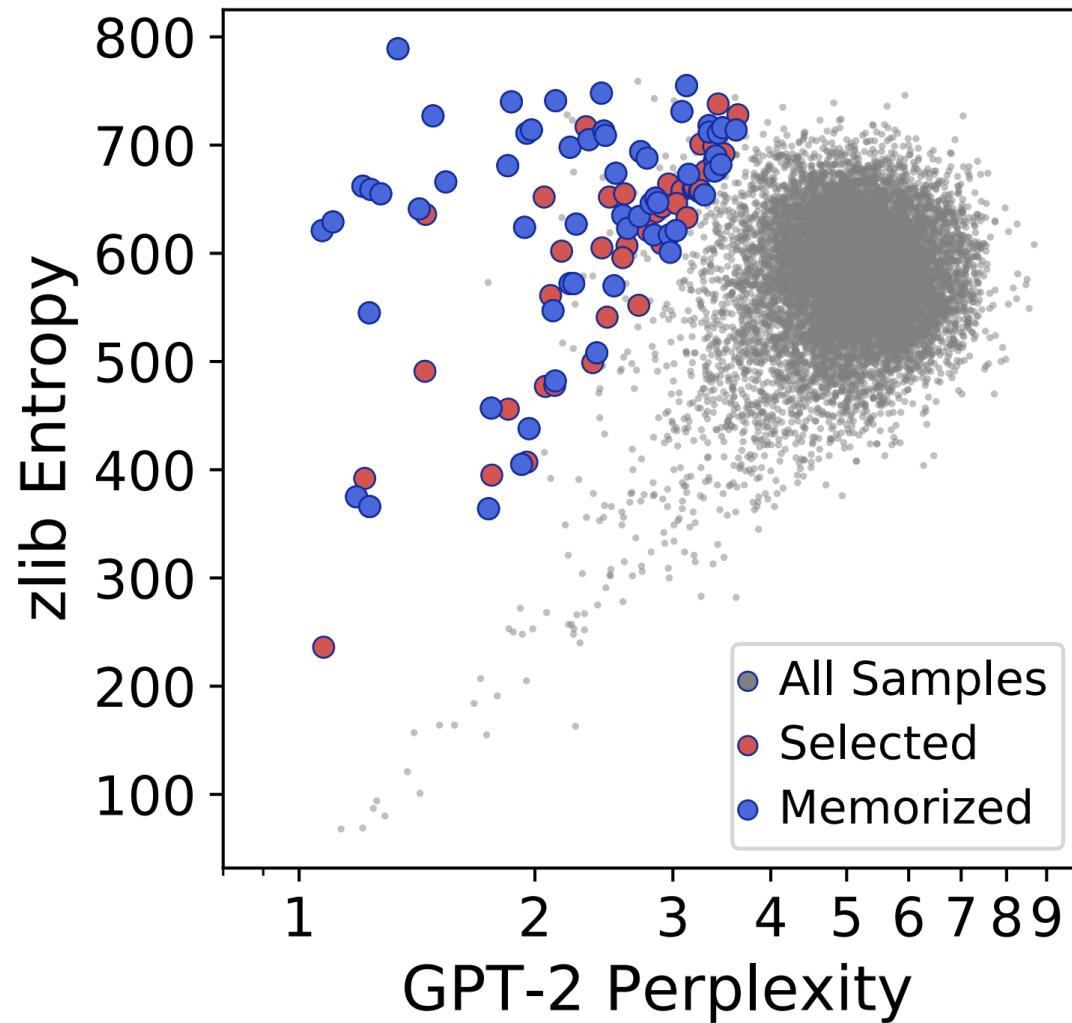
Efficacy of Different Attack Strategies

Inference Strategy	Text Generation Strategy		
	Top- <i>n</i>	Temperature	Internet
Perplexity	9	3	39
Small	41	42	58
Medium	38	33	45
zlib	59	46	67
Window	33	28	58
Lowercase	53	22	60
Total Unique	191	140	273

Categories of Memorized Content

Category	Count
US and international news	109
Log files and error reports	79
License, terms of use, copyright notices	54
Lists of named items (games, countries, etc.)	54
Forum or Wiki entry	53
Valid URLs	50
Named individuals (non-news samples only)	46
Promotional content (products, subscriptions, etc.)	45
High entropy (UUIDs, base64 data)	35
Contact info (address, email, phone, twitter, etc.)	32
Code	31
Configuration files	30
Religious texts	25
Pseudonyms	15
Donald Trump tweets and quotes	12
Web forms (menu items, instructions, etc.)	11
Tech news	11
Lists of numbers (dates, sequences, etc.)	10

zlib vs. perplexity



$k = 1$ eidetic memorization

Memorized String	Sequence Length	Occurrences in Data	
		Docs	Total
Y2...█████...y5	87	1	10
7C...█████...18	40	1	22
XM...█████...WA	54	1	36
ab...█████...2c	64	1	49
ff...█████...af	32	1	64
C7...█████...ow	43	1	83
0x...█████...C0	10	1	96
76...█████...84	17	1	122
a7...█████...4b	40	1	311

What is the effect of model size?

URL (trimmed)	Occurrences		Memorized?		
	Docs	Total	XL	M	S
/r/[REDACTED]51y/milo_evacua...	1	359	✓	✓	1/2
/r/[REDACTED]zin/hi_my_name...	1	113	✓	✓	
/r/[REDACTED]7ne/for_all_yo...	1	76	✓	1/2	
/r/[REDACTED]5mj/fake_news_...	1	72	✓		
/r/[REDACTED]5wn/reddit_admi...	1	64	✓	✓	
/r/[REDACTED]lp8/26_evening...	1	56	✓	✓	
/r/[REDACTED]jla/so_pizzagat...	1	51	✓	1/2	
/r/[REDACTED]ubf/late_night...	1	51	✓	1/2	
/r/[REDACTED]eta/make_christ...	1	35	✓	1/2	
/r/[REDACTED]6ev/its_officia...	1	33	✓		
/r/[REDACTED]3c7/scott_adams...	1	17			
/r/[REDACTED]k2o/because_his...	1	17			
/r/[REDACTED]tu3/armynavy_ga...	1	8			

Larger models
memorize more

Lessons

- Data extraction is very practical
- Memorization does not require overfitting
 - This work greatly underestimates the amount of memorization
- Larger models memorize more
- Discovering memorization is hard
 - Often requires specific prefixes

Mitigation strategies

- Training with differential privacy
- Curating training data
- Limiting Impact of Memorization on Downstream Applications
- Auditing ML Models for Memorization



LARGE LANGUAGE MODELS CAN BE STRONG DIFFERENTIALLY PRIVATE LEARNERS

Xuechen Li¹, Florian Tramèr², Percy Liang¹, Tatsunori Hashimoto¹

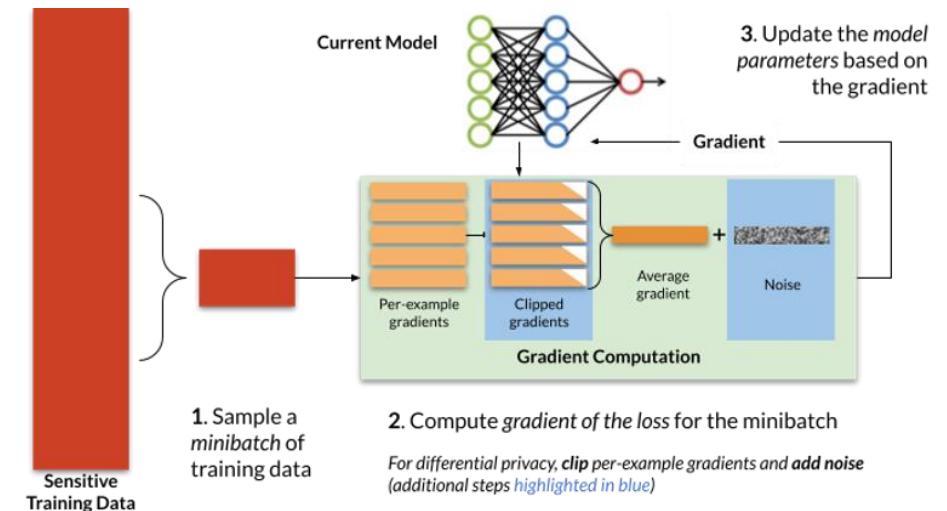
¹Stanford University ²Google Research

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>>> Background

Differential Privacy (DP)

- Gold standard for privacy: Limits info leakage about any individual record.
- Definition:
 - Algorithm \mathcal{M} is (ϵ, δ) – DP if outputs on adjacent datasets X & X' (differ by one record) are similar:
$$P(\mathcal{M}(X) \in Y) \leq \exp(\epsilon) P(\mathcal{M}(X') \in Y) + \delta$$
 - Smaller $\epsilon, \delta \rightarrow$ Stronger privacy
- DP in Deeplearning: DP-SGD(Stochastic Gradient Descent):
 - Core method:
 1. Clips per-example gradients (norm $\leq C$)
 2. adds Gaussian noise $z \sim \mathcal{N}(0, C^2 \sigma^2 I_p)$
 - Problem: The noise must scale with the number of parameters (resulting in large noise levels for large language models)



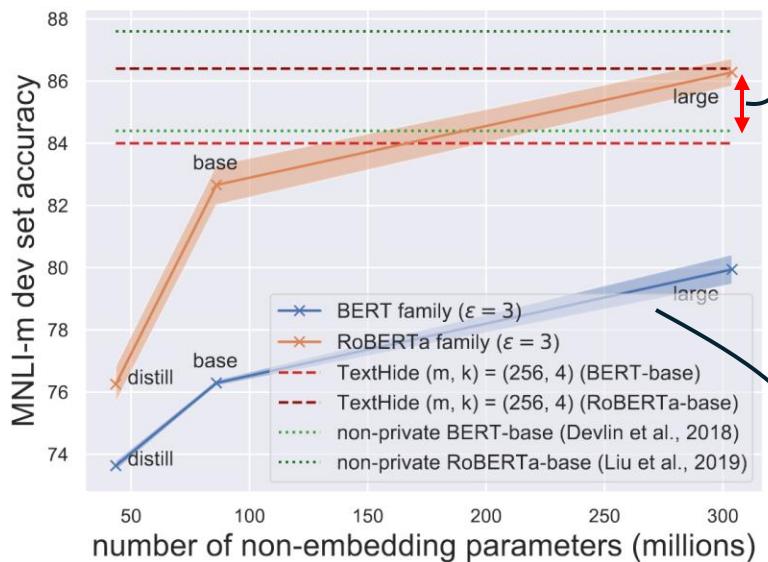


>>> Introduction and Motivation

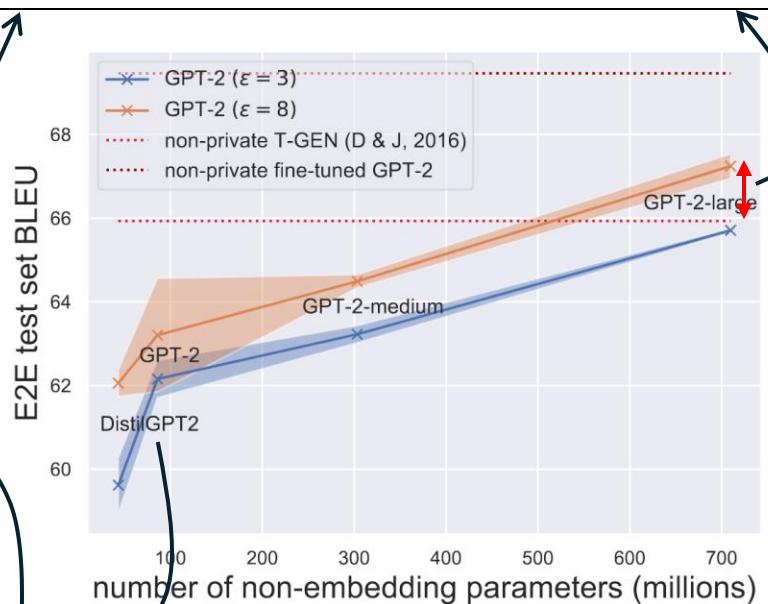
- **Context:** Large language models (LLMs) risk memorizing sensitive training data
- **Problem:** Differential Privacy (DP) ensures privacy but often degrades performance in high-dimensional models due to noise scaling with parameters.
- **Question:** Can we fine-tune large LLMs with DP to achieve high performance under modest privacy budgets ($\varepsilon = \{3, 8\}$, $\delta = \frac{1}{2|\mathcal{D}_{train}|}$, $|\mathcal{D}_{train}|$ is training set size)?
 - Mainstream: **No!**
 - The proposed work: **Yes!**

>>> Main Results

1. Pretrained Models fine-tuned with DP-Adam have strong performance, some of them outperform the non-private baseline



(a) Sentence classification
MNLI-matched (Williams et al., 2018)



(b) Natural language generation
E2E (Novikova et al., 2017)

2. Fine-tuning larger models produces better results.

>>> Method: Research Framework

Start Point:
Pretrained LLMs have rich knowledge, simplifying private fine-tuning

Proposed Method:

1. Effective differentially private fine-tuning
2. Ghost Clipping



Focus on:

1. Sentence Classification
2. Language Generation

Target:
fine-tune large LLMs with DP to achieve high performance

>>> Method 1. Effective DP fine-tuning

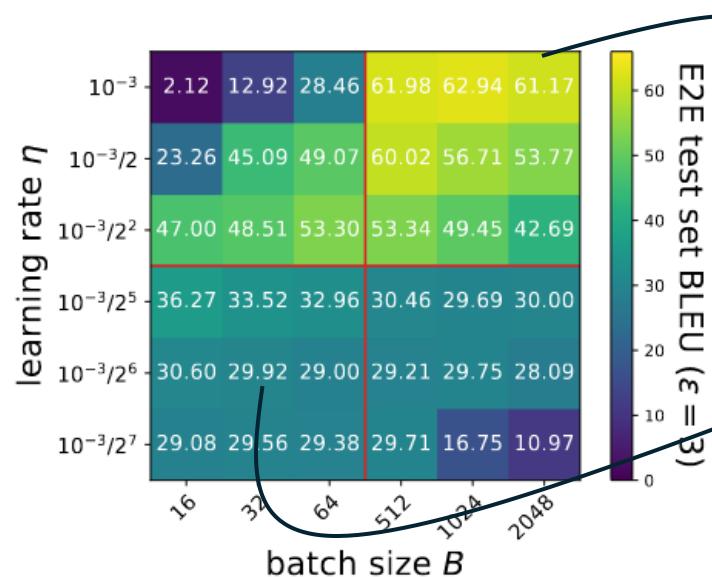
a) Hyperparameter tuning

• Why is it important? Hyperparameter Sensitivity

The experiments suggest that its performance can vary from being close to that of random initialization with ill-chosen hyperparameters to near state-of-the-art with appropriately chosen ones.

• Batch size, learning rate & training epochs

- Fixed Training Epochs E (compute budget constraint): larger batches \rightarrow fewer gradient updates



- The best performing models (BLEU score ~ 62) are obtained with both a large batch size and large learning rate.
- In the non-private setting, pretrained language models are typically fine-tuned using small batch sizes and small learning rates with Adam. Naively applying these hyperparameters to private fine-tuning with DP can lead to unnecessarily poor performance.

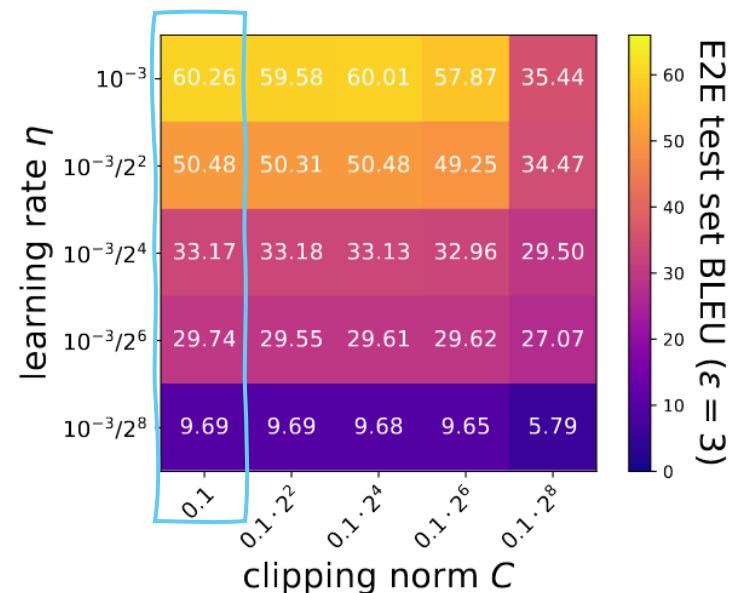
>>> Method 1. Effective differentially private fine-tuning

a) Hyperparameter tuning

- **Batch size**, learning rate & training epochs
 - **Fixed Training Epochs E** (compute budget constraint): larger batches → fewer gradient updates
 - **Fixed Update Steps**: larger batches → more epochs

Using larger batch sizes almost always results in better performance at a given privacy budget at the cost of processing more examples with more compute, once the other hyperparameters $S, \eta, C, \epsilon, \delta$ are fixed.

- Clipping Norm
 - DP optimization is sensitive to the choice of clipping norm
 - The scale of noise depends on this clipping norm (recall its standard deviation is $C\sigma$)
 - Setting the clipping threshold C too high leads to unnecessary noise.
 - In this paper
 - A small clipping norm that clips most gradients yields the best performance.



>>> Method 1. Effective differentially private fine-tuning

b) Improving the task alignment helps private learning

- Motivation
 - Pretraining and finetuning tasks are aligned for language generation (sequence prediction), but **misaligned for classification.**
 - Standard classification finetuning predicts labels from [CLS], unlike pretraining which predicts masked words.
- The approach
 - Reframe classification as a masked token prediction task
 - Example:

Instead of predicting a label for <INPUT>, use template:

“<INPUT>. It is [MASK].”

and compare token probabilities (e.g., "awesome" vs. "terrible").

Table 1: Full fine-tuning larger pretrained models with text infilling has best performance. Results are dev set accuracies. Best numbers based on two-sample test for each privacy level are in bold.

Method	$\epsilon = 3$				$\epsilon = 8$			
	MNLI-(m/mm)	QQP	QNLI	SST-2	MNLI-(m/mm)	QQP	QNLI	SST-2
RGP (RoBERTa-base)	-	-	-	-	80.5/79.6	85.5	87.2	91.6
RGP (RoBERTa-large)	-	-	-	-	86.1/86.0	86.7	90.0	93.0
full (RoBERTa-base)	82.47/82.10	85.41	84.62	86.12	83.30/83.13	86.15	84.81	85.89
full (RoBERTa-large)	85.53/85.81	86.65	88.94	90.71	86.28/86.54	87.49	89.42	90.94
full + infilling (RoBERTa-base)	82.45/82.99	85.56	87.42	91.86	83.20/83.46	86.08	87.94	92.09
full + infilling (RoBERTa-large)	86.43/86.46	86.43	90.76	93.04	87.02/87.26	87.47	91.10	93.81
$\epsilon \approx$ (Gaussian DP + CLT)	2.52	2.52	2.00	1.73	5.83	5.85	4.75	4.33
$\epsilon \approx$ (Compose tradeoff func.)	2.75	2.75	2.57	2.41	7.15	7.16	6.87	6.69

- Benefits:
Improves private fine-tuning accuracy by 3–5% in SST-2.

>>> Method 2. Ghost Clipping

- **Motivation**

- Differentially Private (DP) training requires **per-example gradient clipping**, which is memory-intensive.
- Naïve implementation: compute & store gradients for **every example** → **high GPU memory usage**, especially in large models (e.g., GPT-2).
- Prior work (Lee & Kifer, 2020): only instantiates **one layer at a time**, but still memory-heavy for Transformers.

- **Solution: Ghost Clipping**

- **No per-example gradients are ever instantiated** ("ghost" = they never appear).
- Efficiently computes gradient **norms only**, using layer-wise tricks.
- Computes per-example gradient norm via:

$$\|\nabla_W \mathcal{L}_i\|_F^2 = \text{vec}(a_i a_i^T)^T \text{vec}(g_i g_i^T)$$

- Memory cost
 - B = Batch Size, T = context window, p = hidden dim, d = vocab size

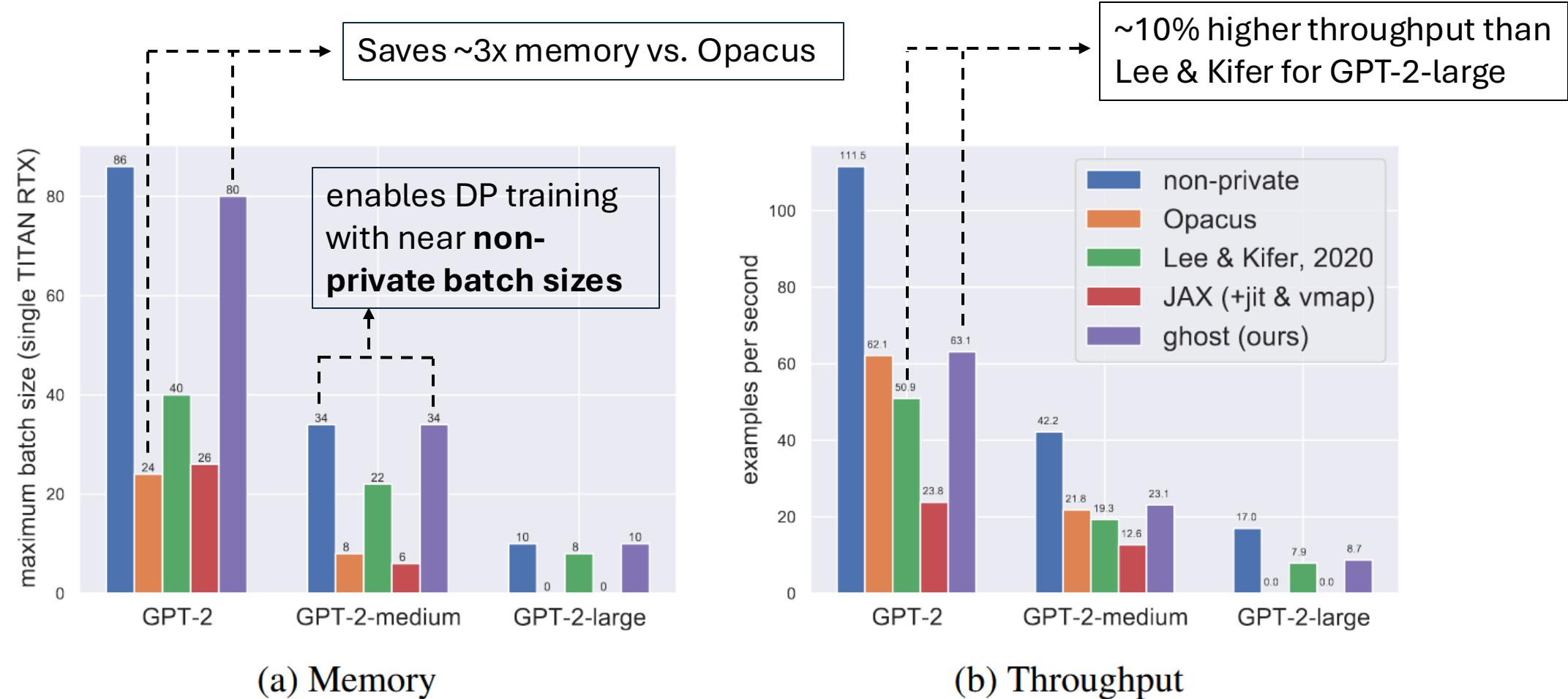
Per-example gradient norms are the end goal, gradients themselves need not be instantiated explicitly

	Naïve Approach	Ghost Clipping
memory complexity	$O(B * p * d)$	$O(B * T^2)$
Example: GPT-2 Embedding Layer	B*38e6	B*1e6

Much Lower!

>>> Method 2. Ghost Clipping

• Benefits



>>> Findings: Low-Dimensional Updates ≠ Better DP Fine-Tuning

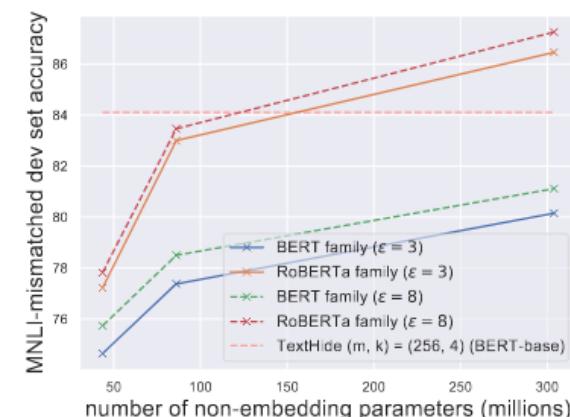
- Motivation
 - DP noise **scales with update dimensionality** → Natural to ask:
“Should we fine-tune fewer parameters to reduce noise?”
- Two Hypotheses Tested
 - Smaller models → better DP performance?
 - Parameter-efficient tuning (e.g., LoRA, RGP) → outperform full tuning?
- Not Necessarily True!
- Key Findings
 - **Larger pretrained models** consistently outperform smaller ones under the same privacy budget (ϵ).
 - **Full fine-tuning** outperforms state-of-the-art low-dim DP methods (e.g., RGP).

Method	RoBERTa-base	RoBERTa-large
RGP	91.6	93.0
Full + Infilling	92.09	93.81

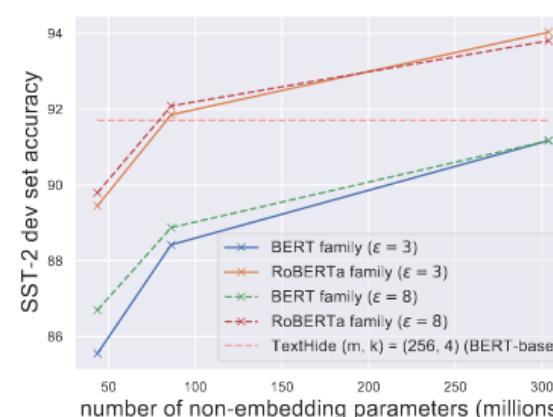
>>> Findings: Low-Dimensional Updates \neq Better DP Fine-Tuning

- Key Findings

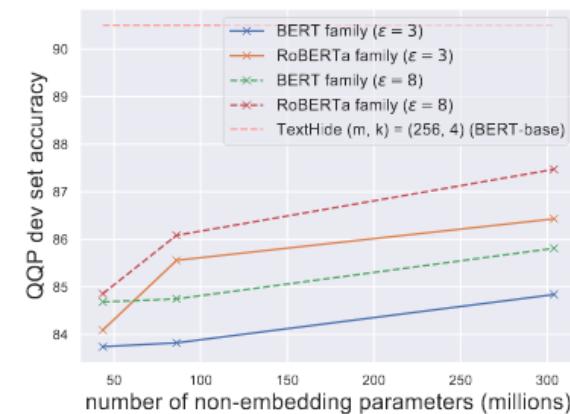
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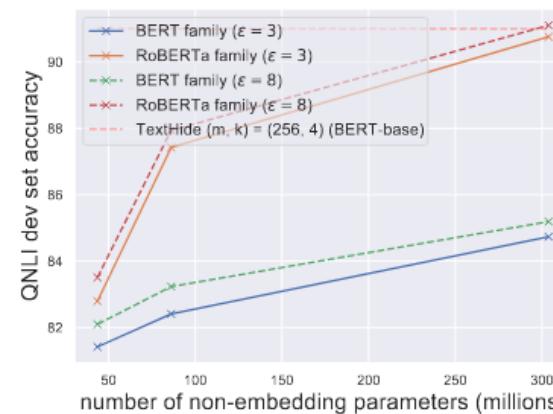
(a) MNLI-mismatched



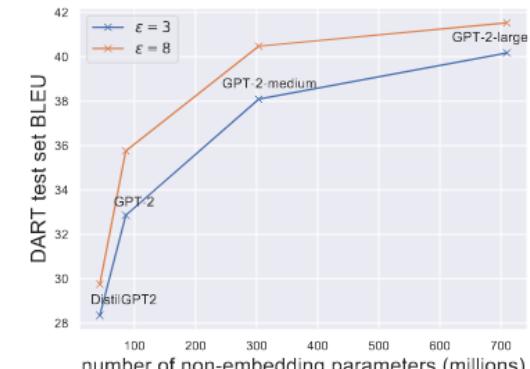
(b) SST-2



(c) QQP



(d) QNLI



(e) DART

Figure 5: Larger and better pretrained models consistently lead to better private fine-tuned performance on sentence classification and language generation tasks.

>>> Findings: Low-Dimensional Updates ≠ Better DP Fine-Tuning

- Key Findings

- Larger pretrained models consistently outperform smaller ones under the same privacy budget (ϵ).
- Full fine-tuning outperforms state-of-the-art low-dim DP methods (e.g., RGP).

Table 2: Full fine-tuning performs on par with or outperforms others methods that execute gradient update in low dimensional spaces. Results are on E2E from fine-tuning GPT-2.

Metric	DP Guarantee	Gaussian DP + CLT	Compose tradeoff func.	full	Method				
					LoRA	prefix	RGP	top2	retrain
BLEU	$\epsilon = 3$	$\epsilon \approx 2.68$	$\epsilon \approx 2.75$	61.519	58.153	47.772	58.482	25.920	15.457
	$\epsilon = 8$	$\epsilon \approx 6.77$	$\epsilon \approx 7.27$	63.189	63.389	49.263	58.455	26.885	24.247
	non-private	-	-	69.463	69.682	68.845	68.328	65.752	65.731
ROUGE-L	$\epsilon = 3$	$\epsilon \approx 2.68$	$\epsilon \approx 2.75$	65.670	65.773	58.964	65.560	44.536	35.240
	$\epsilon = 8$	$\epsilon \approx 6.77$	$\epsilon \approx 7.27$	66.429	67.525	60.730	65.030	46.421	39.951
	non-private	-	-	71.359	71.709	70.805	68.844	68.704	68.751



>>> Takeaway: What This Paper Shows

- **Strong performance under DP**

With proper tuning, large pretrained language models (e.g., BERT, GPT-2) can be **effectively fine-tuned under (ϵ, δ) -DP**, outperforming prior DP-NLP methods and even some non-private baselines.

- **Ghost Clipping: Memory-Efficient DP Training**

Introduced **Ghost Clipping**, a technique that removes the need to instantiate per-example gradients, making DP fine-tuning **as memory-efficient as non-private training** — enabling training of large models (e.g., GPT-2-large) under DP.

- **Rethinking Dimensionality in DP**

Contrary to conventional belief, **larger models** and **full fine-tuning** can perform better than low-dimensional adaptations (e.g., LoRA, RGP) — dimensionality does not necessarily hurt DP learning.

- **Alignment Matters**

Using objectives **aligned with pretraining** (e.g., text infilling for classification) significantly improves DP learning outcomes.

This work challenges the belief that DP is too expensive for NLP. It **paves the way for practical, privacy-preserving deployment** of LLM — especially in settings with limited private data.

>>> Limitations & Future Directions

Public Pretraining

- *Limitation:* Off-the-shelf models may contain sensitive data from the web
- *Future:* Develop curated, privacy-safe corpora for pretraining

Hyperparameter Tuning

- *Limitation:* Key factors like weight decay and scheduling remain underexplored
- *Future:* Build transparent tuning pipelines with privacy-aware accounting

Pretraining & DP Learning

- *Limitation:* Unclear why larger models help under DP
- *Future:* Study how pretraining objectives influence DP fine-tuning effectiveness

Scaling Laws

- *Limitation:* No established scaling laws in private learning
- *Future:* Develop principles to guide compute–privacy–performance tradeoffs



QUANTIFYING MEMORIZATION ACROSS NEURAL LANGUAGE MODELS

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Prior work

Is there a lower bound for memorization?

- Carlini et al. (2020)
 - 0.00000015% of the dataset is memorized
- Gao et al. (2020)
 - memorizes at least 1% of its training dataset

How does memorization vary across LMs, datasets, and scales?

- Models/datasets of fixed size
- Narrow memorization vs. scale relationship
- No focus on identifying the maximal amount of data memorization

Contribution

Quantify the degree to which LMs emit memorized training data

Main properties

1. Model scale: Within a model family, larger models memorize 2-5× more than smaller models
2. Data duplication: Examples repeated more often are more likely to be extractable
3. Context: It is orders of magnitude easier to extract sequences when given a longer context

Defining memorization

Definition 3.1. A string s is *extractable with k tokens of context* from a model f if there exists a (length- k) string p , such that the concatenation $[p \parallel s]$ is contained in the training data for f , and f produces s when prompted with p using greedy decoding.

For example, if a model's training dataset contains the sequence:

“My phone number is 555-6789”

and, given a prefix of length $k = 4$:

“My phone number is”

the most likely output is:

“555-6789”

then this sequence is considered **extractable** (with 4 words of context)

Selection of evaluation data

1. Uniform random samples of 50,000 sequences
 - poorly suited for studying how memorization scales with data properties that are not uniformly represented in the training set
2. Random sample normalized by both sequence lengths and duplication counts
 - more accurate measure of memorization as a function of a sample's duplication factor and prompt length

Method 2: normalized random sample

For each sequence length

$\ell \in \{50, 100, 150, \dots, 500\}$, and for each integer n , we select 1,000 sequences of length ℓ that appear in the training dataset between $2^{n/4}$ and $2^{(n+1)/4}$ times.

We continue this process until we reach a value of n for which 1,000 such sequences are no longer available.

This procedure results in:

- 1,000 sequences that repeat between 6 and 8 times (approximately $2^{11/4}$ to $2^{12/4}$), and
- 1,000 sequences that repeat between 724 and 861 times (approximately $2^{38/4}$ to $2^{39/4}$).

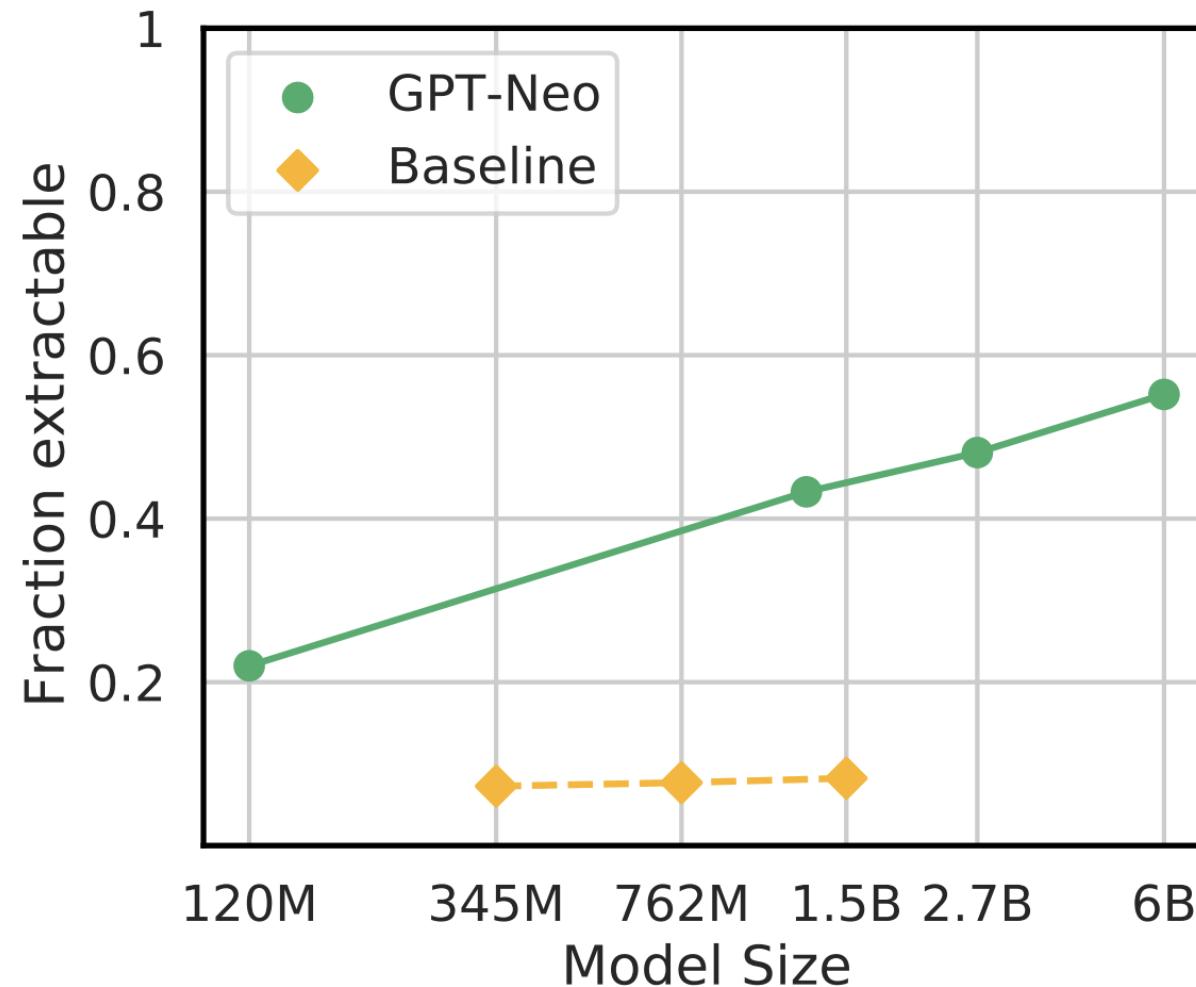
Selection of evaluation data

- Collected **50,000 examples** per length from **50 to 500 tokens**, totaling **~500,000 sequences**
- For each sequence of length ℓ , the model is prompted with the first $\ell - 50$ tokens
- A sequence is “**extractable**” if the model **exactly predicts the final 50 tokens**
- **Fifty tokens ≈ 127 characters or 25 words**—longer than a typical sentence
- **Average extractability** is computed across all lengths

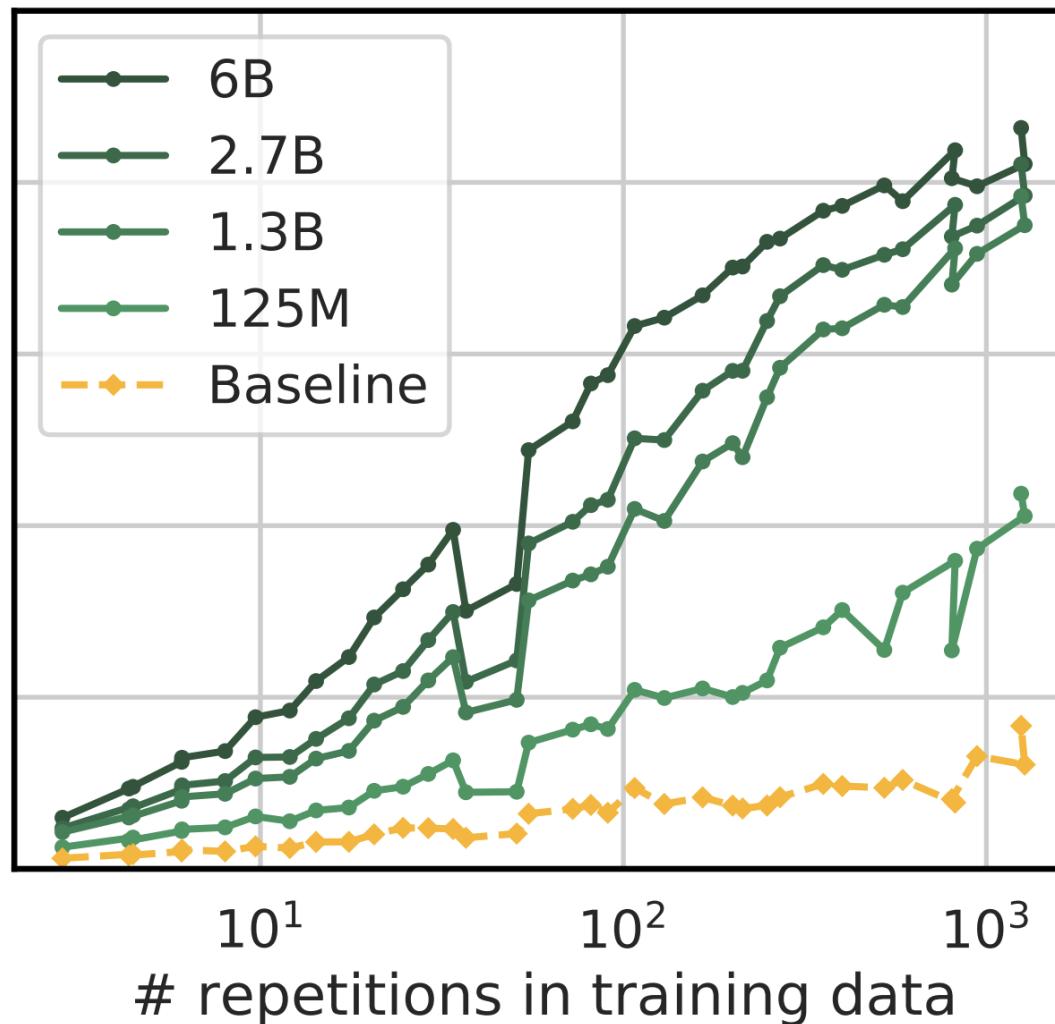
Model

- **GPT-Neo**
 - **causal language models** trained to predict the next token in a sequence
- Trained on **The Pile**
 - **825GB public text dataset** from books, web scrapes, and open-source code
- **Sizes:** 125M, 1.3B, 2.7B, and 6B parameters
- GPT-Neo was the **largest publicly available** language model family

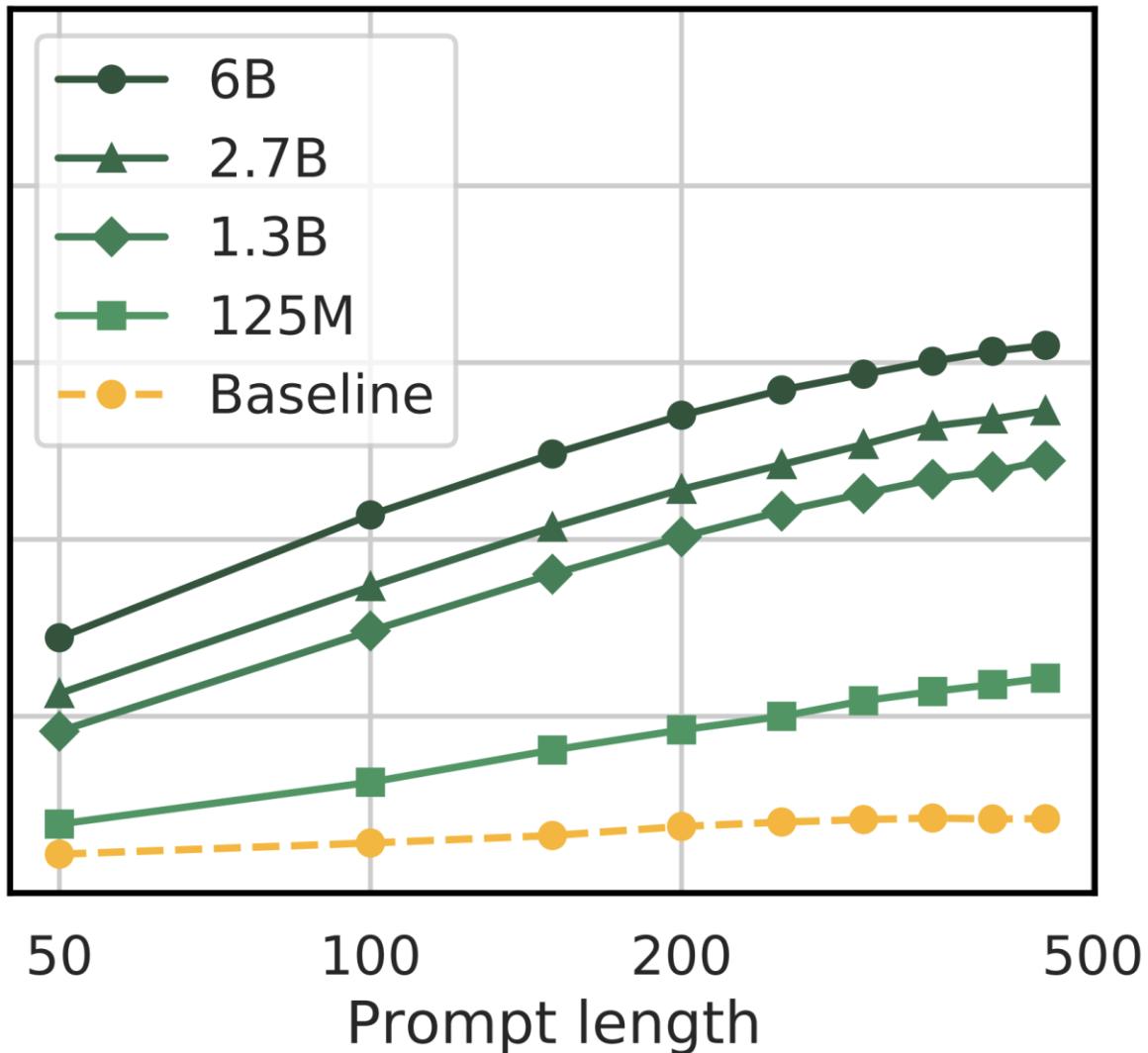
Bigger models memorize more



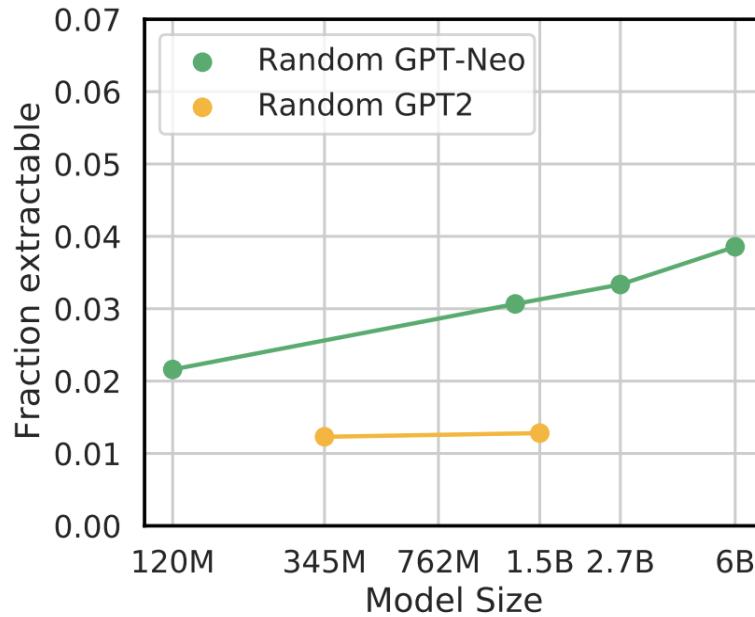
Repeated strings are memorized more



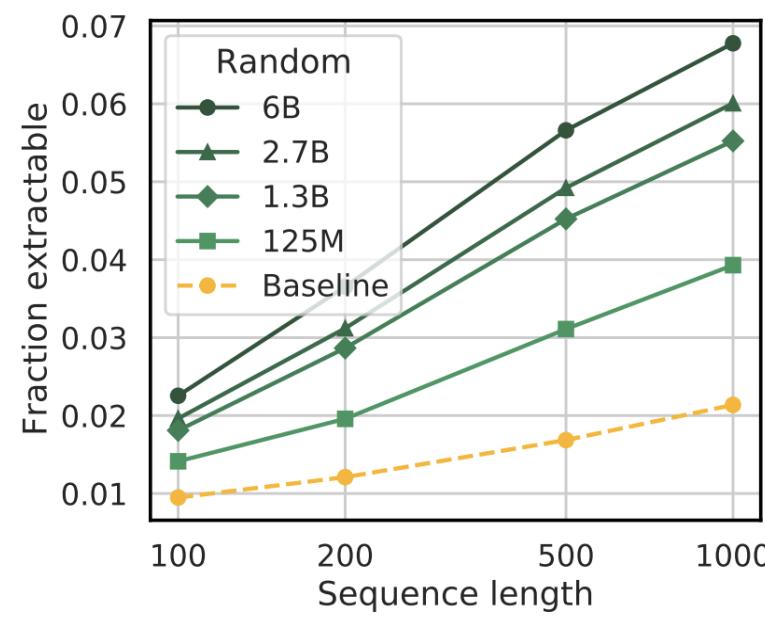
Longer context discovers more memorization



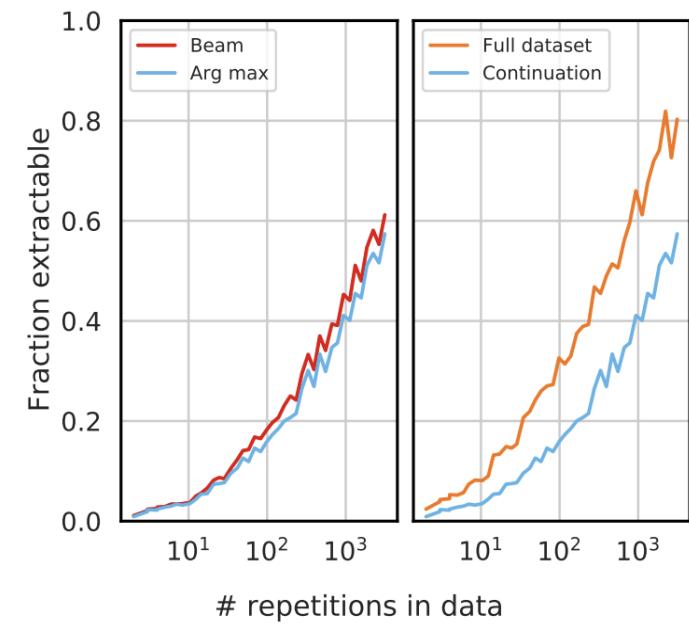
Alternate experimental settings



(a)



(b)



(c)

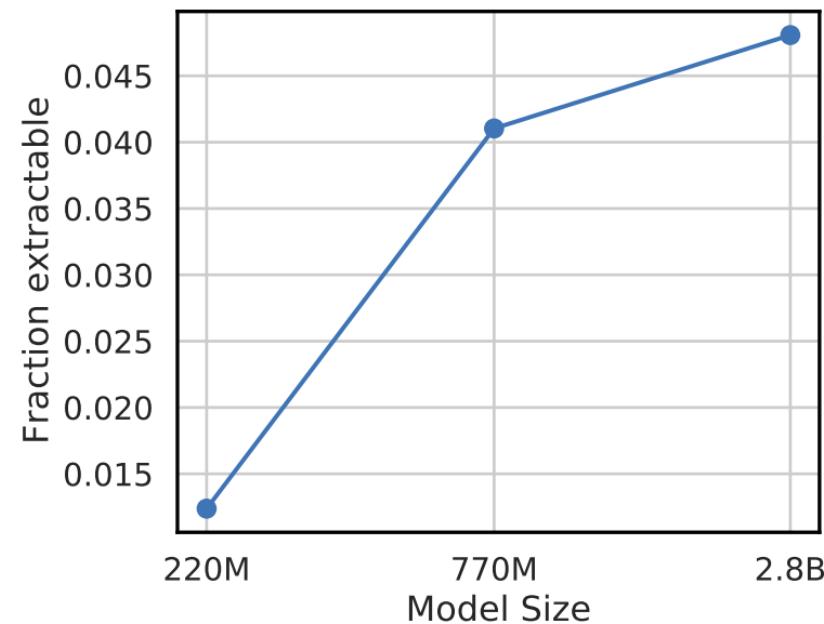
Qualitative examples

Prompt	Continuation (== 6B)	2.7B	1.3B	125M
Gallery "Though defensive violence will always be 'a sad necessity' in the eyes of men of principle, it would be still more unfortunate if wrongdoers should dominate just men." - St. Augustine "A new idea is first	condemned as ridiculous, and then dismissed as trivial, until finally it becomes what everybody knows." - William James "This is the real task before us: to reassert our commitment as a nation to a law higher than our own,	condemned as ridiculous, and then dismissed as trivial, before being accepted as the most important thing in the world." - George Bernard Shaw "The ultimate measure of a man is not where he stands in moments of comfort and convenience, but where	tried in the mind of a child, and then it is tried in the mind of a man." - Thomas Paine "The only thing necessary for the triumph of evil is for good men to do nothing." - Edmund Burke "	and foremost a man's duty to his fellow man. It is a duty to be a man of principle, and to be a
_GPL(crypto_unregister_alg); int crypto_register_template(struct crypto_template *tmpl) { struct crypto_template *q; int err = -EEXIST;	down_write(&crypto_alg_sem); list_for_each_entry(q, &crypto_template_list, list) { if (tmpl->name && tmpl->name!= q->alg.cra_name)	list_for_each_entry(q, &crypto_alg_list, list) { if (tmpl->name && tmpl->name!= q->alg.cra_name)	q = kzalloc(sizeof(*q), GFP_KERNEL); if (!q) goto out; q->alg = tmpl->alg; q->base	struct crypto_template *tmpl = crypto_template_new(tmpl); if (err) return err; tmpl->tmpl = q; tmpl->tmpl->tm

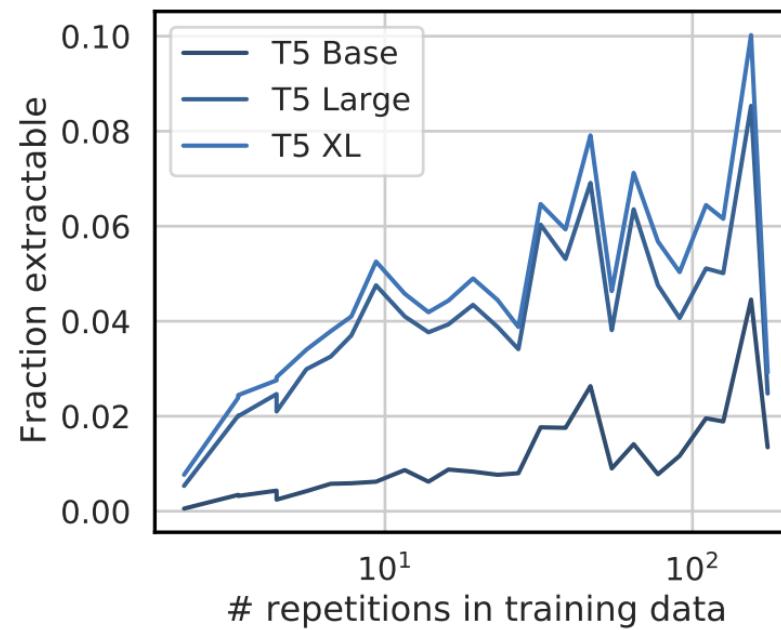
Figure 3: Text examples that are memorized by the 6B model, but not by smaller models. Green highlighted text matches the ground truth continuation, while red text indicates incorrect generation.

syntactically sound, but semantically incorrect

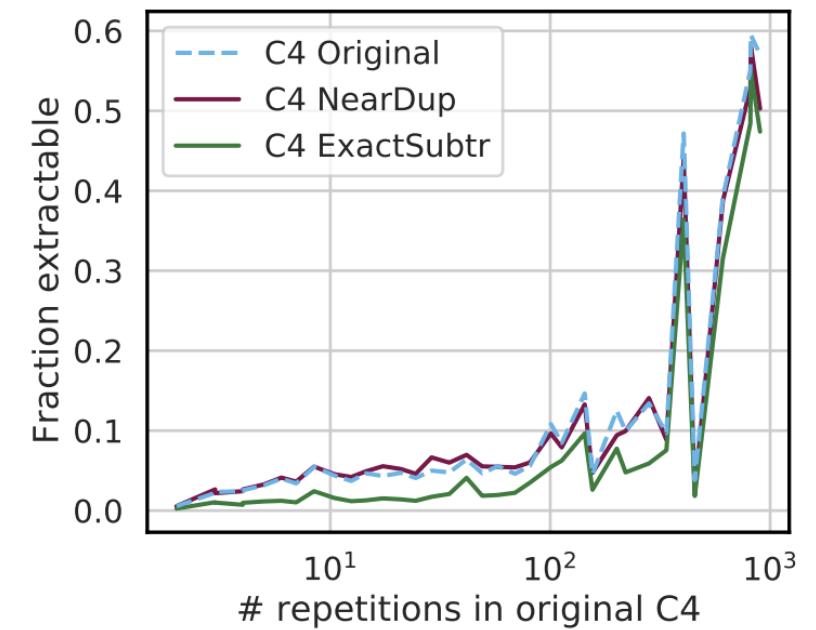
Replication on other models/datasets/objectives



(a)



(b)



(c)

Lessons: generalization

- LLMs **accurately model training data statistics**, but this doesn't ensure they reflect the true underlying data distribution
- When training data is **skewed** (e.g., many duplicates), larger models tend to learn and retain these **dataset artifacts**
- This highlights the need for **careful dataset curation**, especially as models continue to grow in size

Lessons: privacy

- **Memorization scales log-linearly** with model size
- Larger models (e.g., $200\times$ the size of the 6B model studied) likely **memorize sequences seen only a few times**
- **Extracting memorized data is difficult**, requiring **new qualitative attack strategies**
- Data seen **only once** during training is **rarely memorized**
- **Deduplication of training datasets** is an effective method to **reduce memorization risks**

Presentation summary

- 1st paper: LMs can memorize training data verbatim and we can extract these effectively
- 2nd paper: Training with differential privacy is a potential mitigation strategy and may not be too "expensive"
- 3rd paper: The degree of LM memorization can be quantified and varies with model size, data duplication, and context

Questions?