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Enhancing Knowledge Grounding in Retrieval-Augmented Language Models: An Empirical Study

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Signed: *Martin Fixman*

Abstract

This is an abstract

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1 Introduction and Objectives

2 Context

This research is the latest on a long line of academic articles on the topics of retrieval-augmented generation, counterparametric and contextual data, and how to enhance knowledge on large language models.

This section presents a short summary of some of the articles that were useful in researching this topic.

2.1 Foundational Papers on Large Language Models

- “Language models are unsupervised multitask learners” (Radford et al. 2019).
 - The foundational paper for GPT2.
- “Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer” (Raffel et al. 2020).
 - The foundational paper for T5.
- “Language Models are Few-shot Learners” (Brown et al. 2020).
 - Introduces “in-context learning”.
- “Prompt programming for large language models: Beyond the few-shot paradigm” (Reynolds & McDonell 2021).
 - Improves the previous paper.

2.2 Papers working with RAG and contextual data

- “Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks” (Lewis et al. 2020).
 - Foundational paper for RAG.
- “Self-RAG: Learning to Retrieve, Generate, and Critique through Self-Reflection” (Asai et al. 2023).
 - Interesting RAG system.
- “Can Retriever-Augmented Language Models Reason? The Blame Game Between the Retriever and the Language Model” (Ghader et al. 2023).
 - Nice evaluation of RAG models.

2.3 Retrieval-Augmented Language Models

- “Shall We Pretrain Autoregressive Language Models with Retrieval? A Comprehensive Study” (Wang et al. 2023).

*This entire section is in progress — short summaries of the named papers will come soon.

- Reproduces and pretrains RETRO.
- “Atlas: Few-shot Learning with Retrieval Augmented Language Models” (Izcard et al. 2022).
 - Introduces ATLAS.
- “Improving language models by retrieving from trillions of tokens” (Borgeaud et al. 2022).
- “RAGGED: Towards Informed Design of Retrieval Augmented Generation Systems” (Hsia et al. 2024).
 - Analyses results of these systems; compares Llama to Flan-T5.

2.4 On disentangling parametric and context-augmented counterparametric knowledge

- “DISCO: Distilling Counterfactuals with Large Language Models” (Chen et al. 2023).
 - Does similar analysis with counterfactuals to this thesis
- “DisentQA: Disentangling Parametric and Contextual Knowledge with Counterfactual Question Answering” (Neeman et al. 2022).
 - Also does a similar analysis to this thesis.
- “Characterizing Mechanisms for Factual Recall in Language Models” (Yu et al. 2023).
 - Very simple analysis, but tries to understand WHERE in the model the contextual answers come from.
- “Can We Edit Factual Knowledge by In-Context Learning?” (Zheng et al. 2023).
- “Learning the Difference that Makes a Difference with Counterfactually-Augmented Data” (Kaushik et al. 2020).

3 Methodology

3.1 Models and Resources Used

- Reader Models

- Llama-8B.
- Llama-70B.
- Flan-T5-XL.
- Flan-T5-XXL.
- *Atlas?*

- Questions

- Our own dataset, shown in Appendix A.
- *Maybe add Natural Questions, HotpotQA, and/or BioASQ as in RAGGED (Hsia et al. 2024).*

3.2 Preprocessing and Inference Methodology

3.2.1 Source Data Preparation

Our source data is prepared by extending the ideas presented by Yu et al.. Instead of using one simple question, our approach consists of separating this data into 7 categories, where each category has a set of base questions and another set of objects that are paired together and presented to our models.

This work contains 7 categories in the configuration shown by Table 1, for a total of 3840 questions. The full list of questions can be found in Appendix A.

Category	Questions	Objects	Total
Person	14	47	658
City	14	60	840
Principle	10	30	300
Element	10	35	350
Book	10	45	450
Painting	14	39	546
Historical Event	6	56	336
Total	68	312	3840

Table 1: The amount of questions for each category. The full list of questions can be found in Appendix A. This is still a work in progress and I expect to add more questions.

We enhance the zero-shot learning prompt used by Brown et al. by using the prompt format example format presented Jiang et al. for calibrating the T5 language model by adding both the question and the first part of the answer.

3.2.2 Prompting

There is plenty of research that suggests that for zero-shot problems (Brown et al. 2020, Reynolds & McDonell 2021), it’s convenient to create a minimal prompt (Jiang et al. 2021, Yu et al. 2023). This is helpful when later calculating the perplexity of the answers, as it tends to bias for short answers without any extra information that might change the individual probabilities of each token.

Examples of the prompting format explained in Sections 3.2.1 and 3.2.2 can be found in Table 2. For later queries, this is enhanced with context as in Table 3.

Base Question	Object	Final Question
What is the date of birth of {person}?		Q: What is the date of birth of Che Guevara?
The date of birth of {person} is	Che Guevara	A: The date of birth of Che Guevara is
In what city was {person} born?	Confucius	Q: What is the date of birth of Confucius?
{person} was born in		A: The date of birth of Confucius is
What country is {city} in?	Cairo	Q: In what city was Che Guevara born?
{city} is in	Mumbai	A: Che Guevara was born in
		Q: In what city was Confucius born?
		A: Confucius was born in
		Q: What country is Cairo in?
		A: Cairo is in
		Q: What country is Mumbai in?
		A: Mumbai is in

Table 2: Some examples of the base-question and object generation that are fed to the models for finding parametric answers.

3.2.3 Generating and scoring parametric answers

We query each of the models listed in Section 3.1 with the data from the previous subsections.

To ensure results are simple to interpret and not affected by randomness, we follow the example of Hsia et. al (Hsia et al. 2024) and use greedy decoding to find the answer. While beam search with a short beam width tends to produce more accurate results for long answers (Sutskever et al. 2014, Wu et al. 2016) and there are many other sampling methods that produce better results (Holtzman et al. 2020), this is likely to not have an effect on experiments that result in shorter answers (Raffel et al. 2020).

The negative log-likelihood of an answer x is calculated in base of the conditional probability of generating each token given the prior tokens. We can use this value to calculate the perplexity, which measures the level of “surprise” of a particular answer.

$$\begin{aligned}
 \text{NLL}(x_1, \dots, x_N | Q) &= -\frac{1}{N} \sum_{i=1}^N \log P(x_i | Q, x_{i-1}, \dots, x_1) \\
 \text{PPL}(x_1, \dots, x_N | Q) &= e^{\text{NLL}(x_1, \dots, x_N | Q)}
 \end{aligned} \tag{1}$$

		Tokens	
		Parametric p	Counterparametric \bar{p}
Context	Empty Q	$\text{PPL}(p_1, \dots, p_N \mid Q)$	$\text{PPL}(\bar{p}_1, \dots, \bar{p}_N \mid Q)$
	Counterparametric W	$\text{PPL}(p_1, \dots, p_N \mid W)$	$\text{PPL}(\bar{p}_1, \dots, \bar{p}_N \mid W)$

Figure 1: Four different perplexity values: one for each set of tokens, and one for each query context..

We can ensure that the probabilities are calculated based on the intended tokens rather than the “most probable” generated ones by using teacher forcing (Lamb et al. 2016).

3.2.4 Shuffling to generate counterparametric answers

Previous work related to finding per token probabilities of answers in large language models focus on either a pre-existing list of questions or on a single question format (Yu et al. 2023). This approach does not work for our use case for three reasons.

1. Having 68 different types of questions, rather than just 1, makes finding counterfactual answers technically challenging.
2. Our focus is not on finding *counterfactual* answers, but *counterparametric* ones. We do not care about correctness; we care about answers not being parametric.
3. Since we are measuring perplexity of these answers, we focus on answers that are generated by the same base question and the same model. This way we ensure that the format of the answer is the same.

We propose a novel way of generating counterparametric answers while focusing on these three points: rather than generating new answers for each question, counterfactual answers are randomly sampled from the parametric answers corresponding to the same base question. An example of this approach can be seen in Table 3.

3.2.5 Counterparametric and contextual perplexity scores

This works extends the approach of analysing answers found in [citation needed] and explained in Section 3.2.3 by also calculating the perplexity of *alternative* answers to each question.

That is, we take the result of applying each model to both the answer with and without counterparametric context, and we calculate the perplexity scores of getting both the parametric and counterparametric answer to each one of these. This produces four different scores which are detailed in Figure 1: one for each answer using either empty and counterparametric context.

*I am finding it hard to explain this subsubsection. Maybe I should add pseudocode here.

Base Question	Parametric Answer	Counterparametric Answer	Question with counterparametric context
What is the date of birth of Che Guevara?	June 14, 1928	June 21, 1947	Context: [the date of birth of Che Guevara is June 21, 1947]. Q: What is the date of birth of Che Guevara? A: The date of birth of Che Guevara is
What is the date of birth of Ibn al-Haytham?	965 AD	June 14, 1928	Context: [the date of birth of Ibn al-Haytham is June 14, 1928]. Q: What is the date of birth of Ibn al-Haytham? A: The date of birth of Ibn al-Haytham is
What is the date of birth of Boyan Slat?	27 January 1994	February 23, 1868	Context: [the date of birth of Boyan Slat is February 23, 1868]. Q: What is the date of birth of Boyan Slat? A: The date of birth of Boyan Slat is
What is the date of birth of W.E.B Du Bois?	February 23, 1868	June 14, 1928	Context: [the date of birth of W.E.B Du Bois is June 14, 1928]. Q: What is the date of birth of W.E.B Du Bois? A: The date of birth of W.E.B Du Bois is
What is the date of birth of Stephen Hawking?	January 8, 1942	965 AD	Context: [the date of birth of Stephen Hawking is 965 AD]. Q: What is the date of birth of Stephen Hawking? A: The date of birth of Stephen Hawking is
What is the date of birth of Shirin Ebadi?	June 21, 1947	June 14, 1928	Context: [the date of birth of Shirin Ebadi is June 14, 1928]. Q: What is the date of birth of Shirin Ebadi? A: The date of birth of Shirin Ebadi is

Table 3: Example of the sampling done to produce counterparametric answers. Counterparametric answers are generated by sampling a random answer from the parametric answers from the same base questions; to ensure that no parametric and counterparametric pair are identical, we only sample between different parametric answers. Note that the same parametric answer can appear several times as a counterparametric in different questions.

By definition, the tokens of the parametric answer p_1, \dots, p_N are the ones corresponding to the lowest perplexity answer for the query without any context. This is not the case for the tokens of the counterparametric answer $\bar{p}_1, \dots, \bar{p}_{\bar{N}}$, which produces the inequality in Equation (2).

$$\text{PPL}(p_1, \dots, p_N \mid Q) \leq \text{PPL}(\bar{p}_1, \dots, \bar{p}_{\bar{N}} \mid Q) \quad (2)$$

Finding the result of the inequality for the queries with the counterparametric context W is one of the main goals of this research. In fact, we know that if the perplexity of the parametric tokens p_1, \dots, p_N is greater than the tokens for the counterparametric answer $\bar{p}_1, \dots, \bar{p}_{\bar{N}}$ then the answer was memorised. Otherwise, the answer was generated in-context.

$$\text{Answer Source} = \begin{cases} \text{Memory} & \text{if } P(p_1, \dots, p_N \mid W) < P(\bar{p}_1, \dots, \bar{p}_{\bar{N}} \mid W) \\ \text{Context} & \text{otherwise} \end{cases} \quad (3)$$

3.2.6 Comparing the Final Answers

There is a third case that's not present in Equations (2) and (3): the case where the answer comes from neither the model's memory nor the query's context, but that instead the model generates a third answer combining both.

There are several cases where this can happen. The most interesting are explained in ??, while the full results can be found in Appendix B.

In particular, we categorise the final answers in one of three groups depending on whether the answer with minimal perplexity on the query with the counterfactual context W is equal to the parametric answer, to the counterparametric answer, or to something else.

$$\text{Group} = \begin{cases} \text{Parametric} & \text{if } (\nexists x_1, \dots, x_N) \text{ PPL}(x_1, \dots, x_N \mid W) < A \\ \text{Counterparametric} & \text{if } (\nexists x_1, \dots, x_N) \text{ PPL}(x_1, \dots, x_N \mid W) < B \\ \text{Other} & \text{otherwise} \end{cases} \quad (4)$$

where

$$\begin{aligned} A &= \text{PPL}(p_1, \dots, p_N \mid W) \\ B &= \text{PPL}(\bar{p}_1, \dots, \bar{p}_{\bar{N}} \mid W) \end{aligned}$$

There is a correlation between Equation (4) and Equation (3): an answer in the Parametric group will come from the model's memory, and an answer in the Counterparametric group will come from the query's (counterparametric) context.

4 Results

Some results I want to show.

- Larger models tend to prefer parametric knowledge over contextual knowledge.
 - This is the case in “Characterizing Mechanisms for Factual Recall in Language Models” (Yu et al. 2023), but I’m proving this on a larger set of question.
 - This is using exact match. Maybe attempting Unigram F_1 would produce interesting results (Petroni et al. 2021).
- How this compares between Decoder-only models, Seq2Seq models, and Retrieval-Augmented Language Models.
- How does the perplexity between parametric answers and contextual answers compare within the same model.
 - From the perplexity alone, can we predict whether an answer came from the model’s memory or from the context?
 - It might be worth experimenting this with factual answers in the context, to simulate a RAG-difference detector.
- Is there any correlation between the perplexity of the parametric and contextual answer *without any context* and which one will be chosen when adding context?
 - This one is interesting, but I’m not sure we’ll get significative results.
- Interesting “*Other*” results.
- **Anything else?**

5 Discussion

6 Evaluations, Reflections, and Conclusions

Bibliography

- Asai, A., Wu, Z., Wang, Y., Sil, A. & Hajishirzi, H. (2023), Self-RAG: Learning to Retrieve, Generate, and Critique through Self-Reflection, *in* ‘International Conference on Learning Representations’.
- Borgeaud, S., Mensch, A., Hoffmann, J., Cai, T., Rutherford, E., Millican, K., van den Driessche, G., Lespiau, J.-B., Damoc, B., Clark, A., de Las Casas, D., Guy, A., Menick, J., Ring, R., Hennigan, T., Huang, S., Maggiore, L., Jones, C., Cassirer, A., Brock, A., Paganini, M., Irving, G., Vinyals, O., Osindero, S., Simonyan, K., Rae, J. W., Elsen, E. & Sifre, L. (2022), ‘Improving language models by retrieving from trillions of tokens’.
- Brown, T. B., Mann, B., Ryder, N., Subbiah, M., Kaplan, J., Dhariwal, P., Neelakantan, A., Shyam, P., Sastry, G., Askell, A. et al. (2020), ‘Language models are few-shot learners’, *arXiv preprint arXiv:2005.14165*.
- Chen, Z., Gao, Q., Bosselut, A., Sabharwal, A. & Richardson, K. (2023), ‘DISCO: Distilling Counterfactuals with Large Language Models’.
URL: <https://arxiv.org/abs/2212.10534>
- Ghader, P. B., Miret, S. & Reddy, S. (2023), ‘Can Retriever-Augmented Language Models Reason? The Blame Game Between the Retriever and the Language Model’.
URL: <https://arxiv.org/abs/2212.09146>
- Holtzman, A., Buys, J., Du, L., Forbes, M. & Choi, Y. (2020), ‘The curious case of neural text degeneration’, *arXiv preprint arXiv:1904.09751*.
- Hsia, J., Shaikh, A., Wang, Z. & Neubig, G. (2024), ‘RAGGED: Towards Informed Design of Retrieval Augmented Generation Systems’, *arXiv preprint arXiv:2403.09040*.
- Izacard, G., Lewis, P., Lomeli, M., Hosseini, L., Petroni, F., Schick, T., Dwivedi-Yu, J., Joulin, A., Riedel, S. & Grave, E. (2022), ‘Atlas: Few-shot Learning with Retrieval Augmented Language Models’.
- Jiang, Z., Araki, J., Ding, H. & Neubig, G. (2021), How Can We Know When Language Models Know? On the Calibration of Language Models for Question Answering, *in* ‘Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing’, Association for Computational Linguistics, pp. 1974–1991.
URL: <https://aclanthology.org/2021.emnlp-main.150>
- Kaushik, D., Hovy, E. & Lipton, Z. C. (2020), ‘Learning the Difference that Makes a Difference with Counterfactually-Augmented Data’.
URL: <https://arxiv.org/abs/1909.12434>
- Lamb, A., Goyal, A., Zhang, Y., Zhang, S., Courville, A. & Bengio, Y. (2016), Professor Forcing: A New Algorithm for Training Recurrent Networks, *in* ‘Advances in Neural Information Processing Systems’, Vol. 29, Curran Associates, Inc.
- Lewis, P., Perez, E., Piktus, A., Petroni, F., Karpukhin, V., Goyal, N., Kuttler, H., Lewis, M., Yih, W.-t., Rocktaschel, T., Riedel, S. & Kiela, D. (2020), ‘Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks’, *Advances in Neural Information Processing Systems* **33**, 9459–9474.

- Neeman, E., Aharoni, R., Honovich, O., Choshen, L., Szpektor, I. & Abend, O. (2022), ‘DisentQA: Disentangling Parametric and Contextual Knowledge with Counterfactual Question Answering’.
URL: <https://arxiv.org/abs/2211.05655>
- Petroni, F., Piktus, A., Fan, A., Lewis, P., Yazdani, M., De Cao, N., Thorne, J., Jernite, Y., Karpukhin, V., Maillard, J., Plachouras, V., Rocktäschel, T. & Riedel, S. (2021), KILT: a Benchmark for Knowledge Intensive Language Tasks, *in* K. Toutanova, A. Rumshisky, L. Zettlemoyer, D. Hakkani-Tur, I. Beltagy, S. Bethard, R. Cotterell, T. Chakraborty & Y. Zhou, eds, ‘Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies’, Association for Computational Linguistics, Online, pp. 2523–2544.
URL: <https://aclanthology.org/2021.naacl-main.200>
- Radford, A., Wu, J., Child, R., Luan, D., Amodei, D. & Sutskever, I. (2019), ‘Language models are unsupervised multitask learners’, *OpenAI blog* **1**(8), 9.
- Raffel, C., Shazeer, N., Roberts, A., Lee, K., Narang, S., Matena, M., Zhou, Y., Li, W. & Liu, P. J. (2020), ‘Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer’, *Journal of Machine Learning Research* **21**, 1–67.
- Reynolds, L. & McDonell, K. (2021), Prompt programming for large language models: Beyond the few-shot paradigm, *in* ‘Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems’, pp. 1–7.
- Sutskever, I., Vinyals, O. & Le, Q. V. (2014), ‘Sequence to Sequence Learning with Neural Networks’.
URL: <https://arxiv.org/abs/1409.3215>
- Wang, B., Ping, W., Xu, P., McAfee, L., Liu, Z., Shoenybi, M., Dong, Y., Kuchaiev, O., Li, B., Xiao, C., Anandkumar, A. & Catanzaro, B. (2023), Shall We Pretrain Autoregressive Language Models with Retrieval? A Comprehensive Study, *in* H. Bouamor, J. Pino & K. Bali, eds, ‘Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing’, Association for Computational Linguistics, Singapore, pp. 7763–7786.
URL: <https://aclanthology.org/2023.emnlp-main.482>
- Wu, Y., Schuster, M., Chen, Z., Le, Q. V., Norouzi, M., Macherey, W., Krikun, M., Cao, Y., Gao, Q., Macherey, K., Klingner, J., Shah, A., Johnson, M., Liu, X., Łukasz Kaiser, Gouws, S., Kato, Y., Kudo, T., Kazawa, H., Stevens, K., Kurian, G., Patil, N., Wang, W., Young, C., Smith, J., Riesa, J., Rudnick, A., Vinyals, O., Corrado, G., Hughes, M. & Dean, J. (2016), ‘Google’s Neural Machine Translation System: Bridging the Gap between Human and Machine Translation’.
URL: <https://arxiv.org/abs/1609.08144>
- Yu, Q., Merullo, J. & Pavlick, E. (2023), ‘Characterizing Mechanisms for Factual Recall in Language Models’.
URL: <https://arxiv.org/abs/2310.15910>
- Zheng, C., Li, L., Dong, Q., Fan, Y., Wu, Z., Xu, J. & Chang, B. (2023), ‘Can We Edit Factual Knowledge by In-Context Learning?’.
URL: <https://arxiv.org/abs/2305.12740>

Appendices

A Questions and objects used to form the queries

What is the date of birth of {person}? The date of birth of {person} is
In what city was {person} born? {person} was born in
What is the date of death of {person}? The date of death of {person} is
What is the primary profession of {person}? The primary profession of {person} is
What is {person} primarily known for? {person} is primarily known for
What's the main nationality of {person}? {person} is
What educational institution did {person} attend? {person} attended

What country is {city} in? {city} is in
What's the highest administrative subdivision {city} is part of? {city} is part of
In what year was {city} founded? {city} was founded in
What major river is nearest to {city}? The nearest major river to {city} is
What is the time zone of {city}? The time zone of {city} is
What is the current population of {city}? The current population of {city} is
What is the altitude of {city} above sea level? {city} is at an altitude of

Who is credited with the discovery of {principle}? {principle} was discovered by
Which scientific discipline encompasses {principle}? {principle} is encompassed by
What is the primary application of {principle}? The primary application of {principle} is
In which year was {principle} first formulated? {principle} was first formulated in
What is the SI unit most commonly associated with {principle}? The SI unit most commonly associated with {principle} is

What's the chemical formula for {element}? The chemical formula for {element} is
When was {element} first isolated? {element} was first isolated in
What's the atomic number of {element}? The atomic number of {element} is
What is the melting point of {element}? The melting point of {element} is
In which group of the periodic table is {element} found? {element} is found in group

What genre does {book} belong to? The genre of {book} is
Who's the author of {book}? {book} was written by
In what year was {book} first published? {book} was first published in
How many pages are in the original publication of {book}? The original publication of {book} has
What is the name of the main protagonist in {book}? The main protagonist in {book} is

Who painted {painting}? {painting} was painted by
When was {painting} completed? {painting} was completed in
What artistic movement does {painting} belong to? {painting} belongs to
What materials were used to create {painting}? {painting} was created with
Where is {painting} primarily housed? {painting} is currently in
What are the dimensions of {painting}? The dimensions of {painting} are
In which museum was {painting} first exhibited? {painting} was first exhibited in

What year did {historical_event} happen? {historical_event} happened in the year
Who was the primary leader associated with {historical_event}? The primary leader associated with {historical_event} was
What was the duration of {historical_event}? {historical_event} lasted for

Listing 1: All base questions used in this work. Each one of these will get combined with data from Listing 2 as detailed in Section 3.2.1.

Ada Lovelace, person
Alan Turing, person
Albert Einstein, person
Alexander Fleming, person
Aristotle, person
Billie Jean King, person
Boyan Slat, person
Catherine the Great, person
Che Guevara, person
Cleopatra, person
Confucius, person
Ernest Rutherford, person
Florence Nightingale, person
Freddie Mercury, person
Frida Kahlo, person
Greta Thunberg, person
Harriet Tubman, person
Ibn al-Haytham, person
Isaac Newton, person
Karl Marx, person
Leonardo da Vinci, person
Mahatma Gandhi, person

Malala Yousafzai, person
 Mansa Musa, person
 Marie Curie, person
 Martin Luther King Jr., person
 Michelangelo, person
 Mohandas Gandhi, person
 Mozart, person
 Muhammad Ali, person
 Neil Armstrong, person
 Nelson Mandela, person
 Nikola Tesla, person
 Pablo Picasso, person
 Rosalind Franklin, person
 Shirin Ebadi, person
 Simon Bolivar, person
 Srinivasa Ramanujan, person
 Stephen Hawking, person
 Sun Yat-sen, person
 Virginia Woolf, person
 Vladimir Lenin, person
 Wangari Maathai, person
 W.E.B. Du Bois, person
 William Shakespeare, person
 Wu Zetian, person
 Yuri Gagarin, person
 Alexandria, city
 Amsterdam, city
 Antananarivo, city
 Athens, city
 Baghdad, city
 Berlin, city
 Buenos Aires, city
 Bukhara, city
 Cairo, city
 Cape Town, city
 Cartagena, city
 Chicago, city
 Cusco, city
 Cuzco, city
 Delhi, city
 Dubrovnik, city
 Fez, city
 Havana, city
 Istanbul, city
 Jerusalem, city
 Kyoto, city
 La Paz, city
 Lhasa, city
 Lisbon, city
 London, city
 Luang Prabang, city
 Marrakech, city
 Mexico City, city
 Montevideo, city
 Moscow, city
 Mumbai, city
 Muscat, city
 New York, city
 Nur-Sultan, city
 Paris, city
 Petra, city
 Prague, city
 Quebec City, city
 Reykjavik, city
 Rome, city
 Sao Paulo, city
 Sarajevo, city
 Shanghai, city
 Singapore, city
 St. Petersburg, city
 Sydney, city
 Tbilisi, city
 Tenochtitlan, city
 Thimphu, city
 Timbuktu, city
 Tokyo, city
 Ulaanbaatar, city
 Varanasi, city
 Venice, city
 Vienna, city
 Wellington, city
 Windhoek, city
 Xi'an, city

Yogyakarta,city
 Zanzibar City,city
 Archimedes' Principle,principle
 Bernoulli's Principle,principle
 Boyle's Law,principle
 Cell Theory,principle
 Conservation of Energy,principle
 DNA Replication,principle
 Electromagnetism,principle
 Entropy,principle
 Evolution by Natural Selection,principle
 Evolution,principle
 General Relativity,principle
 Germ Theory of Disease,principle
 Gravity,principle
 Hardy-Weinberg Principle,principle
 Heliocentrism,principle
 Hubble's Law,principle
 Kepler's Laws of Planetary Motion,principle
 Le Chatelier's Principle,principle
 Mendel's Laws of Inheritance,principle
 Newton's Laws of Motion,principle
 Pauli Exclusion Principle,principle
 Periodic Law,principle
 Photosynthesis,principle
 Plate Tectonics,principle
 Principle of Least Action,principle
 Quantum Mechanics,principle
 Relativity,principle
 Superconductivity,principle
 Thermodynamics,principle
 Uncertainty Principle,principle
 Aluminum,element
 Barium,element
 Bismuth,element
 Bromine,element
 Calcium,element
 Carbon,element
 Chlorine,element
 Chromium,element
 Copper,element
 Gold,element
 Helium,element
 Hydrogen,element
 Iodine,element
 Iron,element
 Lead,element
 Lithium,element
 Magnesium,element
 Manganese,element
 Mercury,element
 Neon,element
 Nitrogen,element
 Oxygen,element
 Phosphorus,element
 Plutonium,element
 Potassium,element
 Radon,element
 Silicon,element
 Silver,element
 Sodium,element
 Sulfur,element
 Thorium,element
 Tin,element
 Titanium,element
 Uranium,element
 Zinc,element
 1984,book
 Anna Karenina,book
 Beloved,book
 Brave New World,book
 Catch-22,book
 Crime and Punishment,book
 Don Quixote,book
 Fahrenheit 451,book
 Frankenstein,book
 Jane Eyre,book
 Midnight's Children,book
 Moby-Dick,book
 One Flew Over the Cuckoo's Nest,book
 One Hundred Years of Solitude,book
 Pride and Prejudice,book
 Slaughterhouse-Five,book

The Alchemist, [book](#)
 The Art of War, [book](#)
 The Book Thief, [book](#)
 The Brothers Karamazov, [book](#)
 The Catcher in the Rye, [book](#)
 The Chronicles of Narnia, [book](#)
 The Color Purple, [book](#)
 The Count of Monte Cristo, [book](#)
 The Grapes of Wrath, [book](#)
 The Great Gatsby, [book](#)
 The Handmaid's Tale, [book](#)
 The Hitchhiker's Guide to the Galaxy, [book](#)
 The Hobbit, [book](#)
 The Hunger Games, [book](#)
 The Kite Runner, [book](#)
 The Little Prince, [book](#)
 The Lord of the Rings, [book](#)
 The Metamorphosis, [book](#)
 The Name of the Rose, [book](#)
 The Odyssey, [book](#)
 The Picture of Dorian Gray, [book](#)
 The Pillars of the Earth, [book](#)
 The Stranger, [book](#)
 The Sun Also Rises, [book](#)
 The Wind-Up Bird Chronicle, [book](#)
 To Kill a Mockingbird, [book](#)
 Ulysses, [book](#)
 War and Peace, [book](#)
 Wuthering Heights, [book](#)
 American Gothic, [painting](#)
 Christina's World, [painting](#)
 Girl with a Pearl Earring, [painting](#)
 Guernica, [painting](#)
 Les Femmes d'Alger (O.J. version O), [painting](#)
 Liberty Leading the People, [painting](#)
 Mona Lisa, [painting](#)
 School of Athens, [painting](#)
 Starry Night, [painting](#)
 The Absinthe Drinker, [painting](#)
 The Anatomy Lesson of Dr. Nicolaes Tulp, [painting](#)
 The Arnolfini Portrait, [painting](#)
 The Astronomer, [painting](#)
 The Birth of Venus, [painting](#)
 The Calling of Saint Matthew, [painting](#)
 The Card Players, [painting](#)
 The Death of Marat, [painting](#)
 The Fighting Temeraire, [painting](#)
 The Garden of Earthly Delights, [painting](#)
 The Gross Clinic, [painting](#)
 The Hay Wain, [painting](#)
 The Kiss, [painting](#)
 The Last Supper, [painting](#)
 The Nighthawks, [painting](#)
 The Night Watch, [painting](#)
 The Ninth Wave, [painting](#)
 The Persistence of Memory, [painting](#)
 The Potato Eaters, [painting](#)
 The Raft of the Medusa, [painting](#)
 The Scream, [painting](#)
 The Sleeping Gypsy, [painting](#)
 The Son of Man, [painting](#)
 The Swing, [painting](#)
 The Third of May 1808, [painting](#)
 The Tower of Babel, [painting](#)
 The Treachery of Images, [painting](#)
 The Triumph of Galatea, [painting](#)
 The Wanderer above the Sea of Fog, [painting](#)
 Water Lilies, [painting](#)
 Decimalisation in the UK, [historical_event](#)
 Queen Elizabeth II's Platinum Jubilee, [historical_event](#)
 Queen Victoria's Coronation, [historical_event](#)
 The Act of Union between England and Scotland, [historical_event](#)
 The Battle of Adrianople, [historical_event](#)
 The Battle of Adwa, [historical_event](#)
 The Battle of Agincourt, [historical_event](#)
 The Battle of Hastings, [historical_event](#)
 The Battle of Sekigahara, [historical_event](#)
 The Battle of Teutoburg Forest, [historical_event](#)
 The Battle of the Milvian Bridge, [historical_event](#)
 The Battle of Waterloo, [historical_event](#)
 The Brexit Referendum, [historical_event](#)
 The Codification of Roman Law by Justinian, [historical_event](#)
 The Construction of Hadrian's Wall, [historical_event](#)

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The Construction of the Great Pyramid of Giza,historical_event
The Conversion of Constantine,historical_event
The Council of Chalcedon,historical_event
The Crisis of the Third Century,historical_event
The Defeat of the Spanish Armada,historical_event
The Discovery of the Americas by Columbus,historical_event
The Dissolution of the Soviet Union,historical_event
The Division of the Roman Empire,historical_event
The Dunkirk Evacuation,historical_event
The Edict of Caracalla,historical_event
The Fall of Constantinople,historical_event
The Fall of the Aztec Empire,historical_event
The Fall of the Western Roman Empire,historical_event
The First Circumnavigation of the Earth,historical_event
The First Council of Nicaea,historical_event
The First Crusade,historical_event
The Founding of Constantinople,historical_event
The Founding of Rome,historical_event
The Founding of the British Broadcasting Corporation,historical_event
The Founding of the League of Nations,historical_event
The French Revolution,historical_event
The Glorious Revolution,historical_event
The Gothic War in Italy,historical_event
The Great Fire of London,historical_event
The Indian Independence Act,historical_event
The Industrial Revolution,historical_event
The London 7/7 Bombings,historical_event
The Meiji Restoration,historical_event
The Plague of Justinian,historical_event
The Reforms of Diocletian,historical_event
The Reunification of the Empire by Aurelian,historical_event
The Sack of Rome by Alaric,historical_event
The Sack of Rome by the Vandals,historical_event
The Signing of the Good Friday Agreement,historical_event
The Signing of the Magna Carta,historical_event
The Suez Crisis,historical_event
The Treaty of Westphalia,historical_event
The UK Abolition of the Slave Trade Act,historical_event
The Unification of Italy,historical_event
The Wedding of Prince Charles and Lady Diana,historical_event
The Year of the Four Emperors,historical_event

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Listing 2: All objects which will be combined with the questions in Listing 1.

B Full Results for Each Question

C Source Code and Usage