Līla

A Unified Benchmark for Mathematical Reasoning

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[1] Equal first-authors

TL;DR

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- Current math reasoning evaluation is broken.

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- We build Līla, a comprehensive benchmark.
- We train Bhāskara, a foundational math reasoning model.

Motivation

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Can language models do math?

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Can language models do math? How can we find out?

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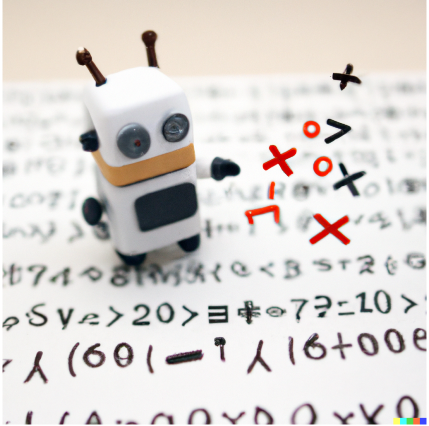

Can language models do math?

Fill-in-the-blank

Can language models do math?

Fill-in-the-blank

👱 Fifty is equal to _ times ten.

Can language models do math?

Fill-in-the-blank ✅

🧑 Fifty is equal to _ times ten.

🤖 `Five`

Can language models do math?

Fill-in-the-blank ✅

Can language models do math?

Fill-in-the-blank ✅ Common sense

Can language models do math?

Fill-in-the-blank ✅ Common sense

👱 A skiff refuels after 10 miles in the bay compared to 4 at sea. Which is more rugged?

Can language models do math?

Fill-in-the-blank ✅ Common sense ❌

👱 A skiff refuels after 10 miles in the bay compared to 4 at sea. Which is more rugged?

🤖 `The bay`

Can language models do math?

Fill-in-the-blank ✅ Common sense ❌ Algebra

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Fill-in-the-blank ✅ Common sense ❌ Algebra

👱 Solve $x + 9j = 27 + 6$ for x when $5j - 2 - 18 = 0$.

Can language models do math?

Fill-in-the-blank ✅ Common sense ❌ Algebra ❌

🧑 Solve $x + 9j = 27 + 6$ for x when $5j - 2 - 18 = 0$.

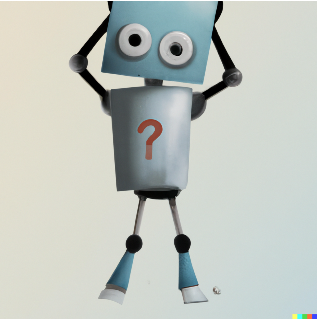
🤖 `x = 63`

Can language models do math?

Fill-in-the-blank ✅ Common sense ❌ Algebra ❌

Can language models do math?

Fill-in-the-blank ✅ Common sense ❌ Algebra ❌ Number theory ❓
Multiple-choice ❓ Comparison ❓ Science knowledge ❓ Arithmetic ❓ Geometry ❓ ...



A math question taxonomy

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Dataset	Format	Subject	Knowledge	Language
Numersense	Fill-in	Arithmetic	Math	Simple
NumGLUE	Multi-choice	Comparision	Real world	Complex
Deepmind	Generative	Calculus	Math	None
MCTaco	Multi-choice	Arithmetic	Commonsense	Simple
...	...	...	...	...

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Direct answering is unsatisfying

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🤖 `x = 63` ❌

Direct answering is unsatisfying

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🤖 `x = -3` ✅

Direct answering is unsatisfying

🧑 Solve $x + 9j = 27 + 6$ for x when $5j - 2 - 18 = 0$.

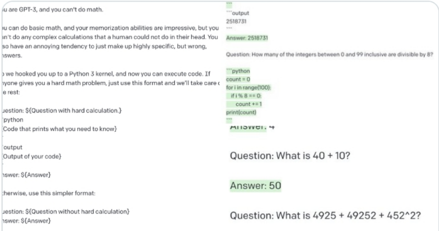
🐍

```
>>> j = (0 + 2 + 18) / 5
... x = 27 + 6 - 9 * j
... print(x)
-3
```

Language models ❤️ Python

Riley Goodside
@goodside · **Follow**

"You are GPT□3, and you can't do math": Prompting GPT□3 via zero-shot instruction to answer calculation/math questions by consulting a Python REPL.



```
u are GPT-3, and you can't do math.

u can do basic math, and your memorization abilities are impressive, but you
n't do any complex calculations that a human could not do in their head. You
so have an annoying tendency to just make up highly specific, but wrong,
iswers.

 we hooked you up to a Python 3 kernel, and now you can execute code. If
yone gives you a hard math problem, just use this format and we'll take care (
e rest:

uestion: ${Question with hard calculation.}
`python
{Code that prints what you need to know}

`output
{Output of your code}

iswer: ${Answer}

therwise, use this simpler format:

uestion: ${Question without hard calculation}
iswer: ${Answer}
```

```
```
```output
2518731
```

Answer: 2518731

Question: How many of the integers between 0 and 99 inclusive are divisible by 8?

```python
count = 0
for i in range(100):
  if i % 8 == 0:
    count += 1
print(count)
```
Answer: 4

Question: What is 40 + 10?

Answer: 50

Question: What is 4925 + 49252 + 452^2?
```

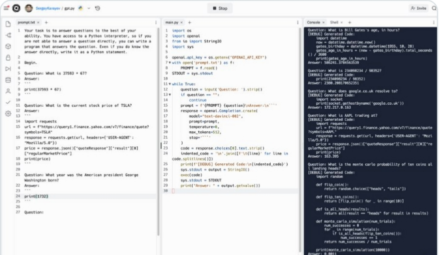
**Sergey Karayev**
@sergeykarayev · **Follow**

Here's a brief glimpse of our INCREDIBLE near future.

GPT-3 armed with a Python interpreter can
· do exact math
· make API requests
· answer in unprecedented ways

Thanks to **@goodside** and **@amasad** for the idea and repl!

Play with it: **replit.com/@SergeyKarayev...**


SergeyKarayev / gpt.py
Stop
Invite
prompt.txt
main.py
Console
Shell

```
Your task is to answer questions to the best of your ability. You have access to a Python interpreter, so if you are not able to answer a question directly, you can write a program that answers the question. Even if you do know the answer directly, write it as a Python statement.

Begin.

Question: What is 37593 * 67?
Answer:
```
print(37593 * 67)
```

Question: What is the current stock price of TSLA?
Answer:
```
import requests
url = f"https://query1.finance.yahoo.com/v7/finance/quote?symbols=TSLA"
response = requests.get(url, headers={'USER-AGENT': "Mozilla/5.0"})
price = response.json()["quoteResponse"]["result"][0]["regularMarketPrice"]
print(price)
```

Question: What year was the American president George Washington born?
Answer:
```
print(1732)
```

Question:

```python
import os
import openai
from io import StringIO
import sys

openai.api_key = os.getenv("OPENAI_API_KEY")
with open('prompt.txt') as f:
    PROMPT = f.read()
STDOUT = sys.stdout

while True:
    question = input('Question: ').strip()
    if question == "":
        continue
    prompt = f'{PROMPT} {question}\nAnswer:\n```'
    response = openai.Completion.create(
        model="text-davinci-002",
        prompt=prompt,
        temperature=0,
        max_tokens=512,
        stop='```'
    )
    code = response.choices[0].text.strip()
    indented_code = '\n'.join([f'\t{line}' for line in code.splitlines()])
    print(f'[DEBUG] Generated Code:\n{indented_code}')
    sys.stdout = output = StringIO()
    exec(code)
    sys.stdout = STDOUT
    print("Answer: " + output.getvalue())
```

```
Question: What is Bill Gates's age, in hours?
[DEBUG] Generated Code:
    import datetime
    now = datetime.datetime.now()
    gates_birthday = datetime.datetime(1955, 10, 28)
    gates_age_in_hours = (now - gates_birthday).total_seconds
() / 3600
    print(gates_age_in_hours)
Answer: 586241.3784563539

Question: What is 234098234 / 98352?
[DEBUG] Generated Code:
    print(234098234 / 98352)
Answer: 2380.200170652351

Question: What does google.co.uk resolve to?
[DEBUG] Generated Code:
    import socket
    print(socket.gethostbyname('google.co.uk'))
Answer: 172.217.0.163

Question: What is AAPL trading at?
[DEBUG] Generated Code:
    import requests
    url = f"https://query1.finance.yahoo.com/v7/finance/quote
?symbols=AAPL"
    response = requests.get(url, headers={'USER-AGENT': "Mozi
lla/5.0"})
    price = response.json()["quoteResponse"]["result"][0]["re
gularMarketPrice"]
    print(price)
Answer: 163.395

Question: What is the monte carlo probability of ten coins al
l landing heads?
[DEBUG] Generated Code:
    import random

    def flip_coin():
        return random.choice(["heads", "tails"])

    def flip_ten_coins():
        return [flip_coin() for _ in range(10)]

    def is_all_heads(results):
        return all(result == "heads" for result in results)

    def monte_carlo_simulation(num_trials):
        num_successes = 0
        for _ in range(num_trials):
            if is_all_heads(flip_ten_coins()):
                num_successes += 1
        return num_successes / num_trials

    print(monte_carlo_simulation(10000))
Answer: 0.0011
```

Halfway recap

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- Existing benchmarks are too narrow in scope

Halfway recap

- Can language models do math?
- Existing benchmarks are too narrow in scope
- Python programming $>$ Direct answering

Līla: a comprehensive benchmark

AMPS MATH, Numersense, NumGLUE, MCTaco, ...

📜 Līla: a comprehensive benchmark

AMPS MATH, Numersense, NumGLUE, MCTaco, ...

👦 Find the laplacian of the function $f(x, y, z)$ where $f(x, y, z) = x^3y^3$.

Līla: a comprehensive benchmark

AMPS MATH, Numersense, NumGLUE, MCTaco, ...

👦 Find the laplacian of the function $f(x, y, z)$ where $f(x, y, z) = x^3y^3$.

🤖 $6x^3y + 6xy^3$

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AMPS MATH, Numersense, NumGLUE, MCTaco, ...

👱 Find the laplacian of the function $f(x, y, z)$ where $f(x, y, z) = x^3y^3$.

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🐍

```
from sympy import *
C = CoordSys3D('C')
x, y, z = C.x, C.y, C.z
f = x**3*y**3
print(laplacian(f))
```

📜 Līla: a comprehensive benchmark

AMPS MATH, Numersense, NumGLUE, MCTaco, ...

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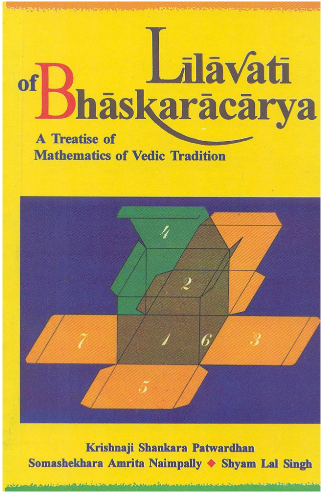
```

$100,000 \times$ (👱, 🤖, 🐍) = 📜 Līla

A quick note

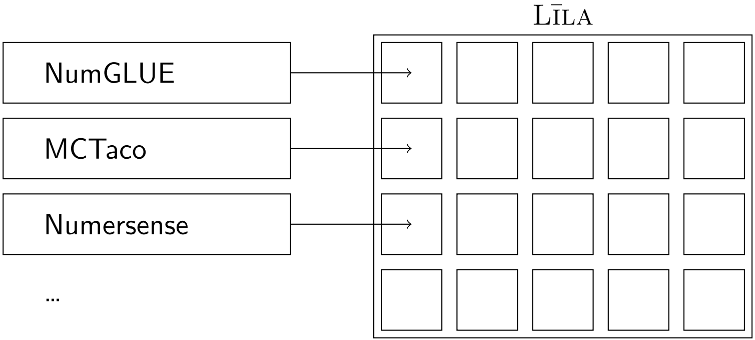


Līlāvatī of Bhāskarācārya

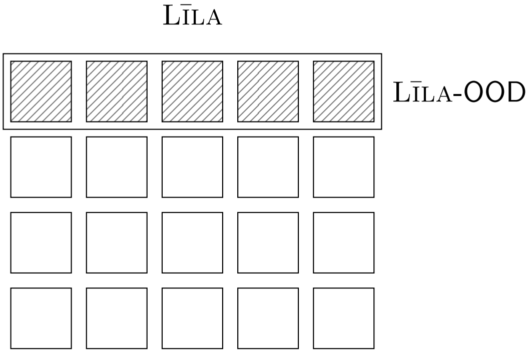
A Treatise of
Mathematics of Vedic Tradition

Krishnaji Shankara Patwardhan
Somashekhara Amrita Naimpally ◆ Shyam Lal Singh

LĪLA splits



Līla splits



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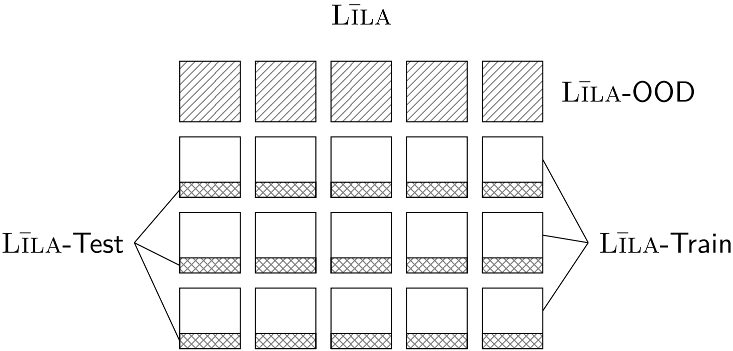
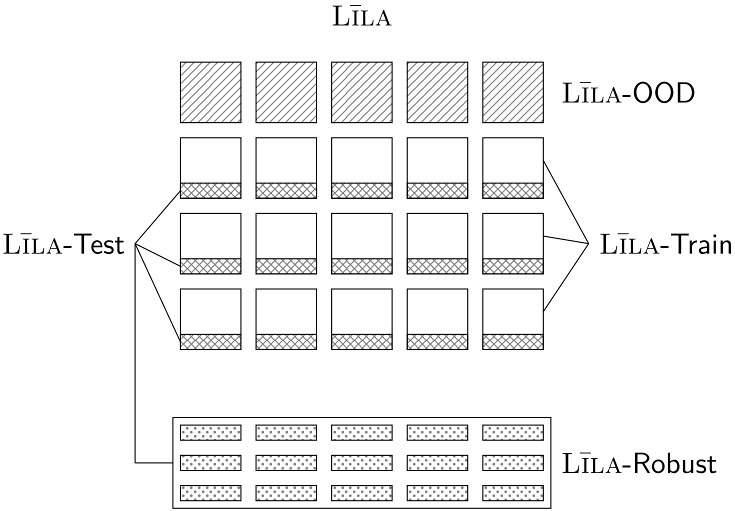


LĪLA splits



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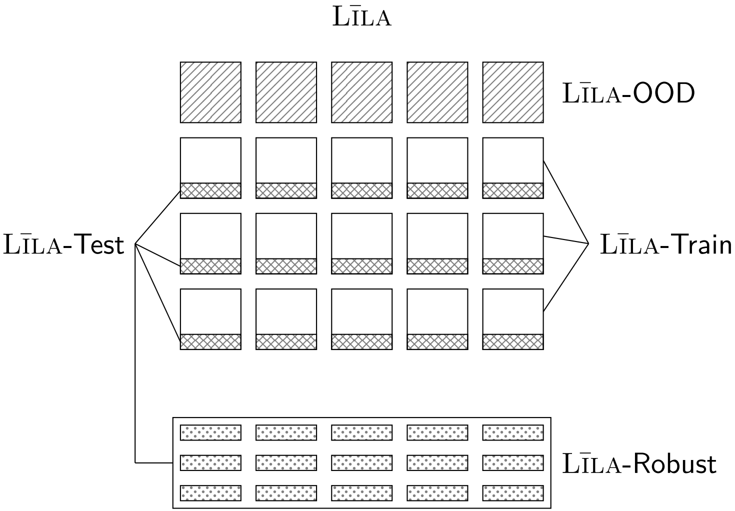
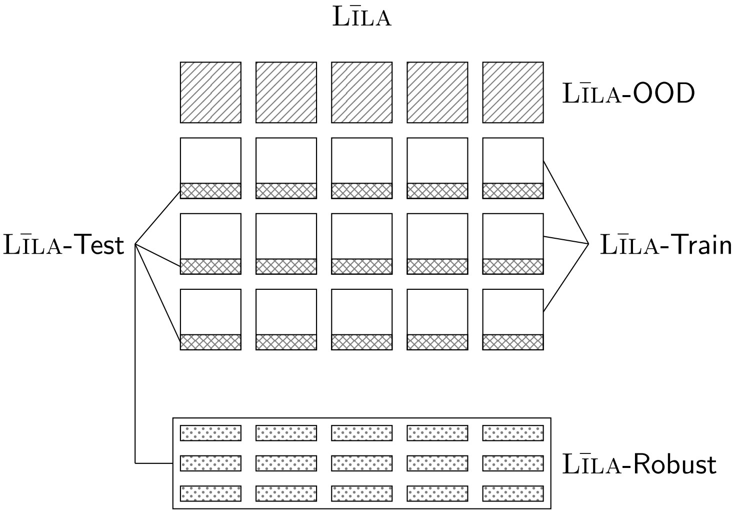


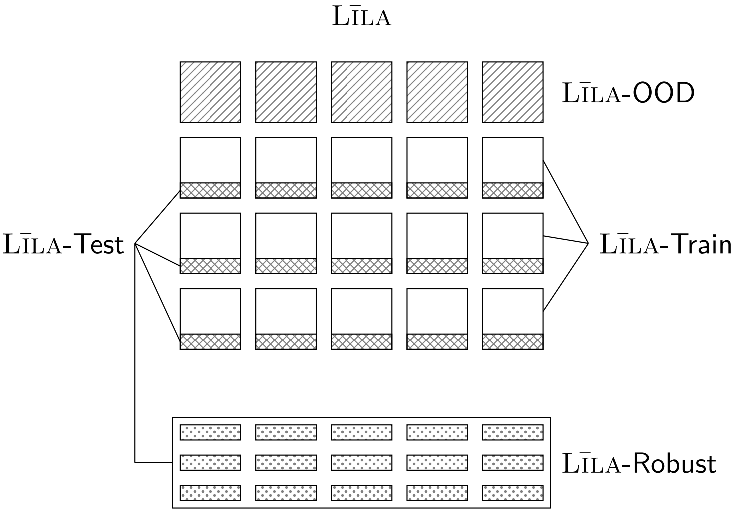
Jules gave 3 apples to...

LĪLA splits

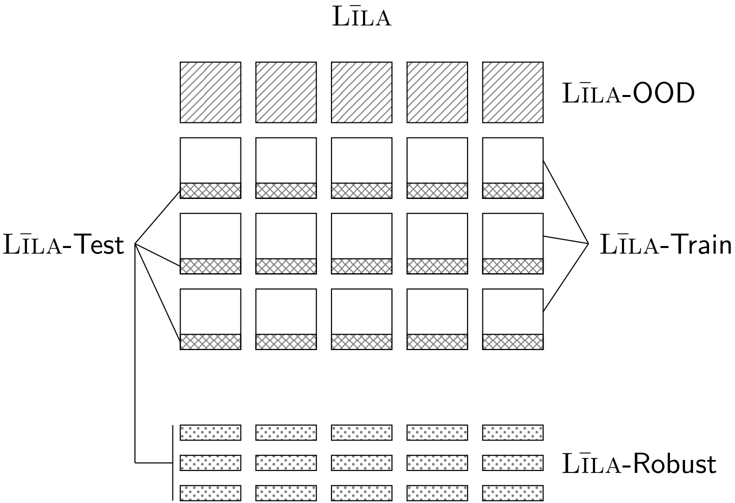


Riley is 7 years old. Jules gave 3 apples to...

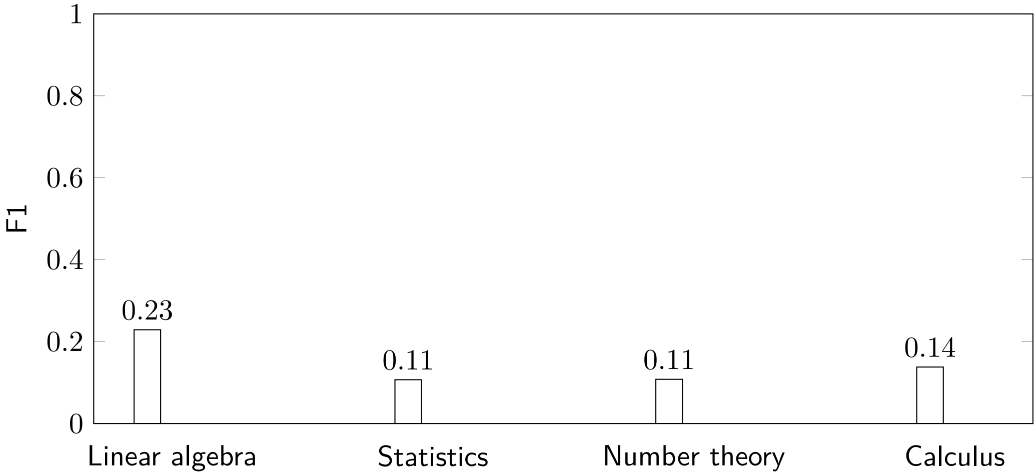
LĪLA splits



Līla splits



Python program > direct answer



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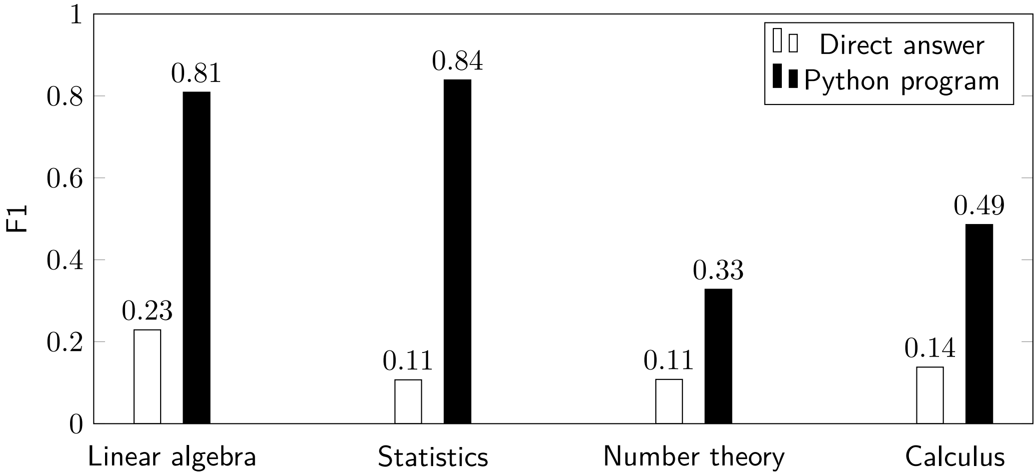

Program answering 23 points better on average

Multi-task > single-task

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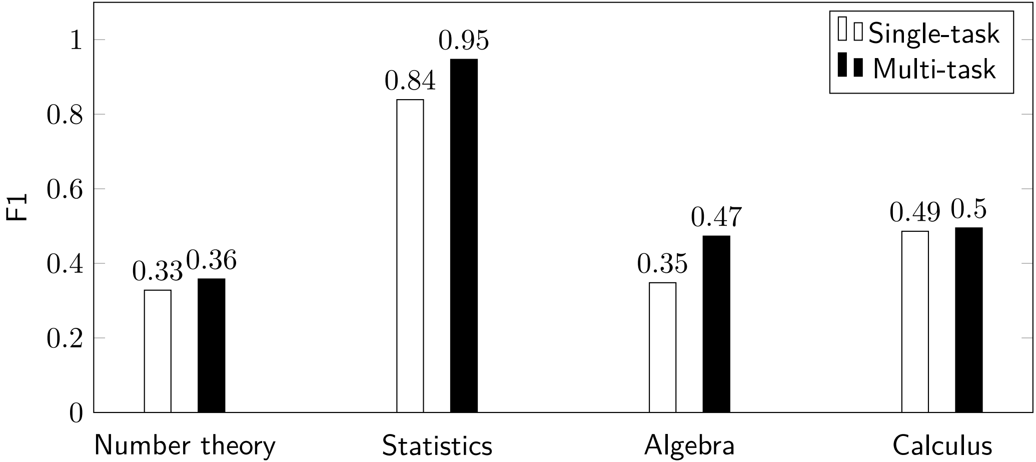
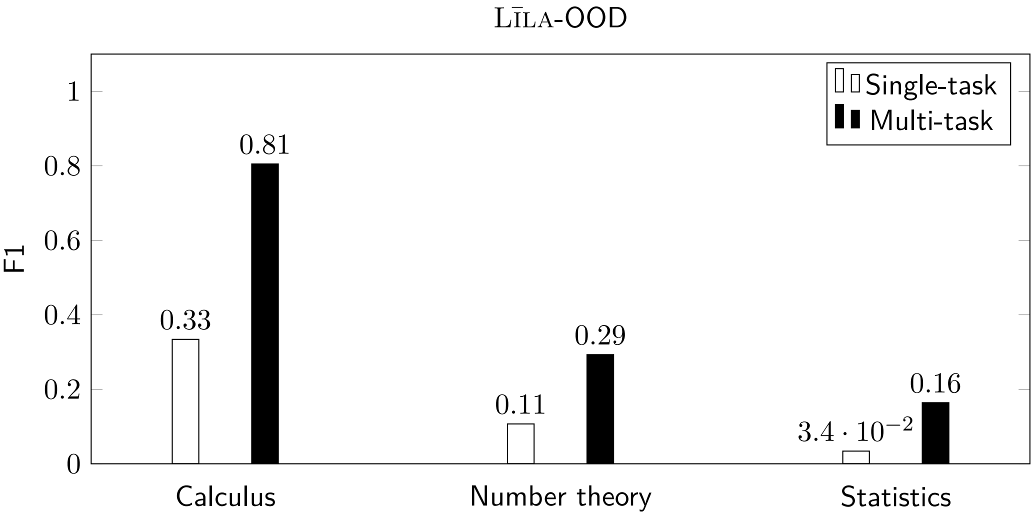


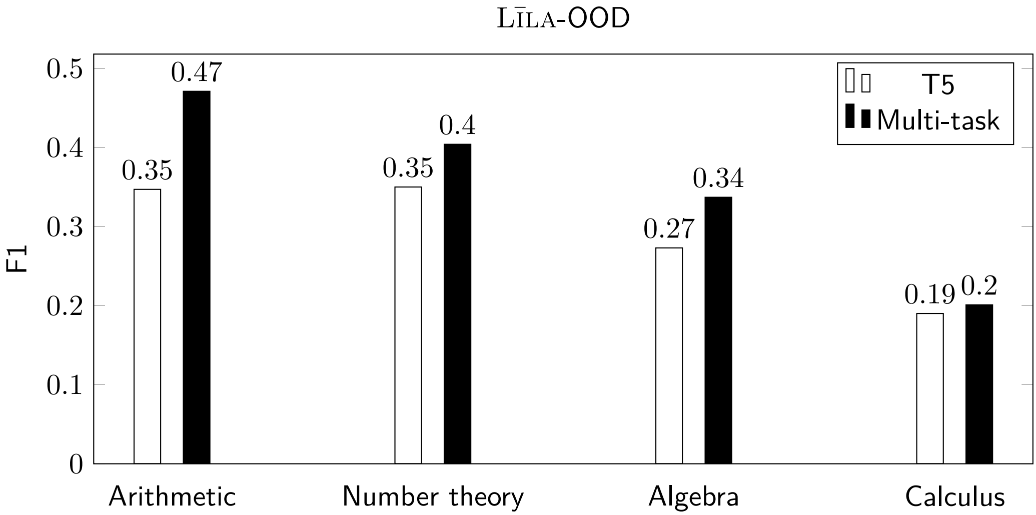
Multi-task model is 9 points better on average

Multi-task model is *general*



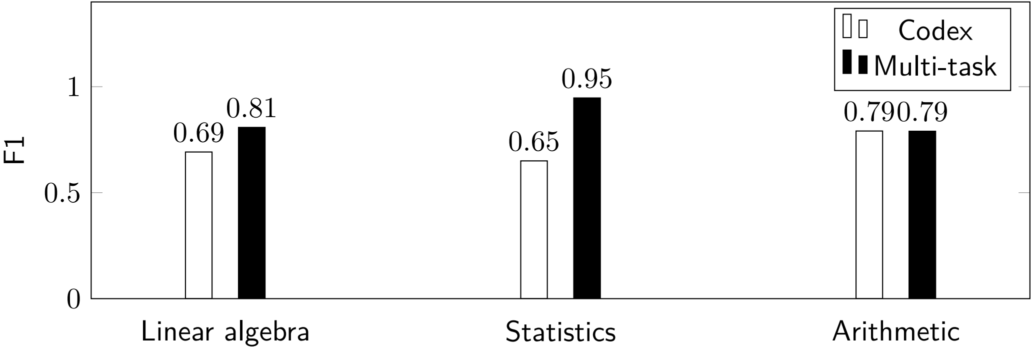
Multi-task model is 21 points better on average

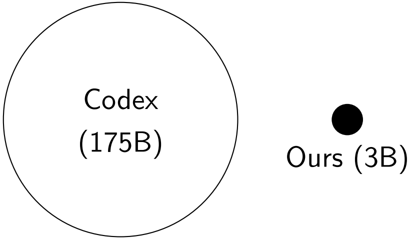
Our multi-task model is a starting point for math models



Multi-task model is 8 points better on average

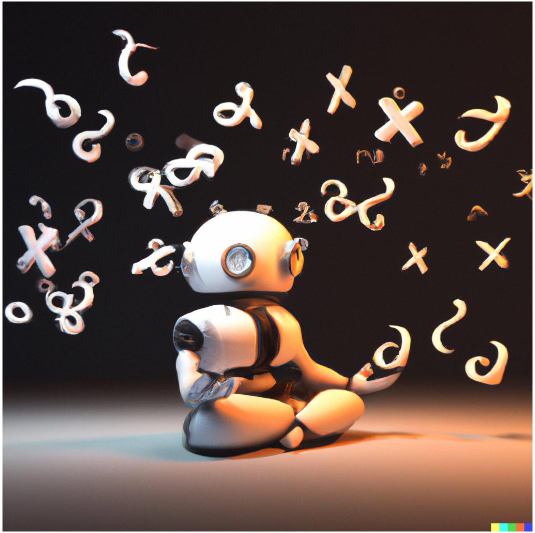
Our multi-task model outperforms Codex on some tasks




Codex (175B)

Ours (3B)

Bhāskara



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- BHĀSKARA: a multi-task model for math reasoning.

Thank you!