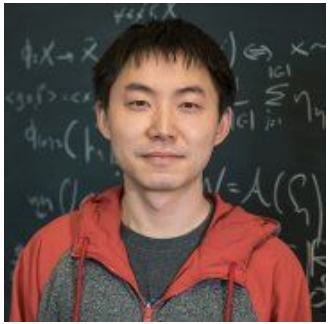
Memorization in Language Models

Katherine Lee
Cornell, Google Brain, Jul 19, 2022

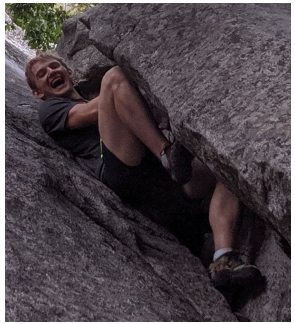
Katherine Lee

Daphne Ippolito

Nicholas Carlini



Chiyuan Zhang



Matthew Jagielski

Florian Tramèr

Andrew Nystrom

David Mimno

Hannah Brown

Fatemehsadat Mireshghallah

Reza Shokri

Language Models

model language

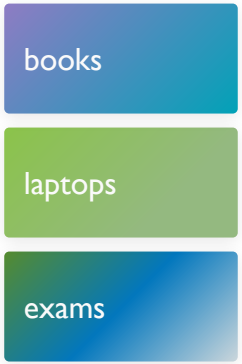
Language Models

learn a probability distribution of a sequence given the previous tokens

P(word | all previous words)

Language Models

The students opened their _____.

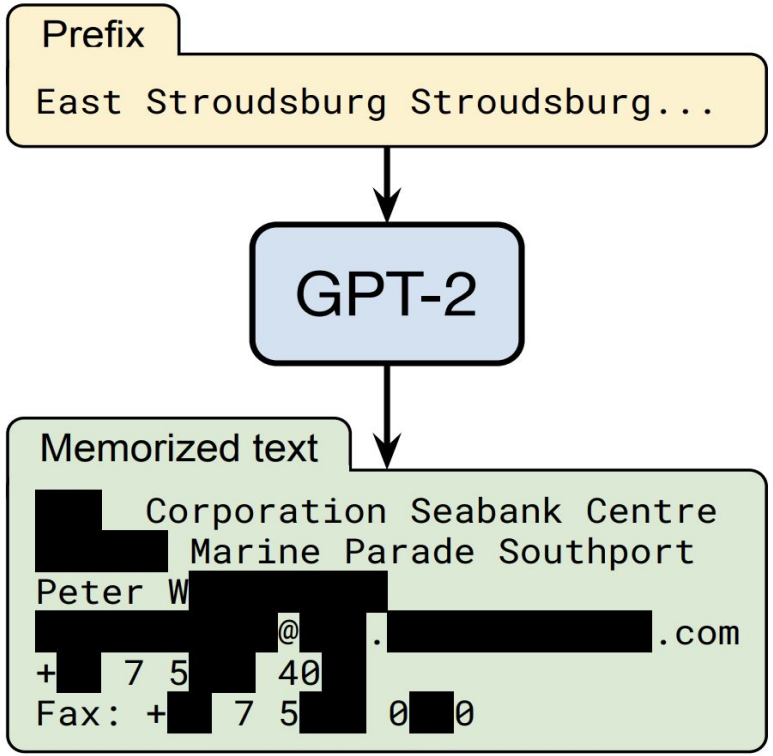


Large Models are Leaky

WHEN YOU TRAIN PREDICTIVE MODELS ON INPUT FROM YOUR USERS, IT CAN LEAK INFORMATION IN UNEXPECTED WAYS.

xkcd.com/2169/

Large Models are Leaky



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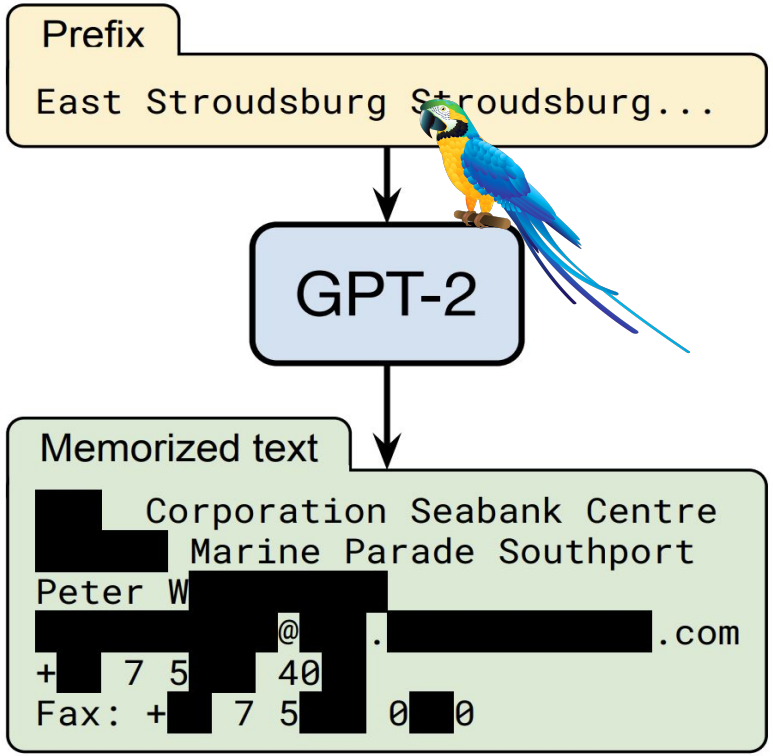

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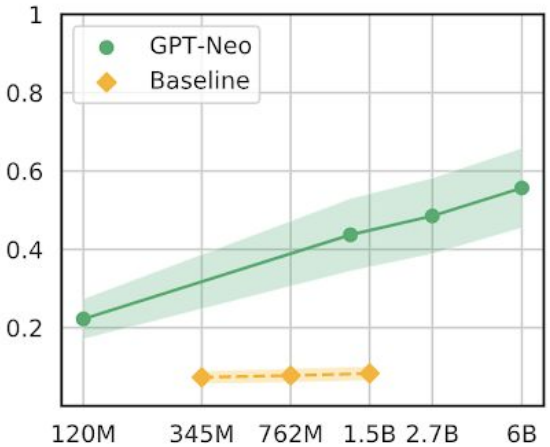
Discoverable memorization **scales**…

…with model scale



(a) Model scale

Carlini, et al., Quantifying Memorization Across Neural Language Models, arxiv, 2022

Neural language models memorize training data.

Our fully equipped family sized lodges offer a comfortable luxurious stay for a fantastic price, giving you beautiful views of the lakes and the surrounding countryside. Offering luxurious self-catering holidays in our fully featured Scandinavian holiday lodges. Perfectly located to explore the beaches, coastline.

you are only looking to find rent to own homes in your city or are open to exploring all kinds of rent to own home listings, our database does it all. One of the best aspects of iRentToOwn.com is that, besides options to rent to buy a house, it has numerous other categories of home sale options. These include bank foreclosure homes, pre-foreclosure homes, short sales, HUD/government foreclosures, auction homes and owner-financing/FSBO (For Sale By Owner) homes. With help from the convenient search features offered by our site, shoppers are able to find their ideal lease to own home, real estate company, and more

you'll need to be knowledgeable to make the very best decisions. We will make sure you know what can be expected. We take the surprises from the picture by giving accurate and thorough information. You can start by talking about your task with our client service staff when you dial 888-353-1299. We'll address all of your questions and arrange the initial meeting. We work closely with you through the whole project, and our team can show up promptly and prepared

Our journeyman also does service work, troubleshooting when a breaker fails or a light stops working. Our journeyman does not offer permits that must be issued by our master. Our journeyman follows our master's plans and directions. Our journeyman's responsibilities will vary based on the work that needs to be done. Our journeymen are skilled with residential, commercial and industrial installations and repairs.ust work from six years as an apprentice, under direct supervision of our master, and pass a journeyman test.

Lee, et al. Deduplicating Training Data Makes Language Models Better. ACL 2022.

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571x

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51x

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5,497x

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6x

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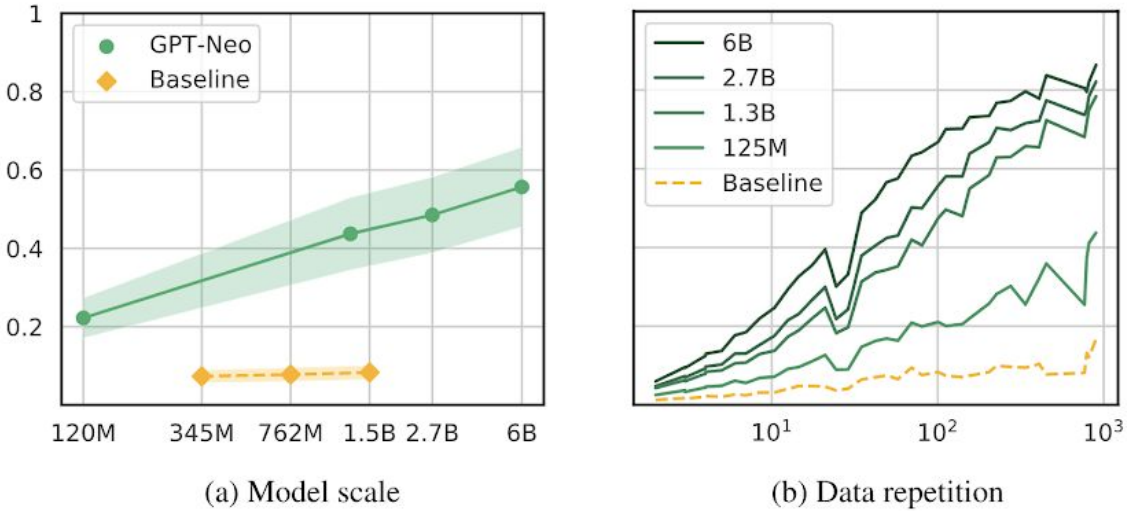
Discoverable memorization **scales**…

…with data repetition



(a) Model scale

(b) Data repetition

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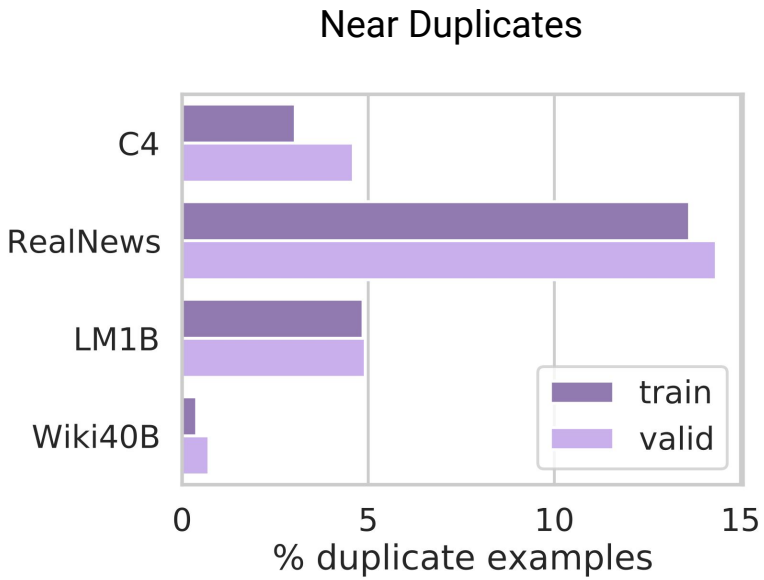
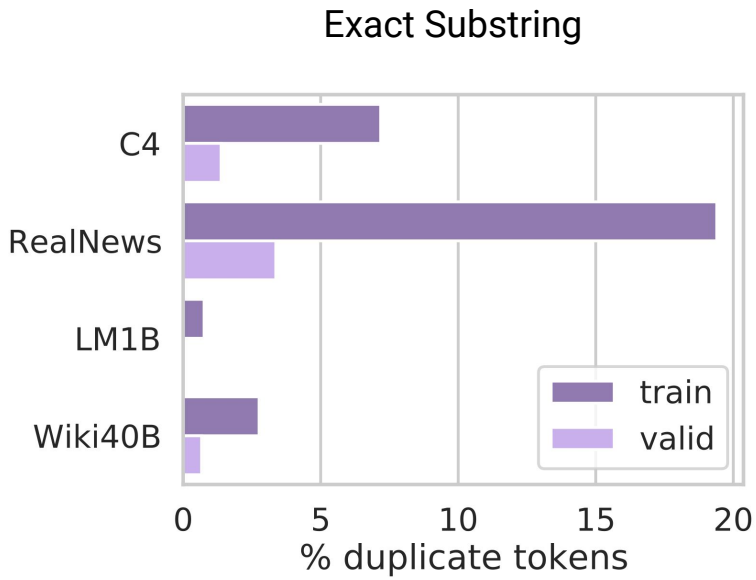
Deduplicating Text Data





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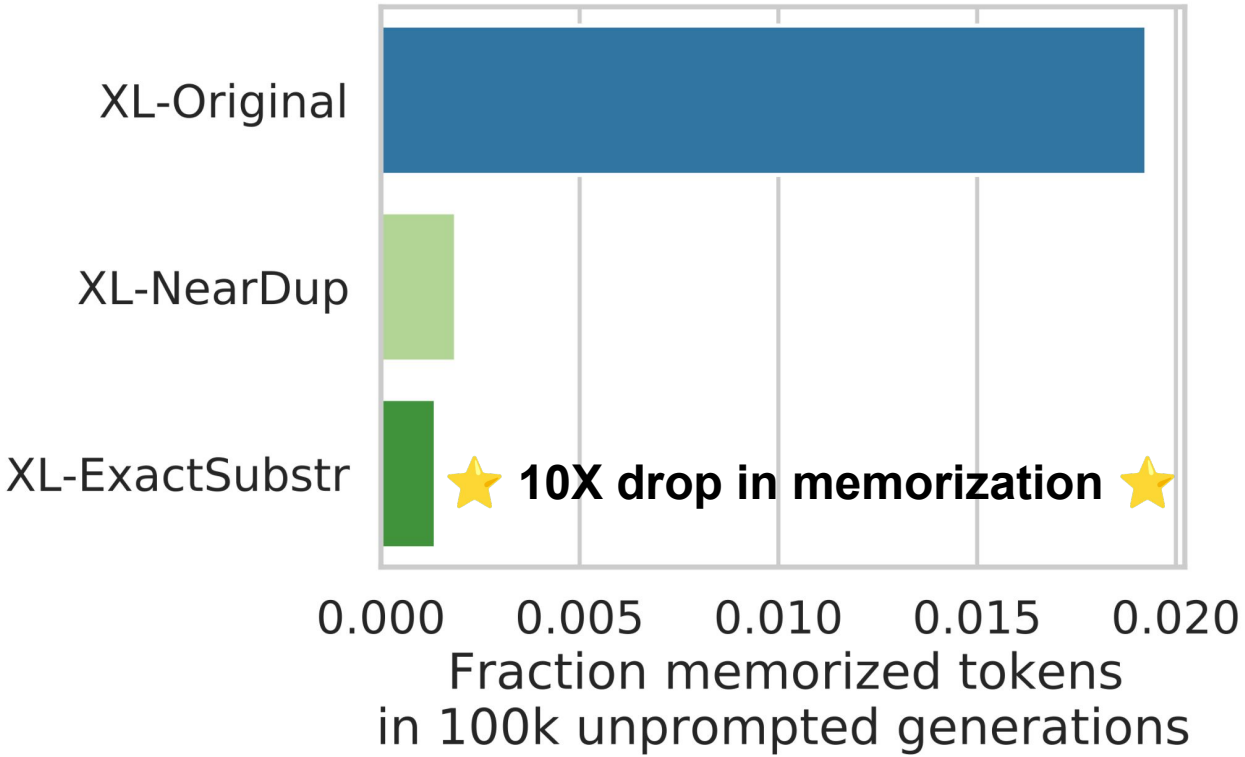
Unprompted Memorization

Generate text with random sampling (top-k=50)



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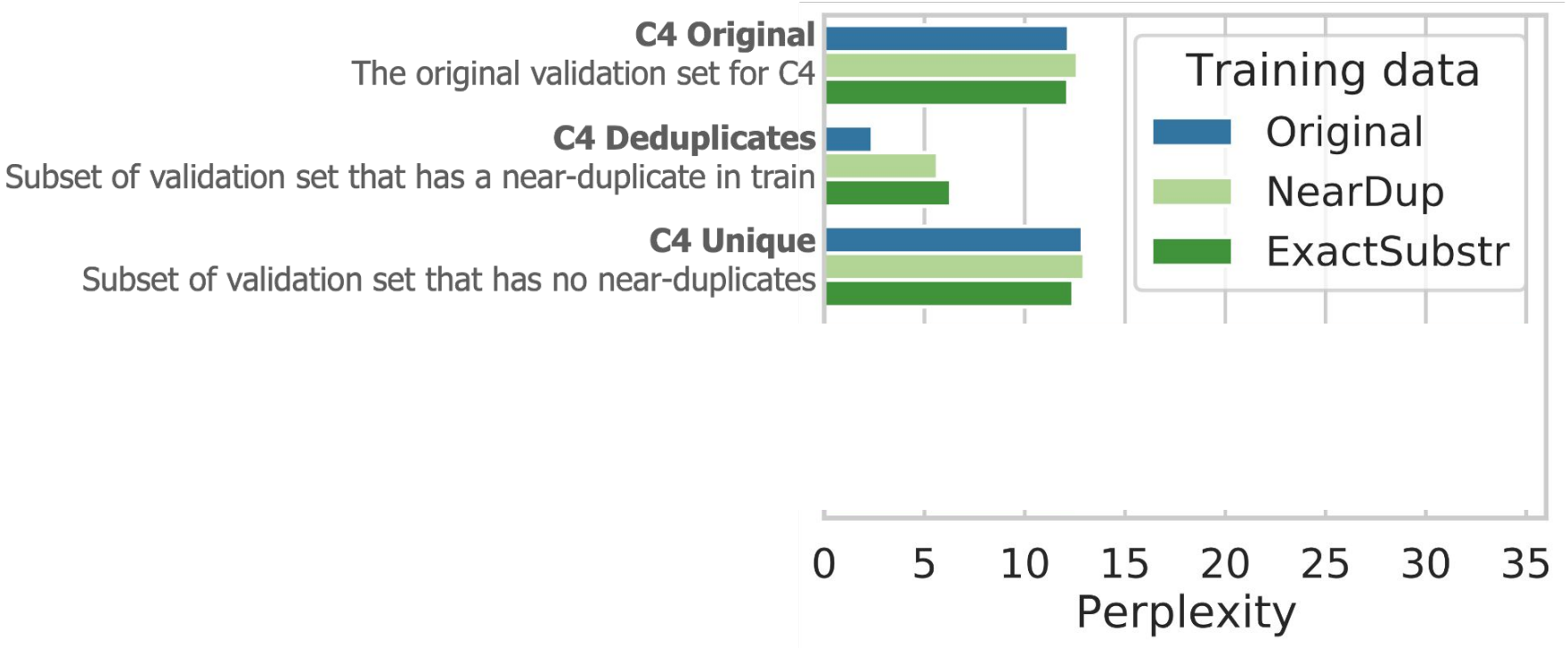
Deduplicated models are better.



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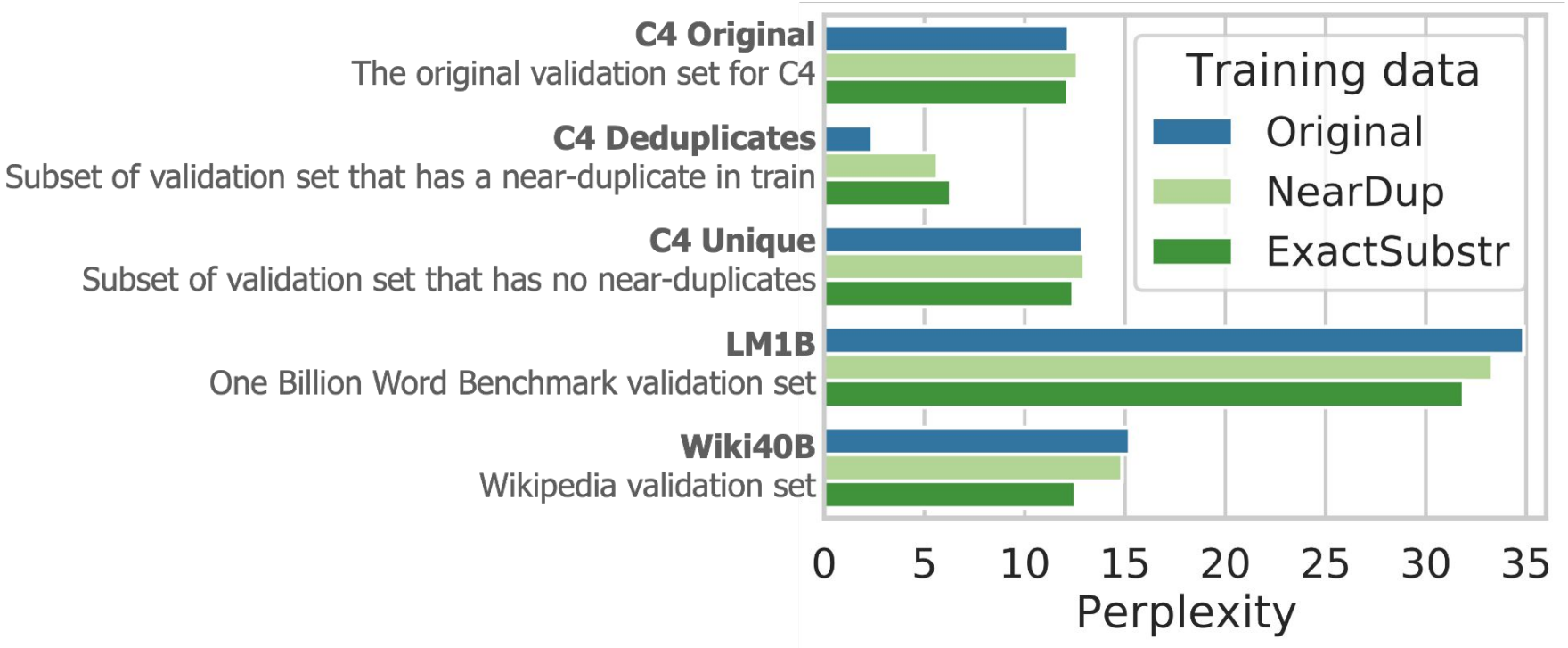

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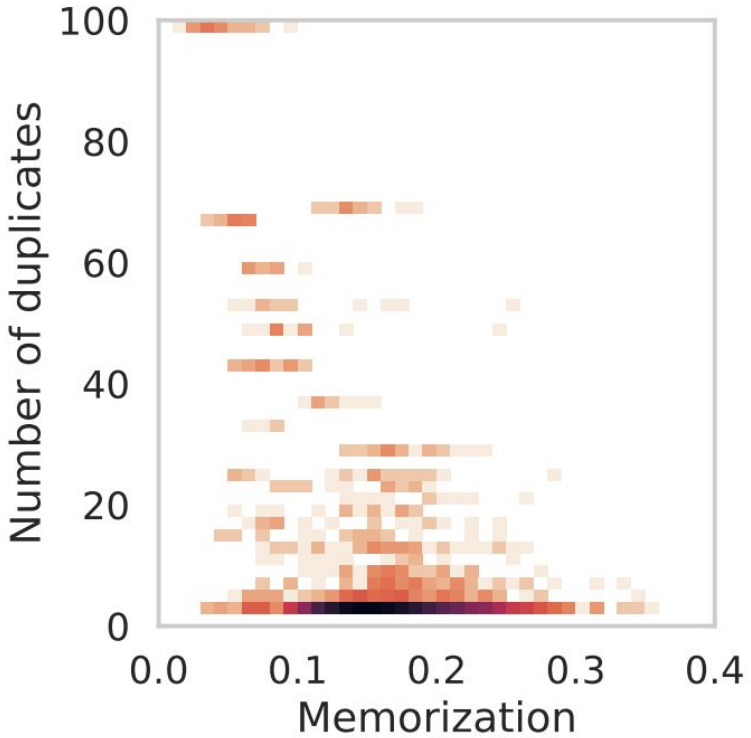
Counterfactual Memorization

Which examples are rarely seen but still memorized?

Counterfactual Memorization



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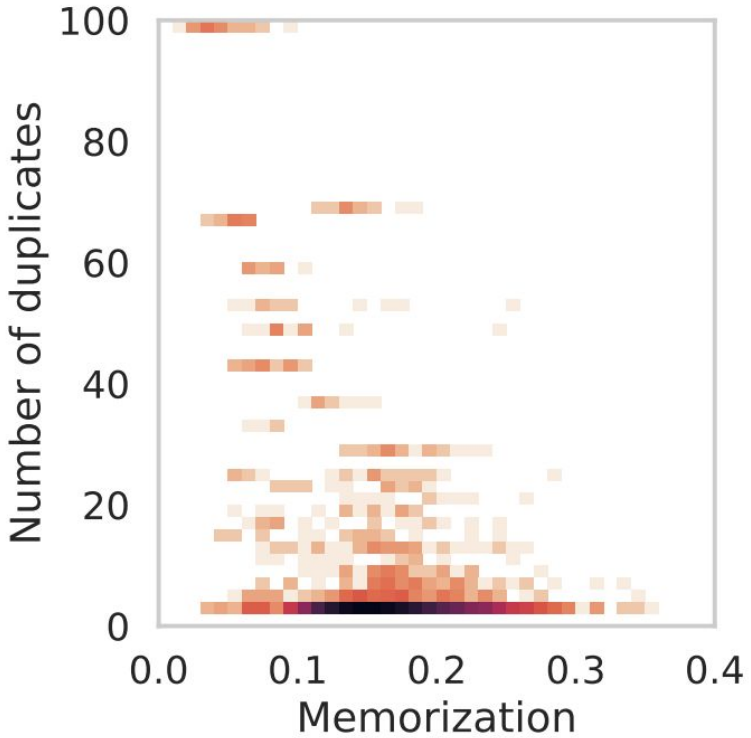
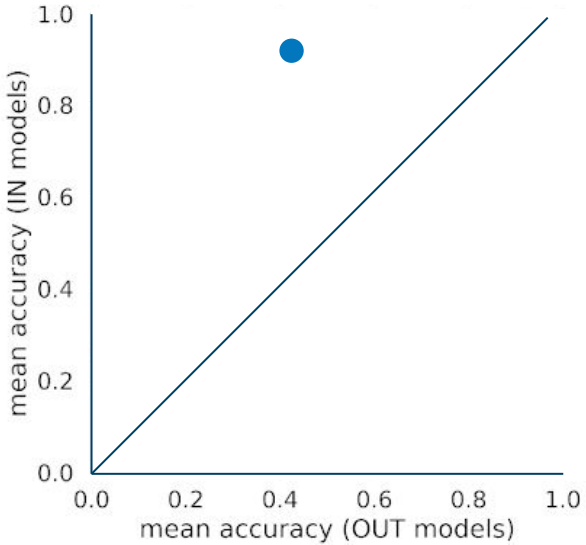
Counterfactual Memorization





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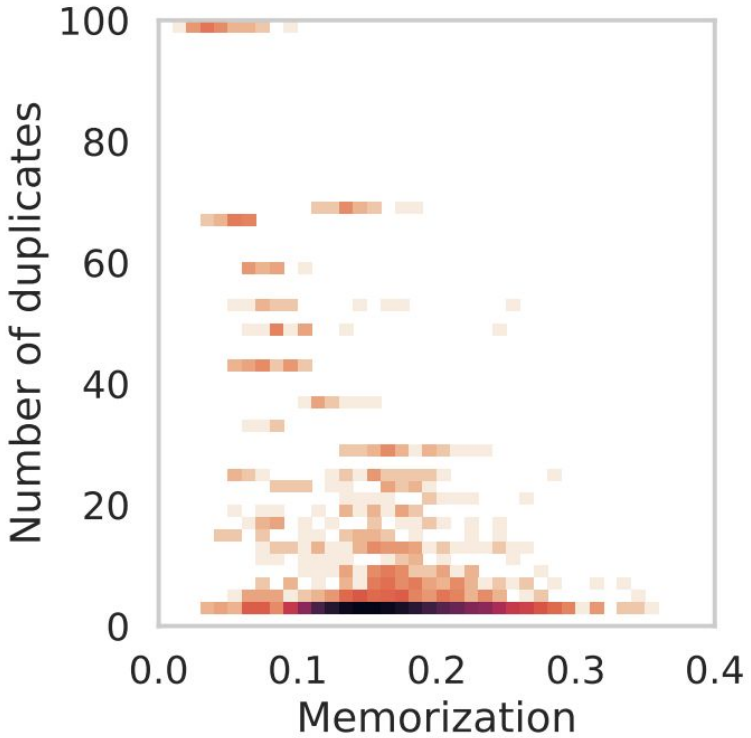
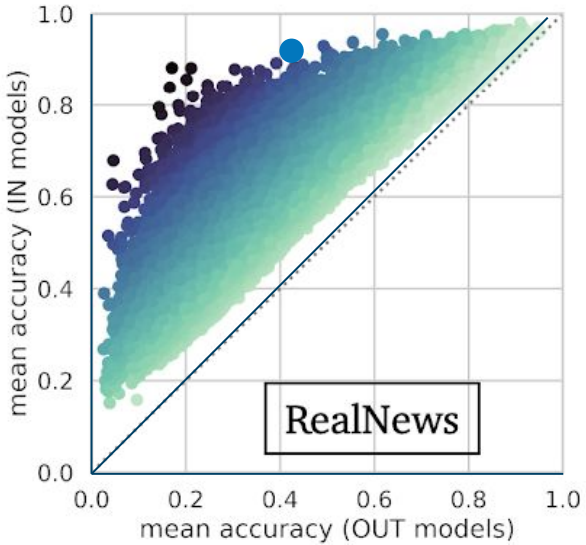
Counterfactual Memorization





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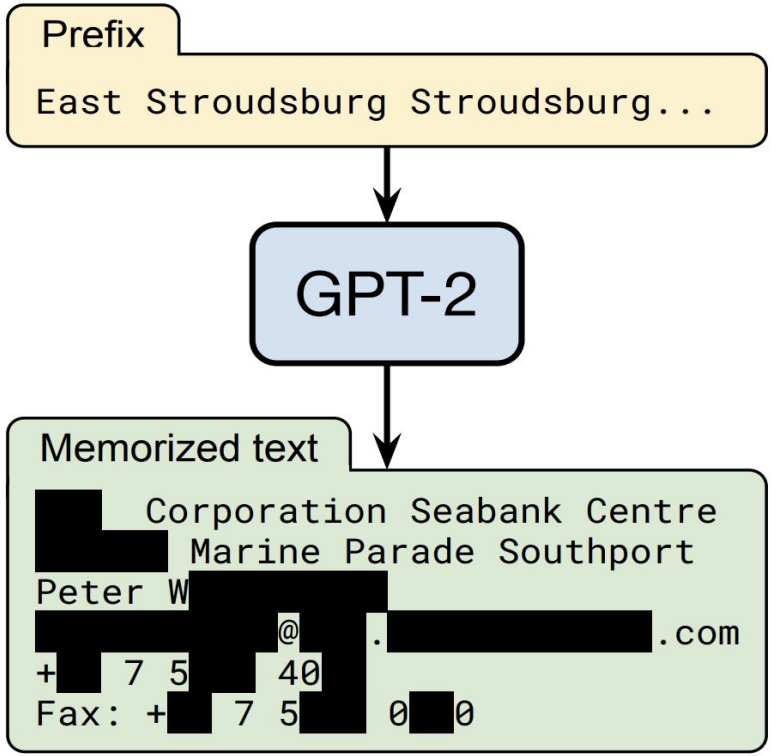
Large Models are Leaky



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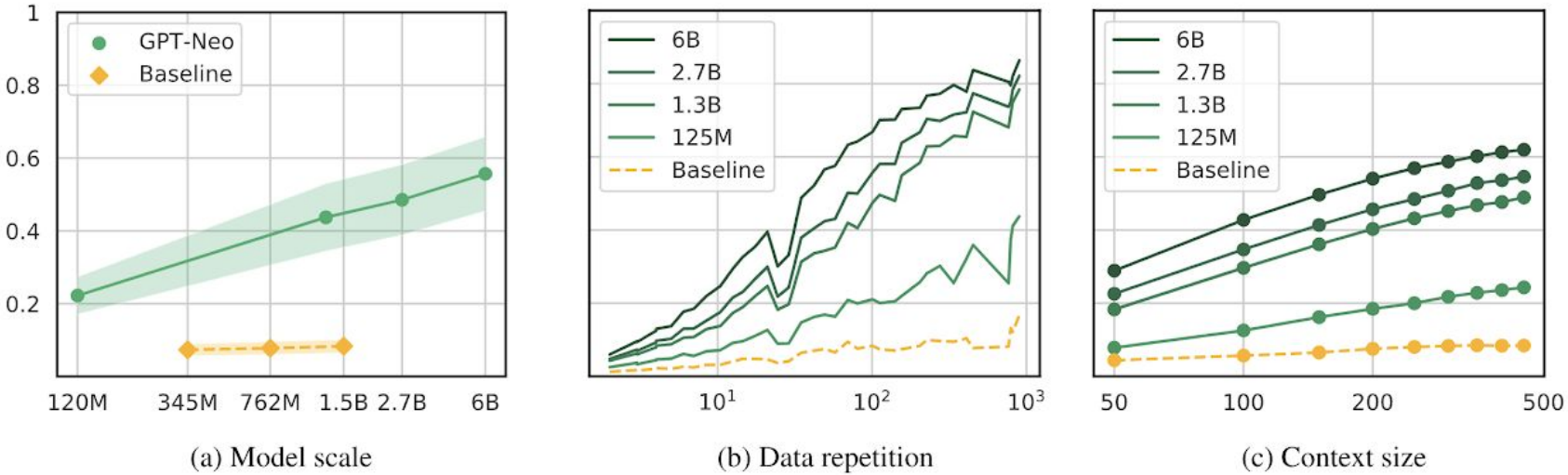
Discoverable memorization **scales**…

…with context length



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What Does it Mean for a Language Model to Preserve Privacy?

Brown, et al. “What Does it Mean for a Language Model to Preserve Privacy?” FAcct 2022

How do we use language?

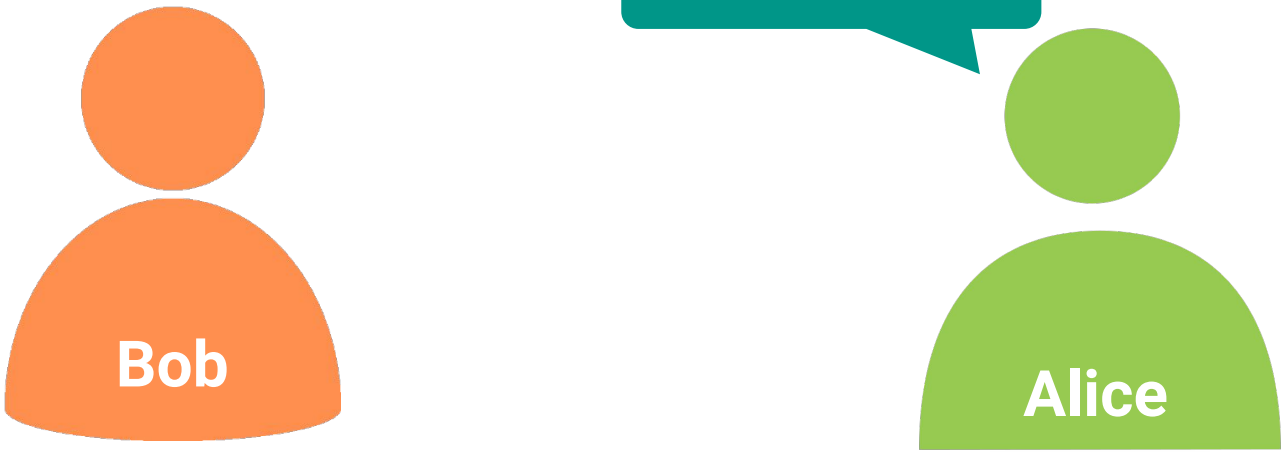
How do we use language?

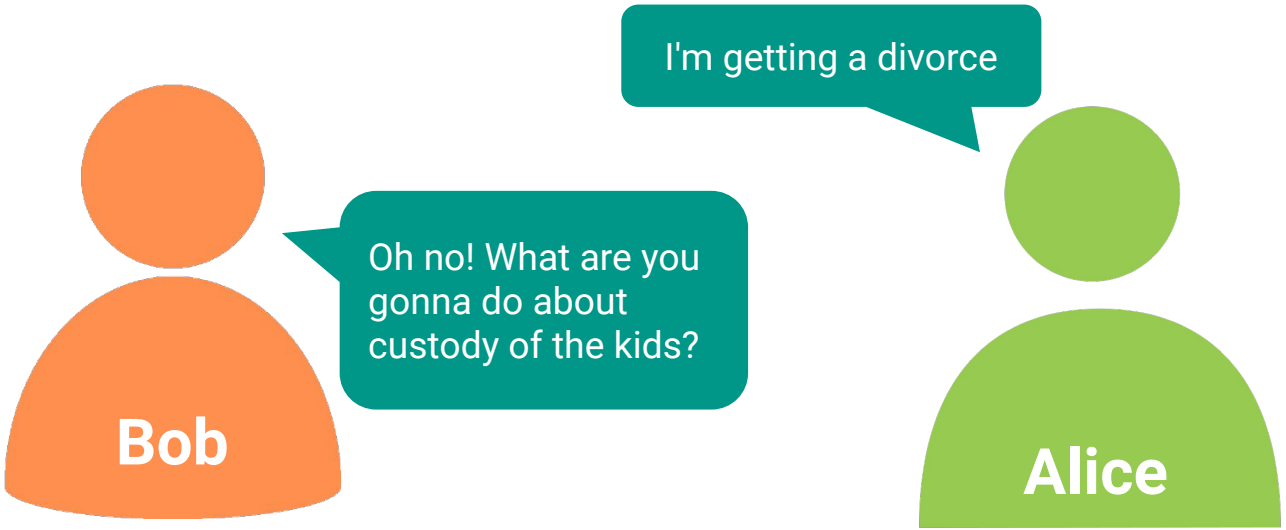
Communicate ideas, wants, needs

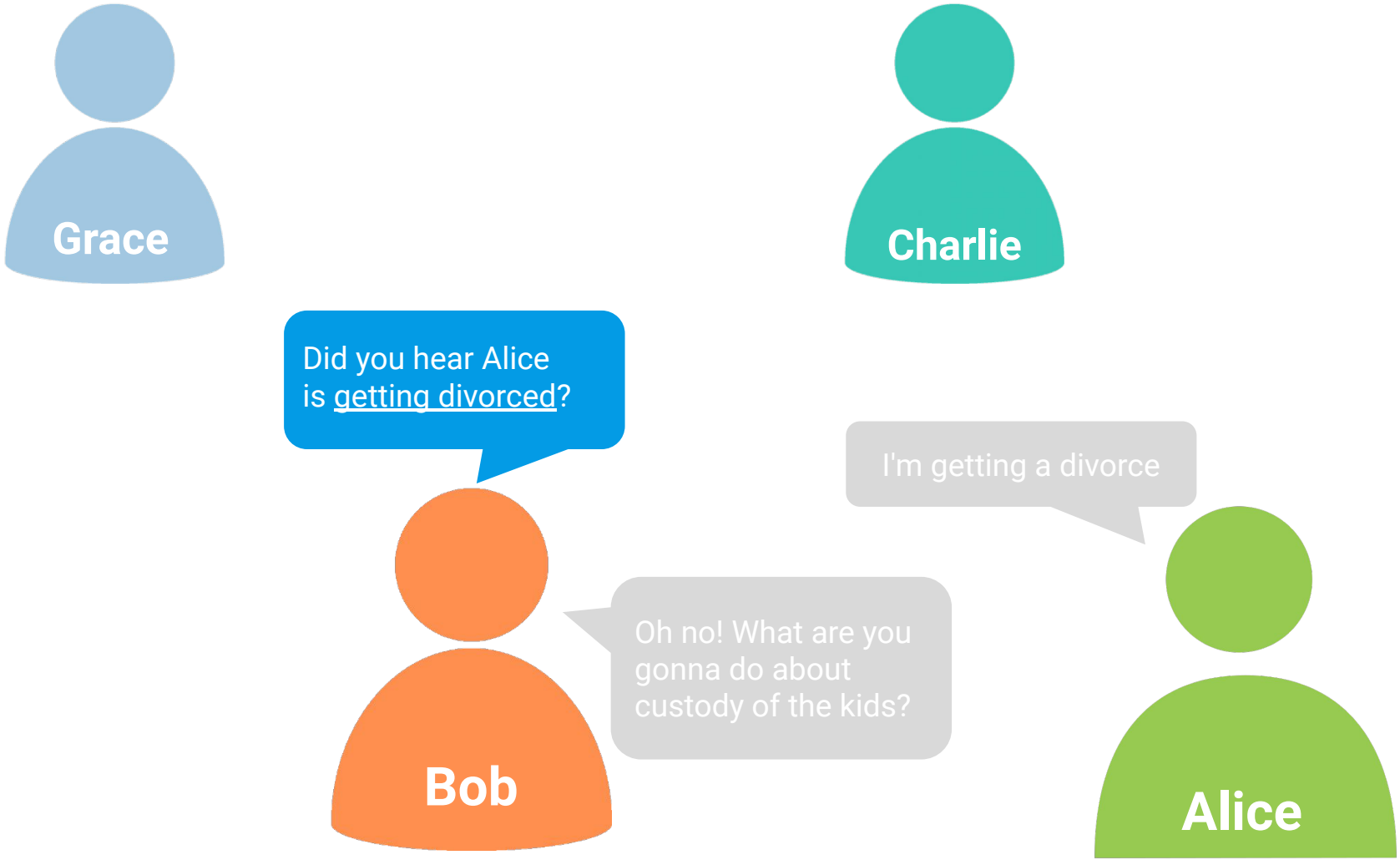
Form identity and community

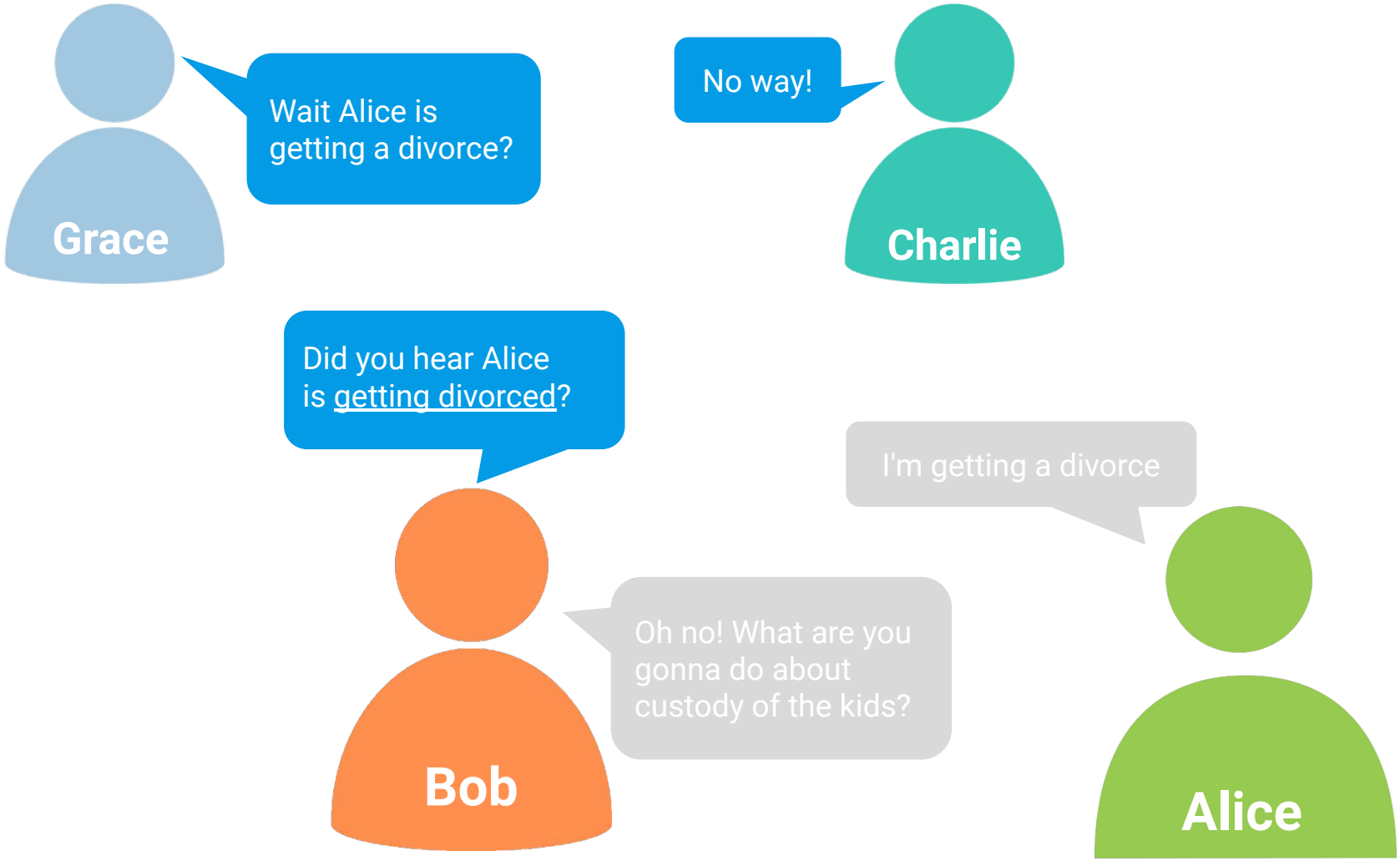
Expression

Privacy concerns are as broad as those of real life


I'm getting a divorce
Bob
Alice


I'm getting a divorce
Oh no! What are you gonna do about custody of the kids?
Bob
Alice


Grace
Charlie
Did you hear Alice is getting divorced?
I'm getting a divorce
Oh no! What are you gonna do about custody of the kids?
Bob
Alice


Grace
Wait Alice is getting a divorce?
Charlie
No way!
Bob
Did you hear Alice is getting divorced?
Oh no! What are you gonna do about custody of the kids?
Alice
I'm getting a divorce

We *memorize* information

We *memorize* information

then judge the *context*

We *memorize* information

then judge the *context*

BUT

Language models don't have this understanding!

Information for context usually is beyond data given

Privacy is not binary…

…it’s contextual

Contextual Integrity

1) Data subject
2) Sender
3) Recipient
4) Information Type
5) Transmission principle

Alice

Alice

Bob

Texts about Alice's divorce

The recipient won't share the information with anyone Alice isn't close with

(Nissenbaum, 2009)

Language is contextual

Shared information ≠ public information

Information may be private to only some people

Or only in some contexts

Identifying all of this is hard!

Harm from memorization is contextual

Private / sensitive information: “My social security number is XXXXX.”

Common phrases: “To whom it may concern...”

Facts: “Christmas is celebrated on Dec 25th”

Quotes: “Trump said, ‘Tariffs are the greatest!’”

Quotes: “Sally Smith said, ‘Sam is the worst.’”

Privacy is not binary

Privacy violations range in severity

When is sharing okay?

Who can we share with?

What is the private information?

All heavily context dependent and can change

Current NLP Privacy Methods

Why can’t we just remove private text?

[aka, text sanitization]

Private information has no one format

lastname AT website DOT com

Language constantly changes

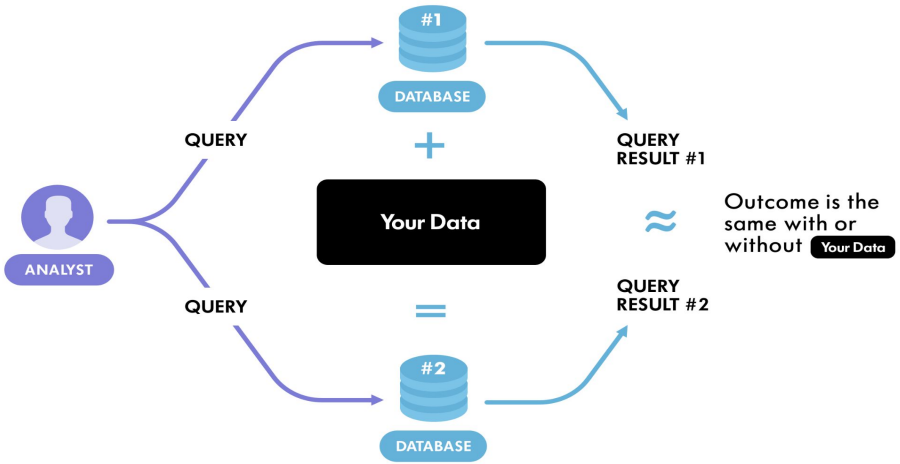
Die → Unalive

Privacy is context dependent

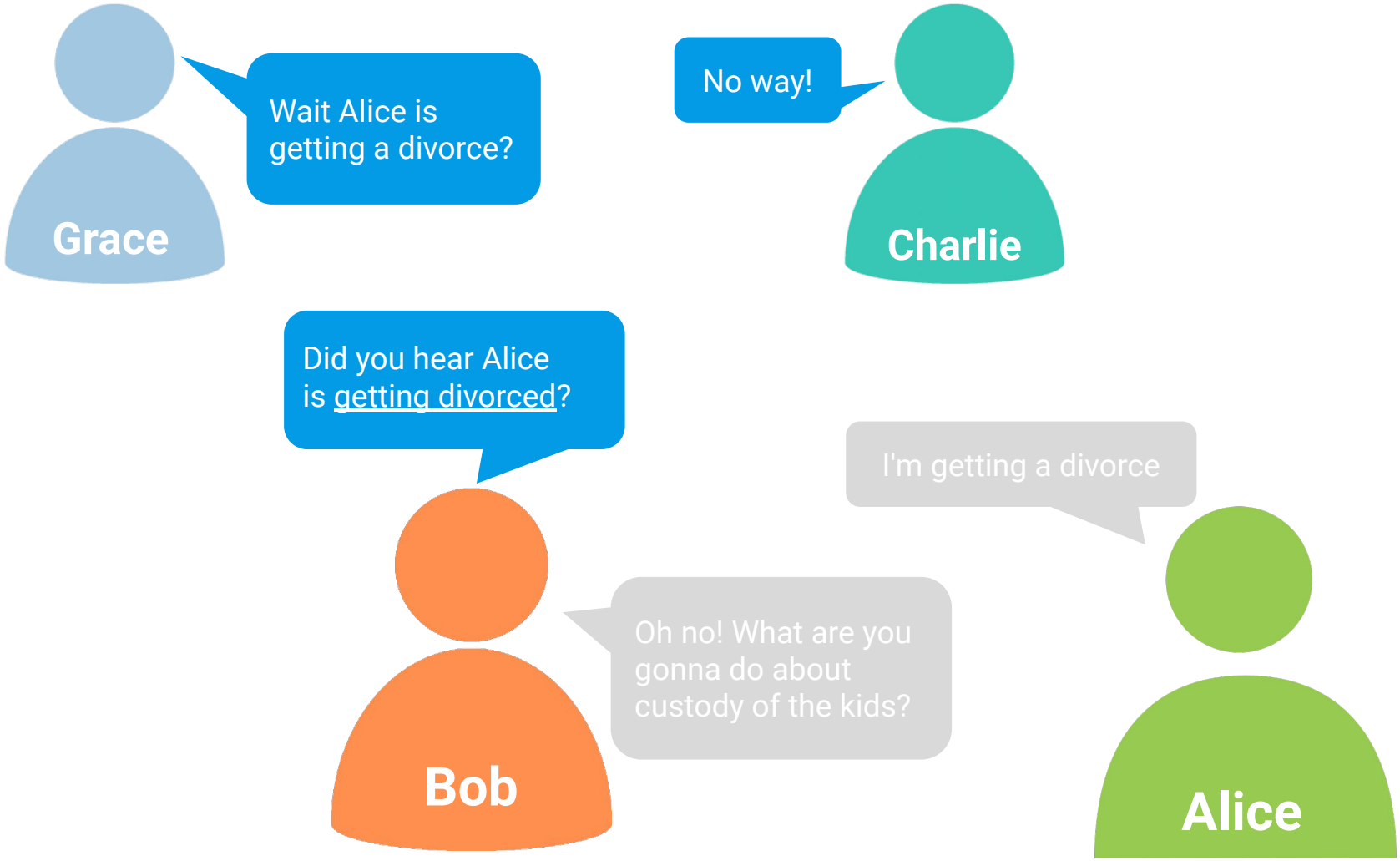
We're throwing Bob a surprise party!

What about differential privacy?

For some value ϵ, and algorithm A, the probability of a single record being in the training dataset of A is indistinguishable (*relative to* ϵ) from the probability that it is not (Dwork, 2006).



(Winton, 2018)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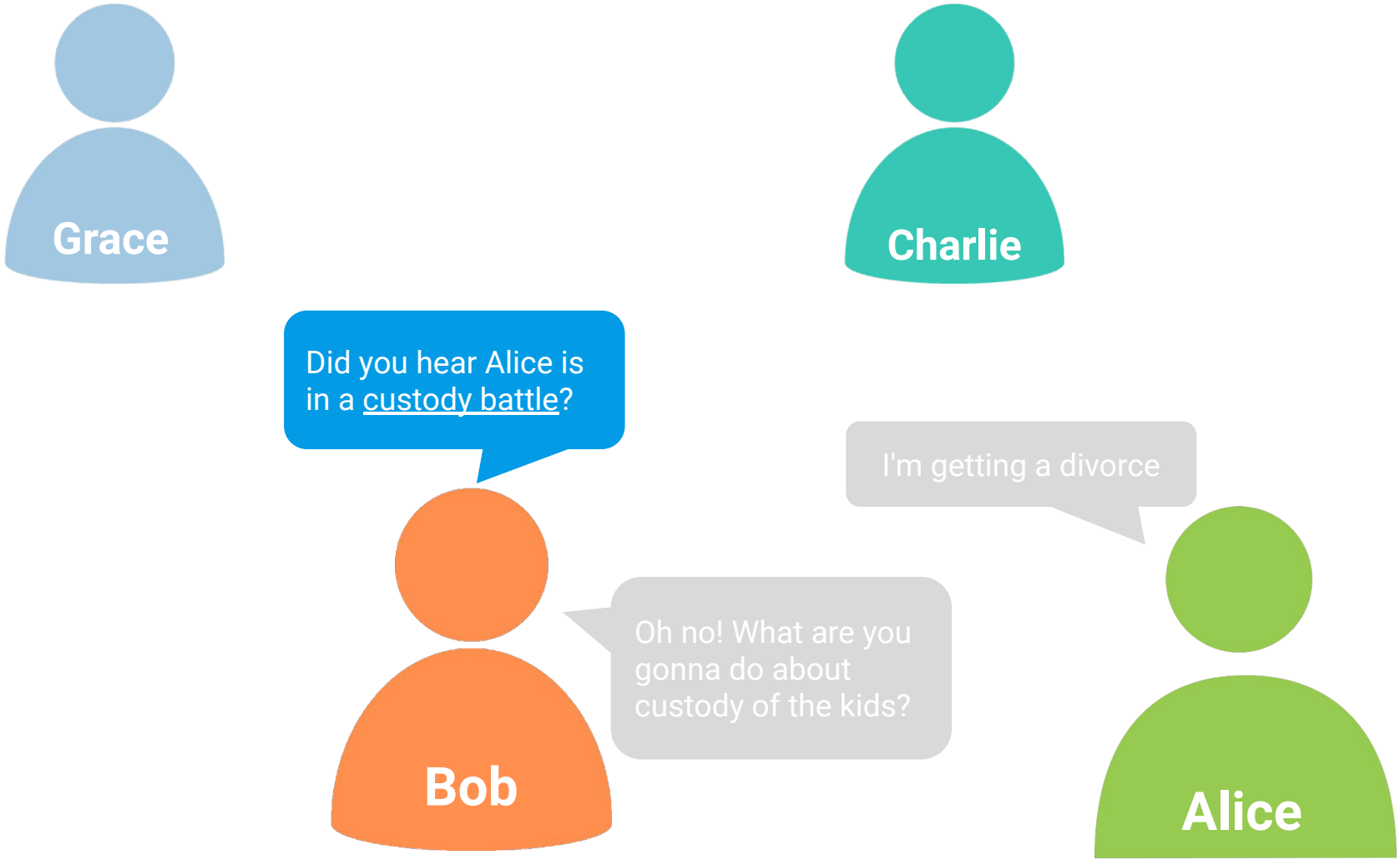
Alice
I'm getting a divorce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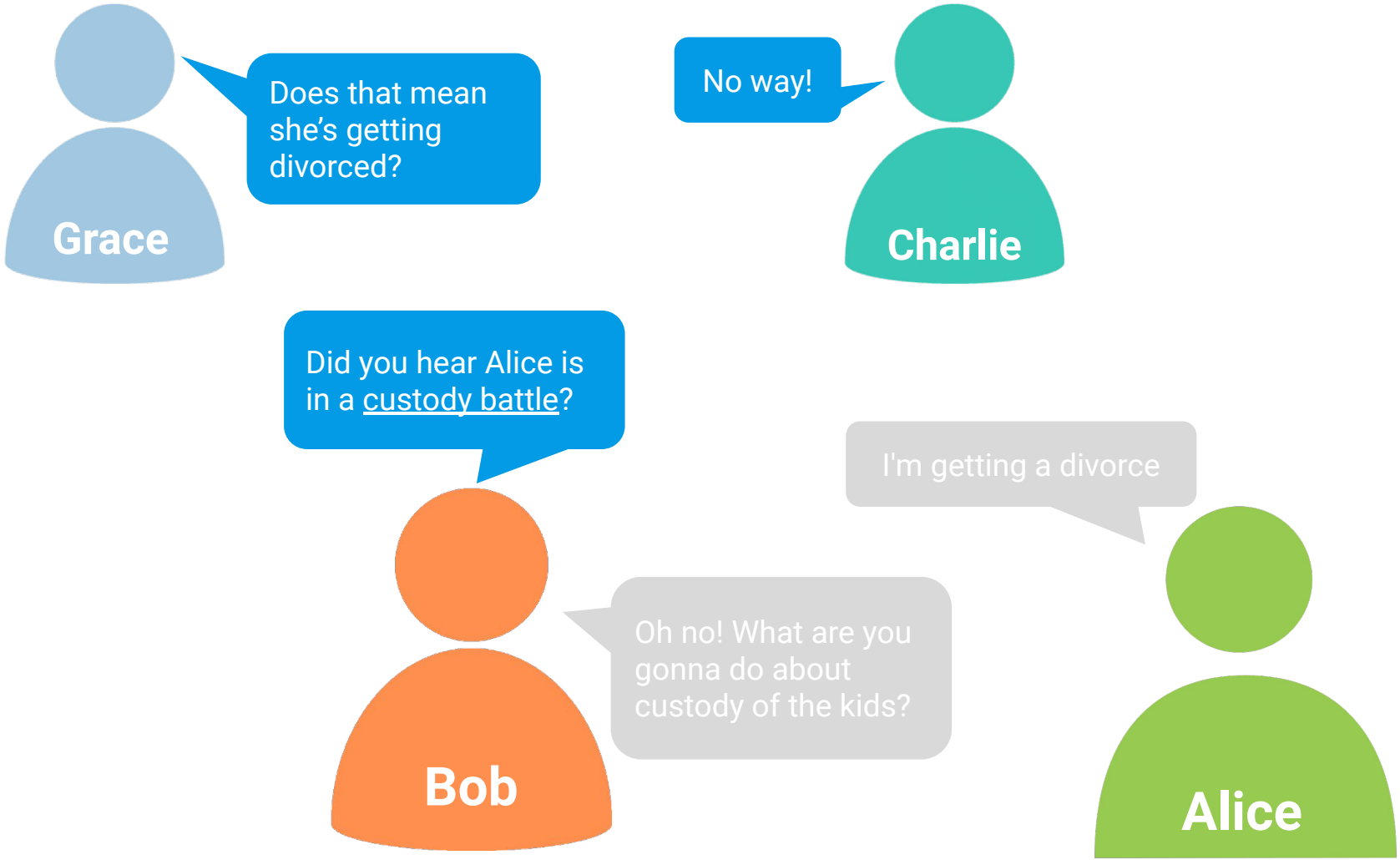
Did you hear Alice is in a custody battle?
I'm getting a divorce
Oh no! What are you gonna do about custody of the kids?
Bob
Alice


Grace
Does that mean she's getting divorced?
Charlie
No way!
Bob
Did you hear Alice is in a custody battle?
Oh no! What are you gonna do about custody of the kids?
Alice
I'm getting a divorce

Can shared information be private?

The Panama Papers: Exposing the Rogue Offshore Finance Industry

(ICIJ, 2016)

DP makes assumptions

Privacy is ***binary***

Private information is ***identifiable***

Private information will ***never be shared***

Units of private information follow defined natural language units

DP makes assumptions

Privacy is ***binary***

Private information is ***identifiable***

Private information will ***never be shared***

Units of private information follow defined natural language units

Guarantees don't align with our ideas of privacy for language

Withholding any unit of data cannot guarantee privacy

Shared information gets less privacy guarantees

What is a record?

How can Language Models Preserve Privacy?

Can users consent?

One person's *data* includes multiple people's *information*

Privacy guarantees that do exist can't be easily explained

Informed consent is generally impossible

Publicly available ≠ publicly directed

Data can be shared without consent

Public posts on social media often have target audiences

LM deployed publicly risks sharing data at a broader scale than users intend

Privacy Preserving LMs?

Train on data intended to be public

Finetune locally on user-contributed data if needed

Privacy is *meaningfully* preserved this way

Questions & Thank you!

What violations of privacy do you accept?

Can informed consent be given?

What questions does this raise for researchers designing the technology?

What sort of data *should* we be using?

References

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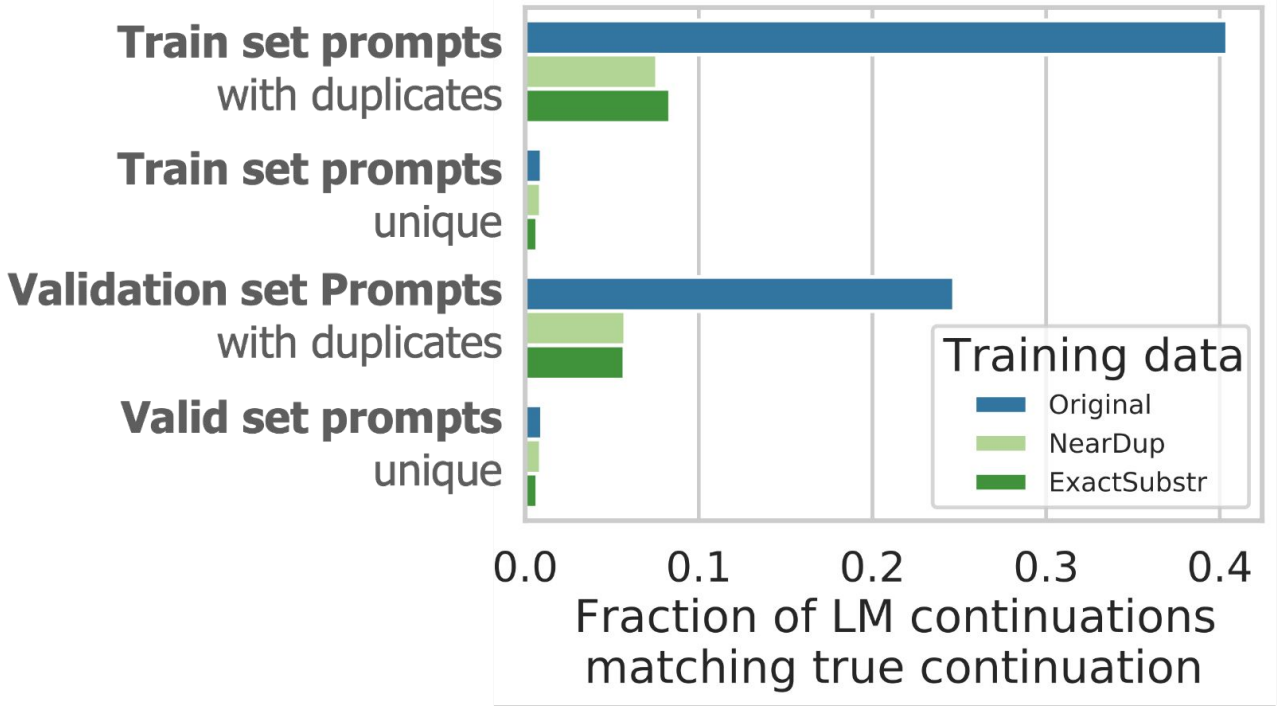
Thank you!

Extra slides

Prompted Memorization

Prompt with 32 tokens, generate with top-k=50



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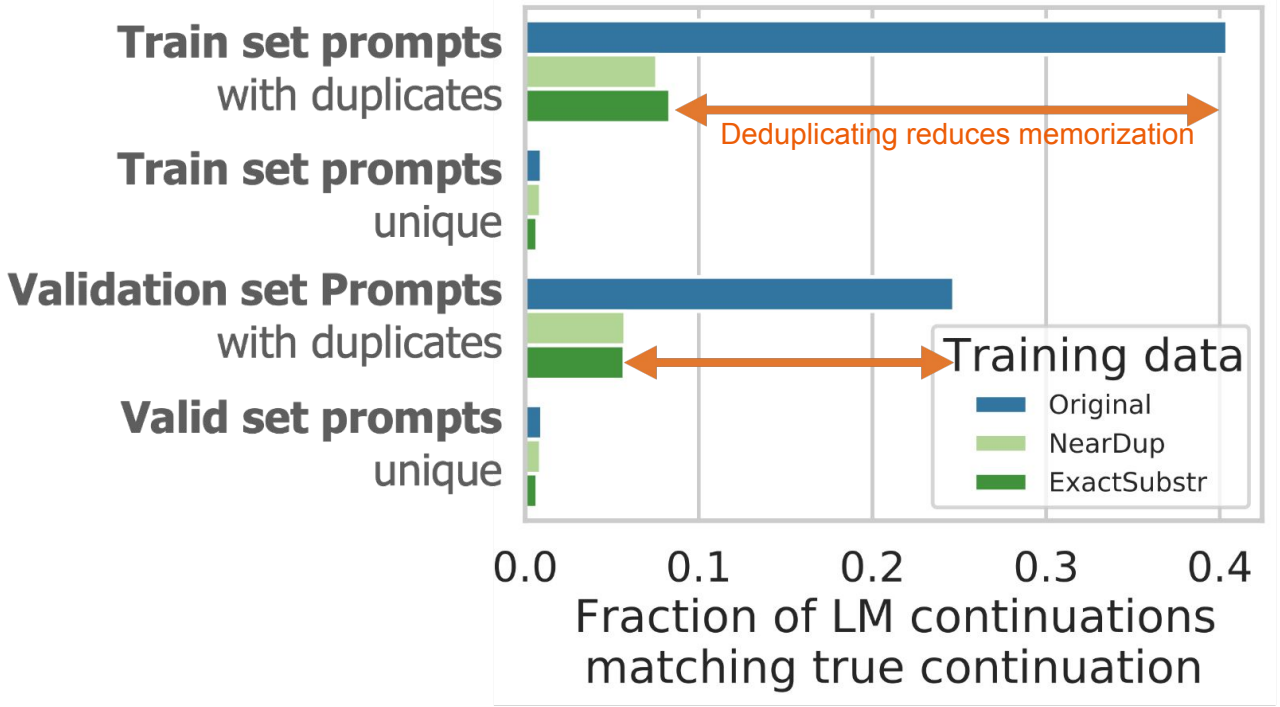

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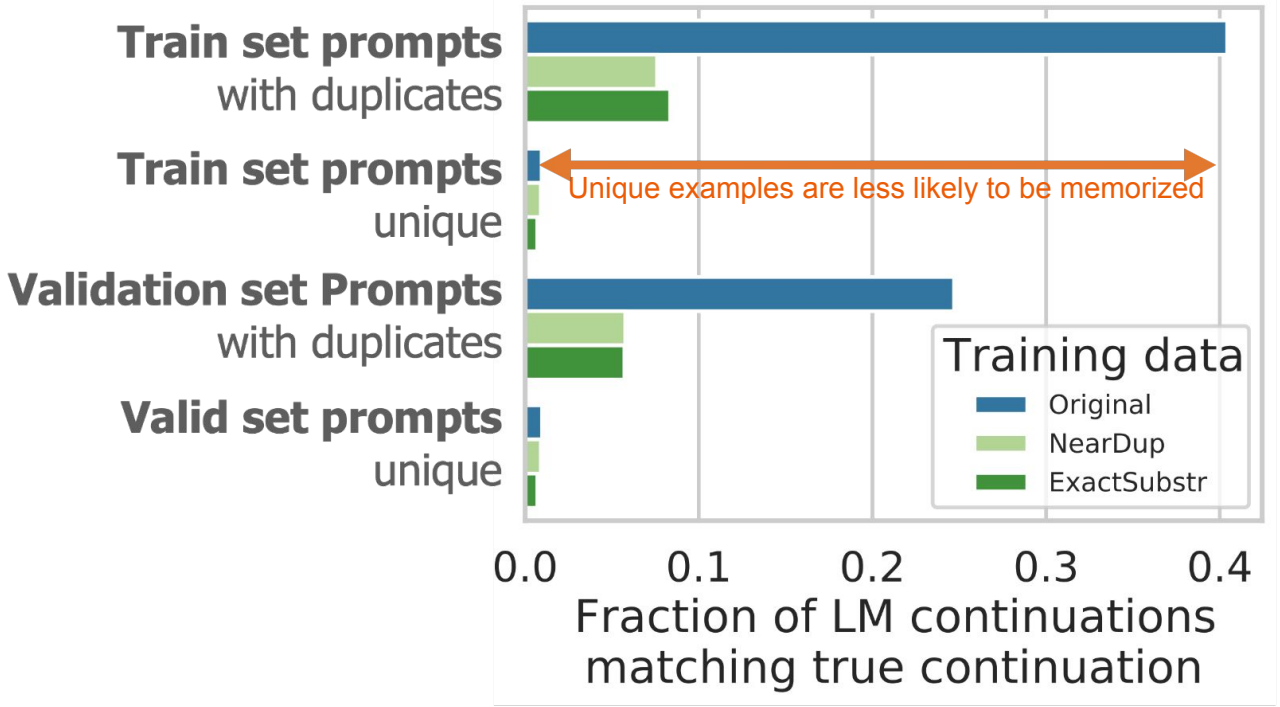

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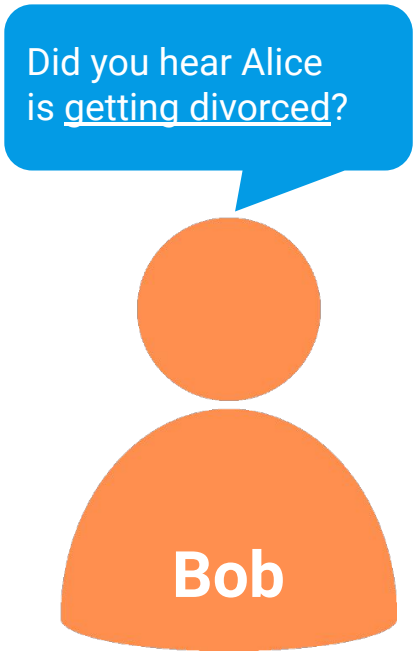
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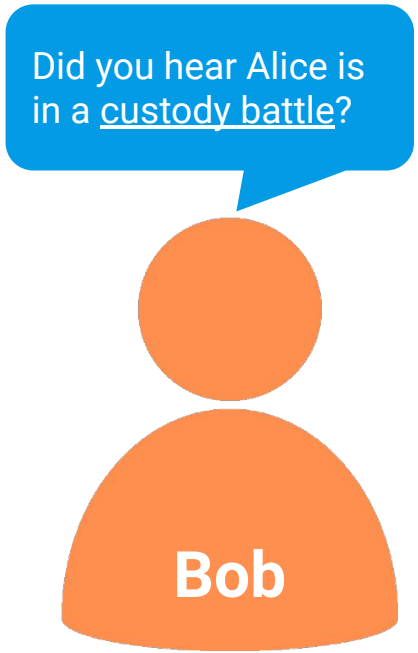
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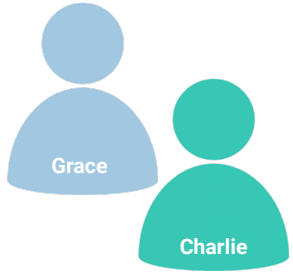
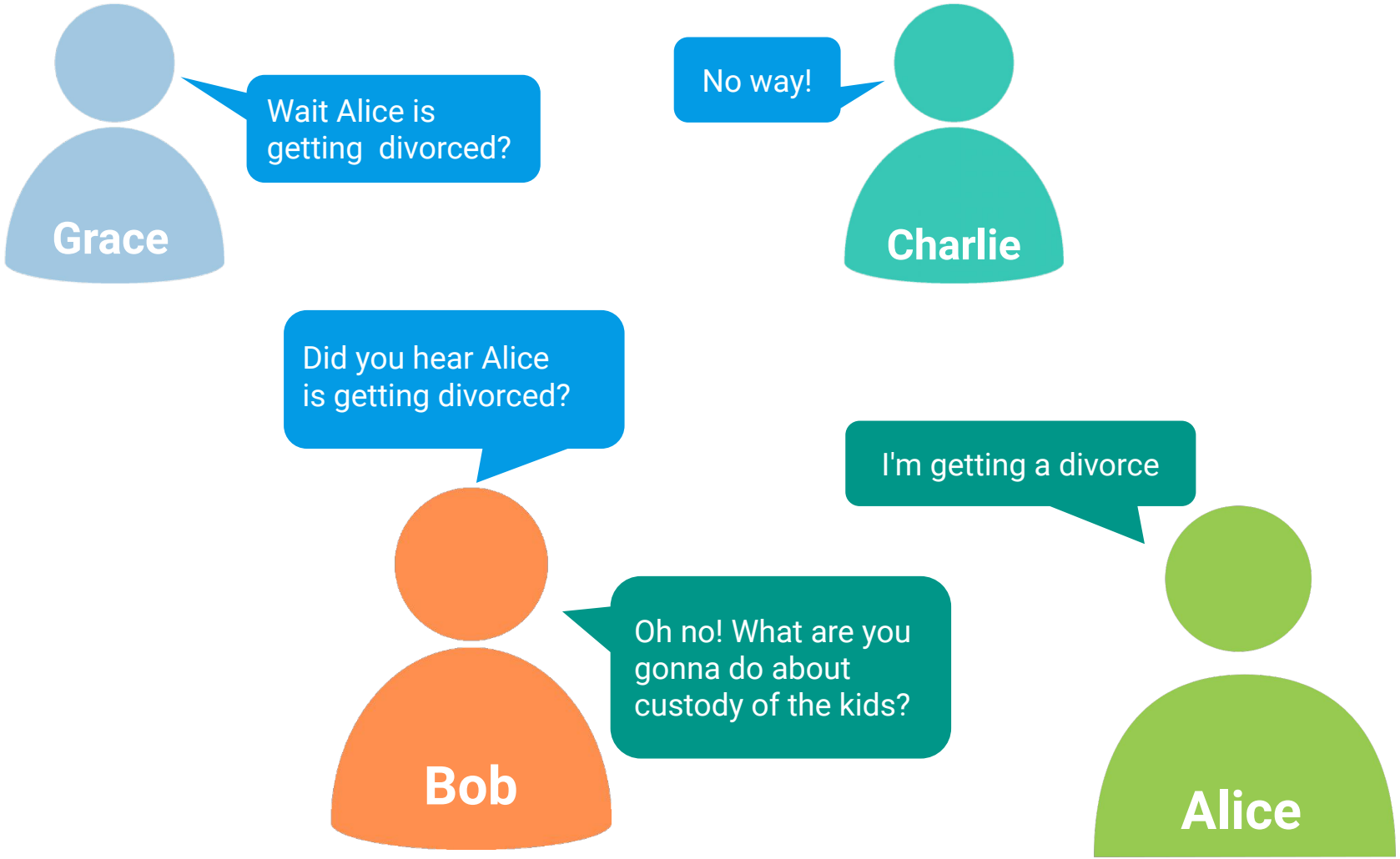

Grace
Charlie


Wait Alice is getting divorced?
Grace
No way!
Charlie
Did you hear Alice is getting divorced?
Bob
Oh no! What are you gonna do about custody of the kids?
I'm getting a divorce
Alice

Who can private information be shared with?

Suicide hotline shares data with for-profit spinoff, raising ethical questions

(Levine, 2022)

References

- Hannah Brown, Katherine Lee, Fatemehsadat Mireshghallah, Reza Shokri, and Florian Tramèr, What Does it Mean for a Language Model to Preserve Privacy? *arXiv preprint arXiv:2202.05520*, 2022.
- Nicholas Carlini, Florian Tramer, Eric Wallace, Matthew Jagielski, Ariel Herbert-Voss, Katherine Lee, Adam Roberts, Tom Brown, Dawn Song, Ulfar Erlingsson, et al. Extracting training data from large language models. *arXiv preprint arXiv:2012.07805*, 2020.
- Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. Bert: Pre-training of deep bidirectional transformers for language understanding. *arXiv preprint arXiv:1810.04805*, 2018.
- Cynthia Dwork, Frank McSherry, Kobbi Nissim, and Adam Smith. Calibrating noise to sensitivity in private data analysis. In *Theory of cryptography conference*, pages 265–284. Springer, 2006.
- International Consortium of Investigative Journalists. About the Panama Papers investigations. https://www.icij.org/investigations/panama-papers/pages/panama-papers-about-the-investigation/, 2016.
- Alexandra S. Levine. Suicide hotline shares data with for-profit spinoff, raising ethical questions, Jan 2022.
- Helen Nissenbaum. *Privacy in context*. Stanford University Press, 2009.