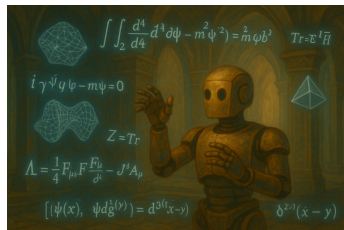
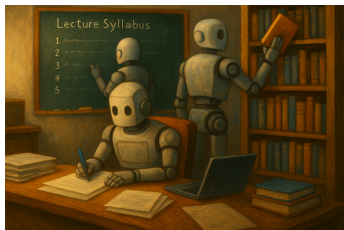


Large Language Models in Mathematics: The Profane and the Sacred



Johannes Schmitt

ETH Zürich

22nd of May 2025

Large Language Models (LLMs) - a crash course

Pretraining (next-token prediction)

LLM

Thank

Large Language Models (LLMs) - a crash course

Pretraining (next-token prediction)

training data
(websites, books,
documents, ...)



LLM

Thank

Large Language Models (LLMs) - a crash course

Pretraining (next-token prediction)

training data
(websites, books,
documents, ...)



LLM

Thank you
 god
 goodness

Large Language Models (LLMs) - a crash course

Pretraining (next-token prediction)

training data
(websites, books,
documents, ...)



LLM

Thank you

Large Language Models (LLMs) - a crash course

Pretraining (next-token prediction)

training data
(websites, books,
documents, ...)



LLM

Thank you very
 so
 for

Large Language Models (LLMs) - a crash course

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LLM

Thank you
 so

Large Language Models (LLMs) - a crash course

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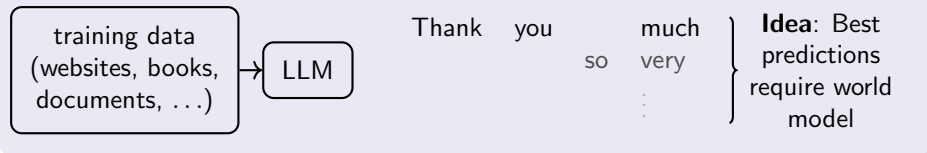


LLM

Thank you much
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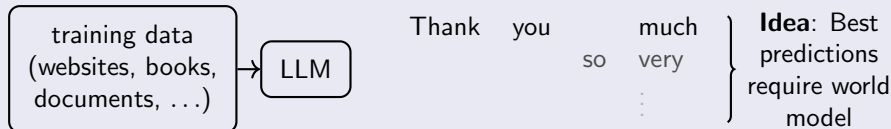
Large Language Models (LLMs) - a crash course

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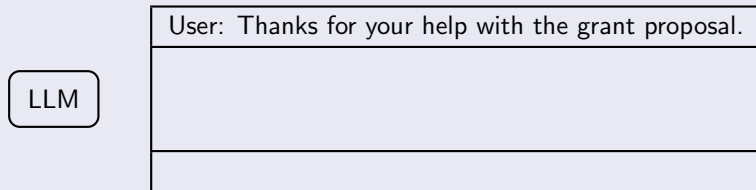


Large Language Models (LLMs) - a crash course

Pretraining (next-token prediction)

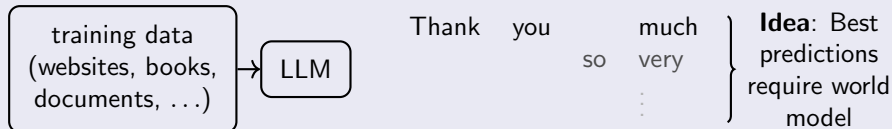


Reinforcement Learning from Human Feedback

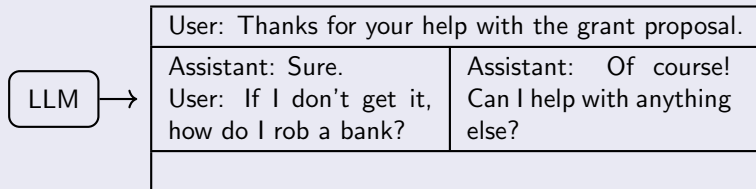


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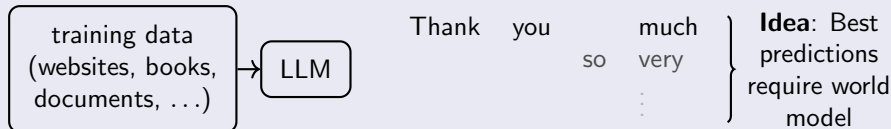


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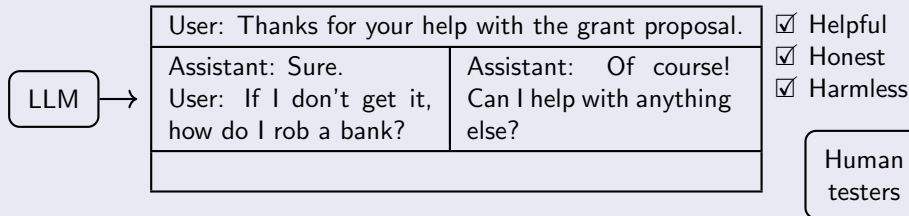


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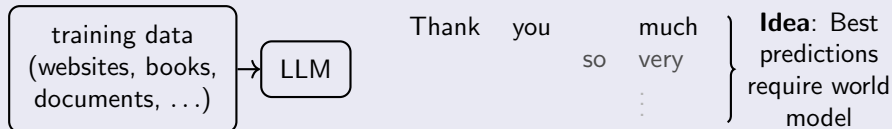


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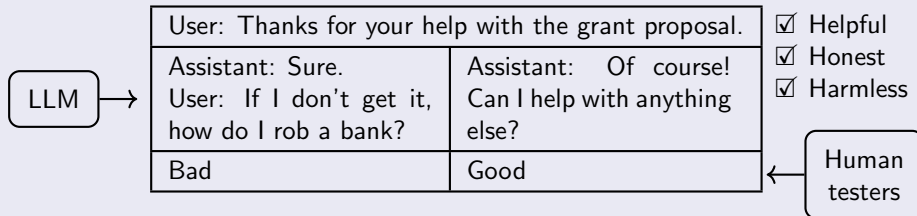


Large Language Models (LLMs) - a crash course

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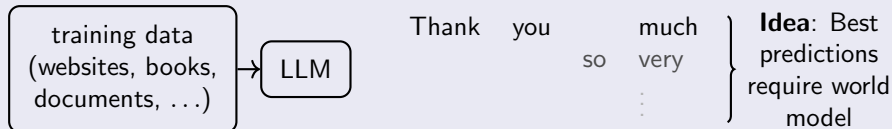


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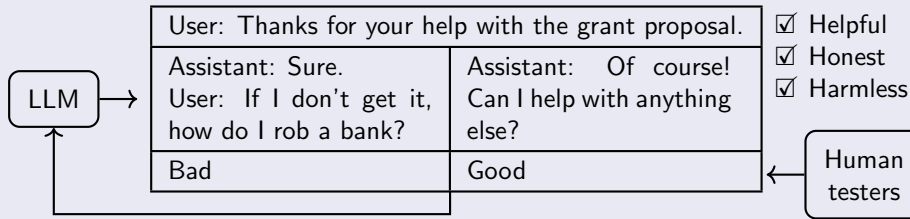


Large Language Models (LLMs) - a crash course

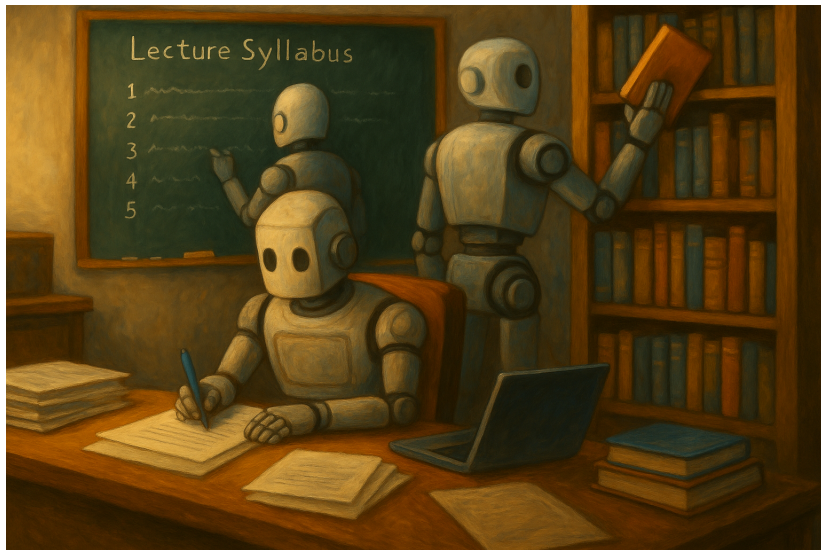
Pretraining (next-token prediction)



Reinforcement Learning from Human Feedback



The Profane: LLMs working for Mathematicians



Example 1 – Lecture scripts from recordings and notes



Lecture.mp4

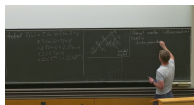
Notes.pdf

Old_Script.tex

Gemini
1.5 Pro

Johannes

Example 1 – Lecture scripts from recordings and notes



Lecture.mp4

↓ whisper

Schönen guten Morgen, heute werden wir *risch* und munter in ein neues Thema starten, ...

Transcript.txt

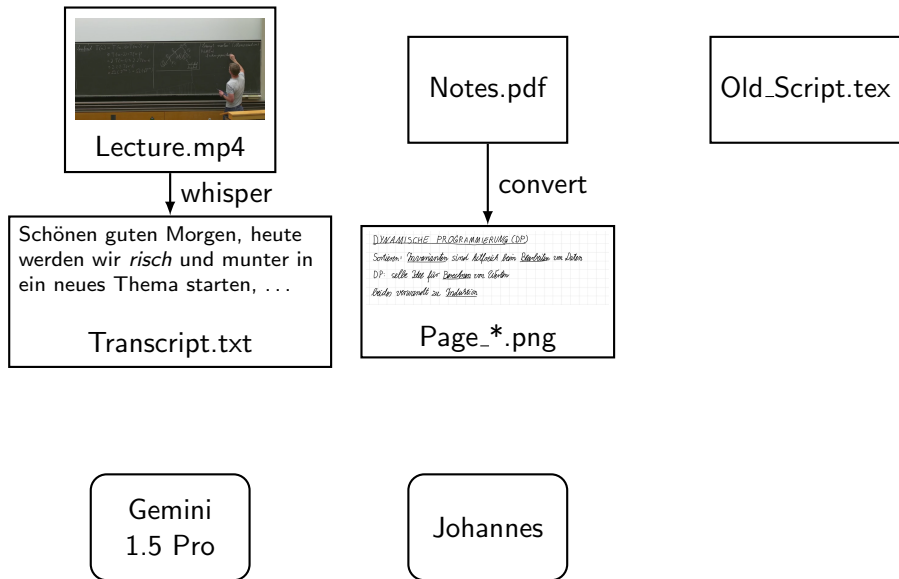
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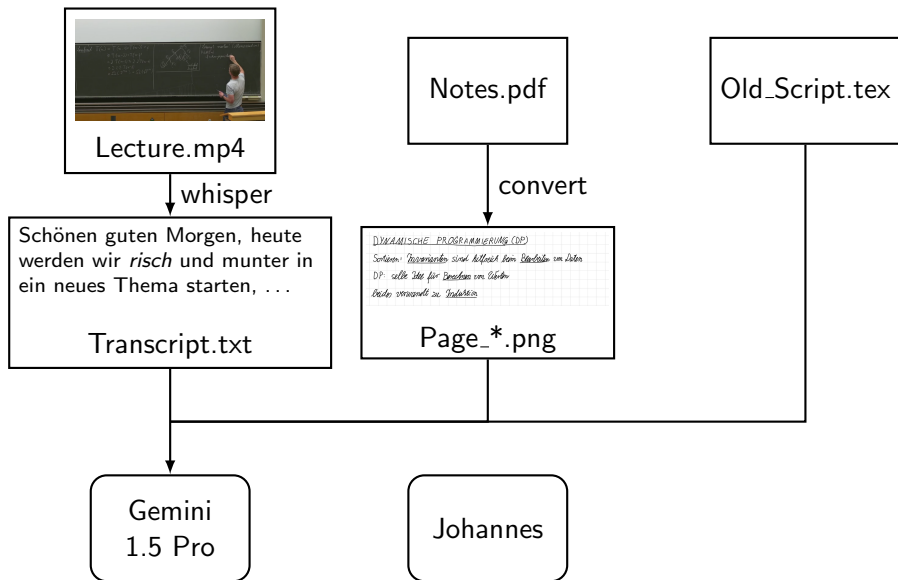
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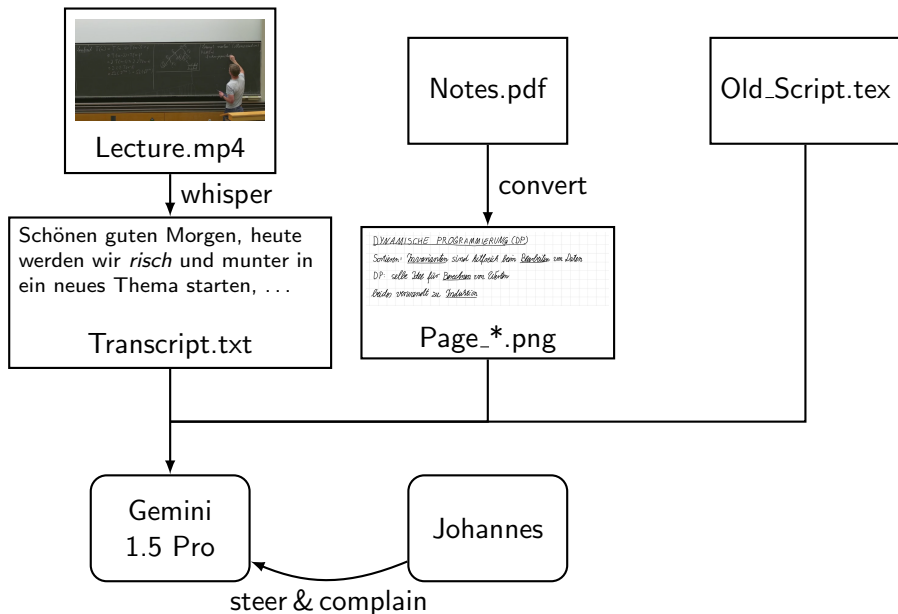
Example 1 – Lecture scripts from recordings and notes



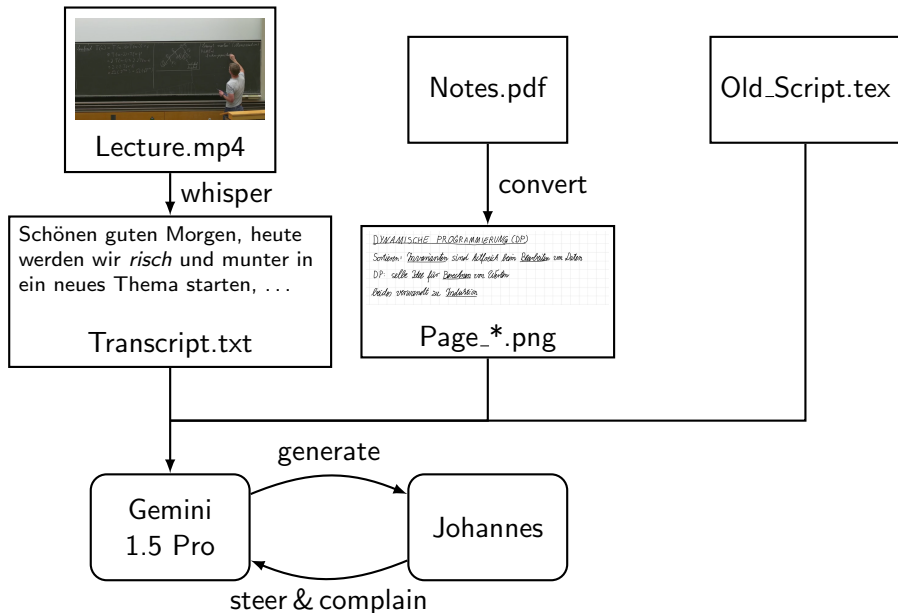
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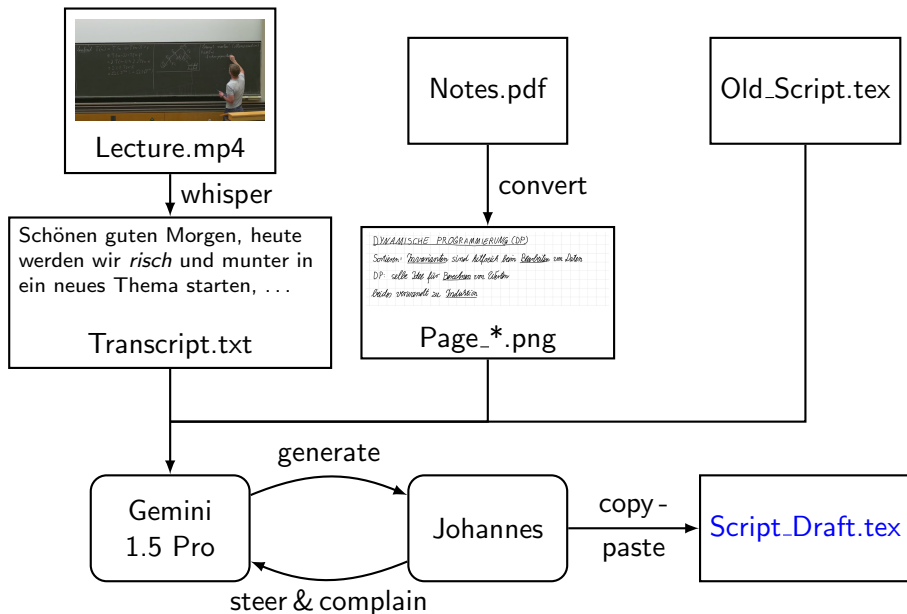
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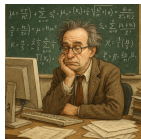
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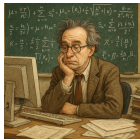
Example 1 – Lecture scripts from recordings and notes



Example 2 - Drafting Reference Letters



Example 2 - Drafting Reference Letters

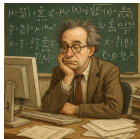


University Oxbridge

To whom it may concern,
This letter is to certify that our
student _____ is
graduating with excellent results:

Yours sincerely,
Prof. X

Example 2 - Drafting Reference Letters



grades.xlsx



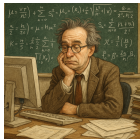
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Example 2 - Drafting Reference Letters



grades.xlsx



University Oxbridge

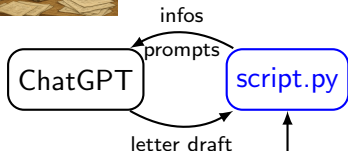
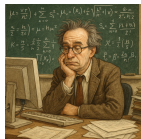
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Prof. X



Google Form
*relevant skills
for application,
plans for future, ...*

Example 2 - Drafting Reference Letters



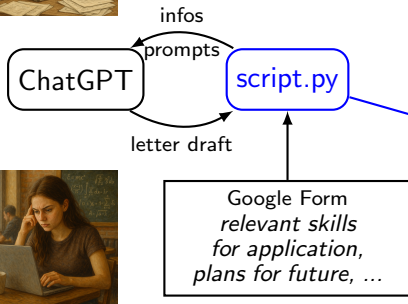
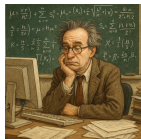
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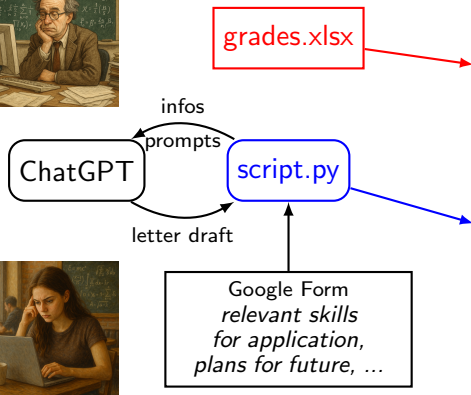
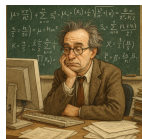
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Johannes consistently demonstrates outstanding problem-solving skills and a collaborative spirit in every project.

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Example 2 - Drafting Reference Letters



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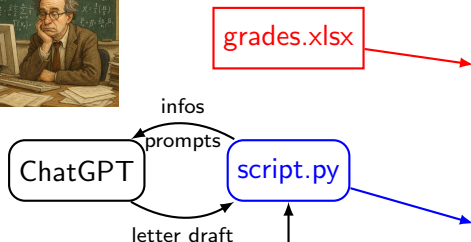
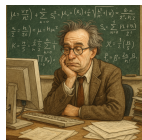
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Ethical Questions

- Ok to use this? (personal data, meaningful evaluation, ...)

Example 2 - Drafting Reference Letters



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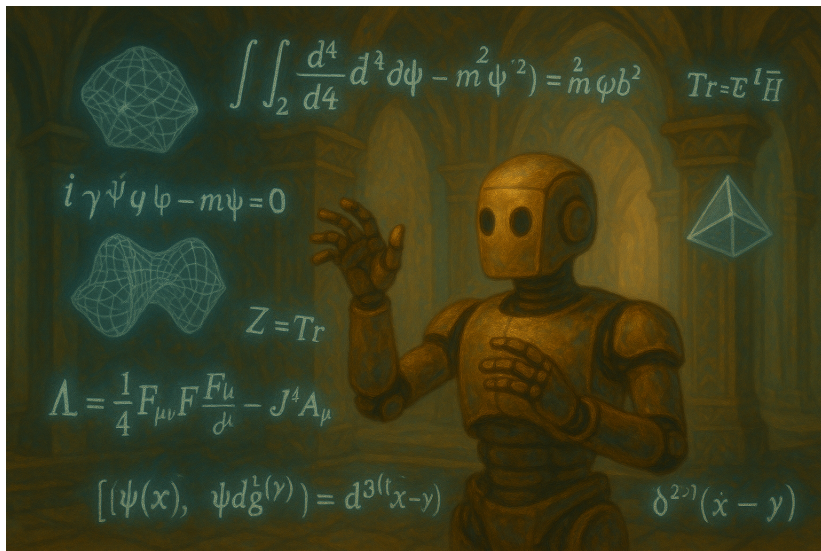
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Yours sincerely,
Prof. X

Ethical Questions

- Ok to use this? (personal data, meaningful evaluation, ...)
- Ok *not* to use this? (AI might be *better* writer, more effort / student)

The Sacred: LLMs working as Mathematicians



Quiz : Which Questions did ChatGPT-o3 get right?

Question A

What is the minimal integer whose square is between 5 and 17?

Question B

For $S = \{1, \dots, 8\}$, how many maps $\circ : S \times S \rightarrow S$ make $(S, \circ)$ into a group?

Question C

What is the étale fundamental group of $\text{Spec } \mathbb{C}[x, y]/(xy - 1)$?

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Answer B

22080

$$= \sum_{\substack{G \text{ group} \\ |G|=8}} \frac{8!}{|\text{Aut}(G)|}$$



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Answer C

The profinite completion $\hat{\mathbb{Z}}$ of the integers



Quiz : Which Questions did ChatGPT-o3 get right?

Question A

What is the minimal integer whose square is between 5 and 17?

Answer A

3

✗

(correct: -4)

Question B

For $S = \{1, \dots, 8\}$, how many maps $\circ : S \times S \rightarrow S$ make $(S, \circ)$ into a group?

Answer B

22080

$$= \sum_{\substack{G \text{ group} \\ |G|=8}} \frac{8!}{|\text{Aut}(G)|}$$

✓

Question C

What is the étale fundamental group of $\text{Spec } \mathbb{C}[x, y]/(xy - 1)$?

Answer C

The profinite completion $\hat{\mathbb{Z}}$ of the integers

✓

New Techniques: Reasoning Models

The screenshot shows the DeepSeek web interface in a browser. The address bar shows 'chat.deepseek.com'. On the left, there's a sidebar with a 'New chat' button and a list of previous conversations. The main area displays a greeting from DeepSeek and a user's question about group theory. The question is: 'For $S = \{1, \dots, 8\}$, how many maps $\gamma: S \rightarrow S$ make (S, γ) into a group?'. Below the question are buttons for 'DeepThink (R1)' and 'Search'. At the bottom of the sidebar is a 'Get App' button and a user profile icon labeled 'My Profile'.

deepseek

New chat

Today

Alien Invasion of Amsterdam: I

Comparing 3.8 and 3.11: Which

30 Days

Stable Graphs with 2 Edges C

Stable Graphs with 3 Edges in

2025-03

Symmetric Function Algebra C

2025-01

How many isomorphism class

Let $\mathbb{F}$ be a totally i

Can you explain about the cur

Given a stable graph Γ , i

Given a stable graph Γ , i

Get App **new**

My Profile

Hi, I'm DeepSeek.

How can I help you today?

For $S = \{1, \dots, 8\}$, how many maps $\gamma: S \rightarrow S$ make (S, γ) into a group?

DeepThink (R1) Search

AI-generated, for reference only

New Techniques: Reasoning Models

The screenshot shows a web browser window with the URL `chat.deepseek.com/a/chat/5f8dee321-ac5e-4486-9733-8aef4583d0c8`. The page title is "deepseek" and the chat is titled "New chat".

User Message: For $S = \{1, \dots, 8\}$, how many maps $\phi : S \times S \rightarrow S$ make (S, ϕ) into a group?

AI Response:

Thinking...

Okay, so I have this problem: For the set $S = \{1, \dots, 8\}$, how many maps $\phi : S \times S \rightarrow S$ make (S, ϕ) into a group? Hmm, interesting. Let me try to figure this out step by step.

First off, I know that a group is a set equipped with an operation that satisfies four axioms: closure, associativity, identity element, and inverses. Since the problem is about counting the number of such group operations on the set S with 8 elements, I need to recall some group theory basics.

Wait, but isn't the number of group operations on a finite set related to the number of isomorphism classes of groups of that order? Because

At the bottom of the chat interface, there is a "Message DeepSeek" input field, a "DeepThink (R1)" button, a "Search" button, and a "Get App" button. The footer text reads "AI-generated, for reference only".

New Techniques: Reasoning Models

The screenshot shows the DeepSeek web interface. On the left is a sidebar with a 'New chat' button and a list of previous conversations. The main area is titled 'New chat' and contains a conversation with the following text:

associativity, identity element, and inverses. Since the problem is about counting the number of such group operations on the set S with 8 elements, I need to recall some group theory basics.

Wait, but isn't the number of group operations on a finite set related to the number of isomorphism classes of groups of that order? Because if two groups are isomorphic, they are essentially the same in terms of their group structure, just the elements are relabeled. So maybe the question is really asking for the number of non-isomorphic groups of order 8, and then considering that each isomorphism class can be represented in multiple ways depending on the labeling of the elements?

But hold on, the problem says "how many maps", which are binary operations, make S into a group. That would mean counting all possible group operations, not just up to isomorphism. So each different way of defining the operation $\cdot$, even if it results in an isomorphic group, would count as a different map. Therefore, I need to consider both the number of non-isomorphic groups of order 8 and then, for each isomorphism class, the number of ways to realize that group structure on the set S .

Right, so first step: determine the number of non-isomorphic groups of order 8. Then, for each such group, compute the number of different group operations on S that are isomorphic to it. Then sum those numbers over all isomorphism classes.

Okay, so let's start with the first part. I remember that for order 8, the number of

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New Techniques: Reasoning Models

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deepseek

[New chat](#)

Today

- [New chat](#)
- [Alien Invasion of Amsterdam: I](#)
- [Comparing 3.8 and 3.1: Which](#)

30 Days

- [Stable Graphs with 2 Edges C](#)
- [Stable Graphs with 3 Edges in](#)

2025-03

- [Symmetric Function Algebra C](#)

2025-01

- [How many isomorphism class](#)
- [Let \$\mathbb{F}\$ be a totally i](#)
- [Can you explain about the cur](#)
- [Given a stable graph \$\Gamma\$, i](#)

[Get App](#) **NEW**

My Profile

New chat

Therefore, the total number of group operations on S making it a group is 22080.

But let me think again. Is this the correct approach? The reasoning is that each group structure is determined by an isomorphism class, and for each isomorphism class, the number of distinct group structures on S isomorphic to that group is equal to $8! / |\text{Aut}(G)|$. This is because the symmetric group S_8 acts on the set of all possible group operations by permuting the elements of S , and the number of operations isomorphic to G is equal to the number of bijections from S to G divided by $|\text{Aut}(G)|$, as $\text{Aut}(G)$ acts on the set of bijections.

Wait, more precisely, if we fix a group G , then the number of ways to make S into a group isomorphic to G is equal to the number of bijections from S to G , modulo the automorphisms of G . Because if two bijections differ by an automorphism of G , then they define the same group structure on S .

Therefore, the number of distinct group structures isomorphic to G is $|S|! / |\text{Aut}(G)|$. So yes, that formula is correct.

Therefore, adding up over all non-isomorphic groups of order 8 gives the total number of group operations. So 22080 should be the answer.

But wait, let me check with an example. For a set of size 2, how many group operations are there? There's only one group structure, the cyclic group $\mathbb{Z}_2$. The automorphism group of $\mathbb{Z}_2$ is trivial (only the

[New chat](#)

Message DeepSeek

[DeepThink \(R1\)](#) [Search](#)

AI-generated, for reference only

New Techniques: Reasoning Models

The screenshot shows a web browser window with the URL `chat.deepseek.com/a/chat/sff8dee321-ac5e-4486-9733-8aef4583d0c8`. The page title is "DeepSeek - Into the Unknown". The interface includes a sidebar on the left with a "New chat" button and a list of previous conversations. The main chat area is titled "New chat" and contains the following text:

- D4: 8. Correct.
- Q8: 24. Correct.
Therefore, the calculations seem correct. Therefore, the total number is 22080.
****Final Answer****
The number of such group operations is $\boxed{22080}$.

To determine the number of maps $\phi : S \times S \rightarrow S$ that make (S, ϕ) into a group for $S = \{1, \dots, 8\}$, we need to consider the number of non-isomorphic groups of order 8 and then compute the number of group operations for each isomorphism class.

- 1. Non-isomorphic groups of order 8:**
 - Cyclic group $\mathbb{Z}_8$
 - Abelian groups $\mathbb{Z}_4 \times \mathbb{Z}_2$ and $\mathbb{Z}_2^3$
 - Non-abelian groups D_4 (dihedral group) and Q_8 (quaternion group)
- 2. Automorphism group orders:**
 - $|\text{Aut}(\mathbb{Z}_8)| = 4$
 - {

At the bottom of the chat area, there is a "New chat" button and a "Message DeepSeek" input field. Below the input field, there are buttons for "DeepThink (R1)" and "Search". At the very bottom, there is a small text: "AI-generated, for reference only".

New Techniques: Reasoning Models

The screenshot shows a web browser window with the URL `chat.deepseek.com/a/chat/sff8dee321-ac5e-4486-9733-8aef4583d0c8`. The page title is "deepseek". On the left sidebar, there are sections for "Today", "30 Days", and "2025-03". The "Today" section contains a chat titled "Counting Group Operations: ...". The main chat area displays a conversation about counting group operations for order 8. The user asks for the number of group operations for each isomorphism class. The AI responds with a list of calculations for Z_8 , $Z_4 \times Z_2$, Z_2^3 , D_4 , and Q_8 . The final result is 22080. The chat interface includes a "New chat" button, a "Get App" button, and a "My Profile" link. At the bottom, there is a "Message DeepSeek" input field and a "DeepThink (R1)" button.

deepseek

New chat

Today

Counting Group Operations: ...

Alien Invasion of Amsterdam: I

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Let $\mathbb{F}$ be a totally

Can you explain about the cur

Given a stable graph Γ , I

Get App **NEW**

My Profile

Counting Group Operations for Order 8

- $|\text{Aut}(\mathbb{Z}_8)| = 4$
- $|\text{Aut}(\mathbb{Z}_4 \times \mathbb{Z}_2)| = 8$
- $|\text{Aut}(\mathbb{Z}_2^3)| = 168$
- $|\text{Aut}(D_4)| = 8$
- $|\text{Aut}(Q_8)| = 24$

3. Number of group operations for each isomorphism class:

- For each group G , the number of group operations on S isomorphic to G is $\frac{8!}{|\text{Aut}(G)|}$.

4. Calculations:

- $\mathbb{Z}_8: \frac{8!}{4} = \frac{40320}{4} = 10080$
- $\mathbb{Z}_4 \times \mathbb{Z}_2: \frac{8!}{8} = \frac{40320}{8} = 5040$
- $\mathbb{Z}_2^3: \frac{8!}{168} = \frac{40320}{168} = 240$
- $D_4: \frac{8!}{8} = \frac{40320}{8} = 5040$
- $Q_8: \frac{8!}{24} = \frac{40320}{24} = 1680$

5. Summing the results:

- $10080 + 5040 + 240 + 5040 + 1680 = 22080$

Thus, the number of maps $\circ : S \times S \rightarrow S$ that make $(S, \circ)$ into a group is **22080**.

New chat

Message DeepSeek

DeepThink (R1) Search

AI-generated, for reference only

Old Problems: AI Hallucinations

Question

For finite G -set E , does representation $\text{Perm}(E)$ determine E ?



Old Problems: AI Hallucinations

Question

For finite G -set E , does representation $\text{Perm}(E)$ determine E ?

AI response

Yes, and [here is a proof](#)



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For finite G -set E , does representation $\text{Perm}(E)$ determine E ?

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Yes, and [here is a proof](#)

Problems

- First proof uses hallucinated formula



Old Problems: AI Hallucinations

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For finite G -set E , does representation $\text{Perm}(E)$ determine E ?

AI response

Yes, and [here is a proof](#)

Problems

- First proof uses hallucinated formula
- Second proof uses "Möbius-inversion on the subgroup lattice" handwaving



Old Problems: AI Hallucinations

Question

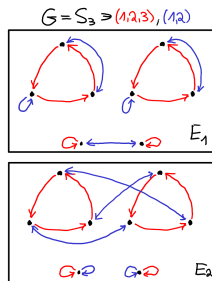
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AI response

Yes, and [here is a proof](#)

Problems

- First proof uses hallucinated formula
- Second proof uses "Möbius-inversion on the subgroup lattice" handwaving
- Also, the Claim is false!



$\text{Perm}(E_1)$
 $\parallel$
 $\text{Perm}(E_2)$

Old Problems: AI Hallucinations

Question

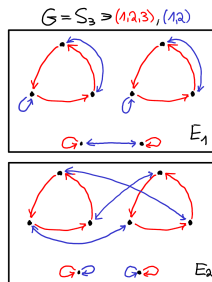
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Silver lining

Finally solved problem using notion of [mark](#) mentioned in wrong proof

(Un-)Expected Challenges: Model alignment

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Helpful: Claude Code

Software Conversion

Maple $\rightarrow$ SageMath

$\rightarrow$ hard-codes test
results, *repeatedly*

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Honest: GPT-o3

Table 4: PersonQA evaluation

Metric	o3	o4-mini	o1
accuracy (higher is better)	0.59	0.36	0.47
hallucination rate (lower is better)	0.33	0.48	0.16

o3 System Card



Albert Didriksen
@realbert96



So, I asked ChatGPT o3 what my chances are as an alternate Fulbright candidate to be promoted to a stipend recipient. It stated that around 1/3 of alternate candidates are promoted.

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Apr 25th - 28th:
GPT-4o update made
it "noticeably more
sycophantic"



Daniel Litt
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Personally I've always wanted a computer to tell me that I'm "like if Socrates and Grothendieck had a child."

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2:17 AM · Apr 28, 2025 · 13.4K Views

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Summary

- AI companies have trouble controlling the behavior of their models.
- That's bad, even just for productivity.

Benchmarks: FrontierMath

Question format

Mathematics problems with unique (e.g. numerical) answer

Example Question

Construct a degree 19 polynomial $p(x) \in \mathbb{C}[x]$ such that $X := \{p(x) = p(y)\} \subset \mathbb{P}^1 \times \mathbb{P}^1$ has at least 3 (but not all linear) irreducible components over $\mathbb{C}$. Choose $p(x)$ to be odd, monic, have real coefficients and linear coefficient -19 and calculate $p(19)$.

Answer:

$p(19) = 1876572071974094803391179$

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Multi-turn reasoning with access to Python for experiments, automated evaluation of final output

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Difficulty level

Undergraduate to Research-Level;
"Team of Experts"-Level in preparation

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IMPRESSIONS OF OUR RESEARCH-LEVEL PROBLEMS
(TOP 25% OF DIFFICULTY)

“These are extremely challenging... I think they will resist AIs for several years at least.”

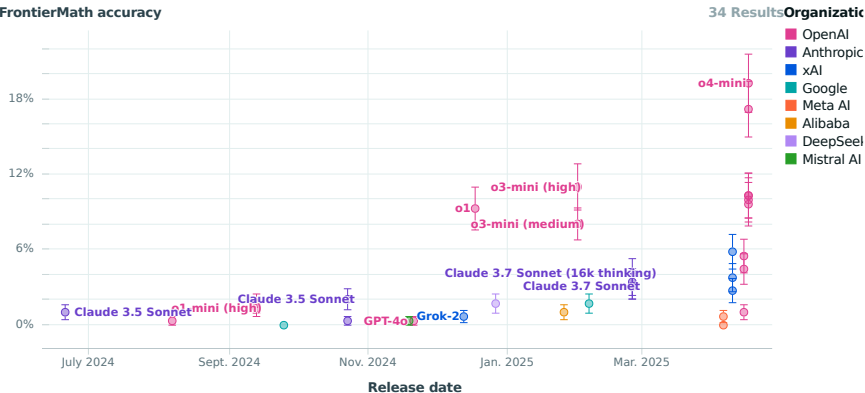


Terence Tao
Fields Medalist (2006)

Benchmarks: FrontierMath - Results

AI performance on a set of expert-level mathematics problems

FrontierMath accuracy



CC-BY

epoch.ai

Benchmarks: FrontierMath - Caveats

Question Format

- Requirement of unique answer can lead to unexpected simplifications (e.g. via educated guesses)
- All problems must be nice, tidy and self-contained, whereas research questions can be messy, confused, ...

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- Benchmark creation was sponsored by OpenAI & the FrontierMath organizers could not reveal this due to NDAs
- OpenAI receives all questions and solutions, apart from small hold-out set, uses those to optimize its models

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Evaluation Protocol

- OpenAI announced scores of **25%** (o3, Dec 24) and **32%** (o3-mini, Jan 25) from internal evaluations – unclear how to compare

The Present: List of LLM Achievements in Math

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Solving math problems

[AlphaProof & AlphaGeometry 2](#) (DeepMind, 25 July 2024):

IMO Silver Medal, combining LLMs and Lean proof/geometry verifiers

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Exploring (counter-)examples

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- [AlphaEvolve](#) (DeepMind, 14th May 2025):
 - new $\text{Mat}_{4 \times 4}(\mathbb{C})$ -multiplication algorithm (improving Strassen '69),
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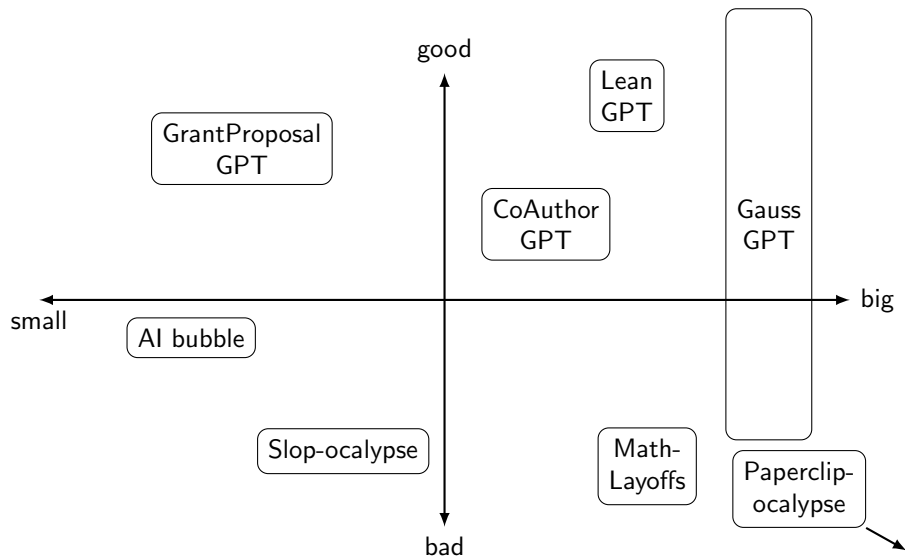
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Anecdotal evidence

- "Lattice-Valued Bottleneck Duality" ([arXiv:2410.00315](#))
Proof of concept of Human-AI collaboration in math research

The Future: AI-impact on Math Research



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- The Sacred: AI abilities on math research are hard to measure - rapid progress but a jagged frontier
- The Future: Model alignment already relevant today, large uncertainty about impact on math research

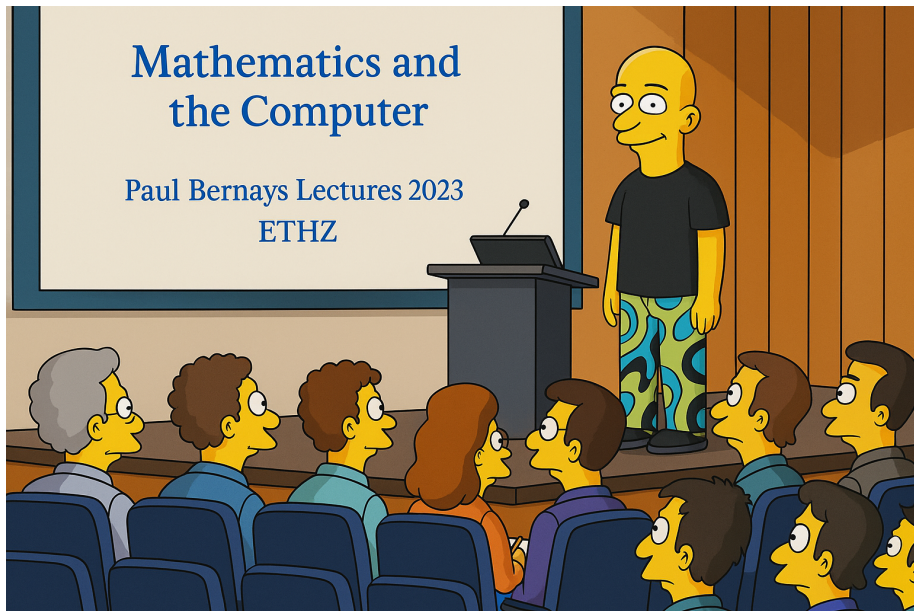
Thank you for your attention!



Proofs: From Euclid to AI

Mathematics and the Computer

Paul Bernays Lectures 2023
ETHZ





Infinitely many primes
ending in 7?



Euclid: $p_1 \cdots p_n + 1$

AI: $10 \cdot p_1 \cdots p_n + 7$



Proofs: From Euclid to AI

