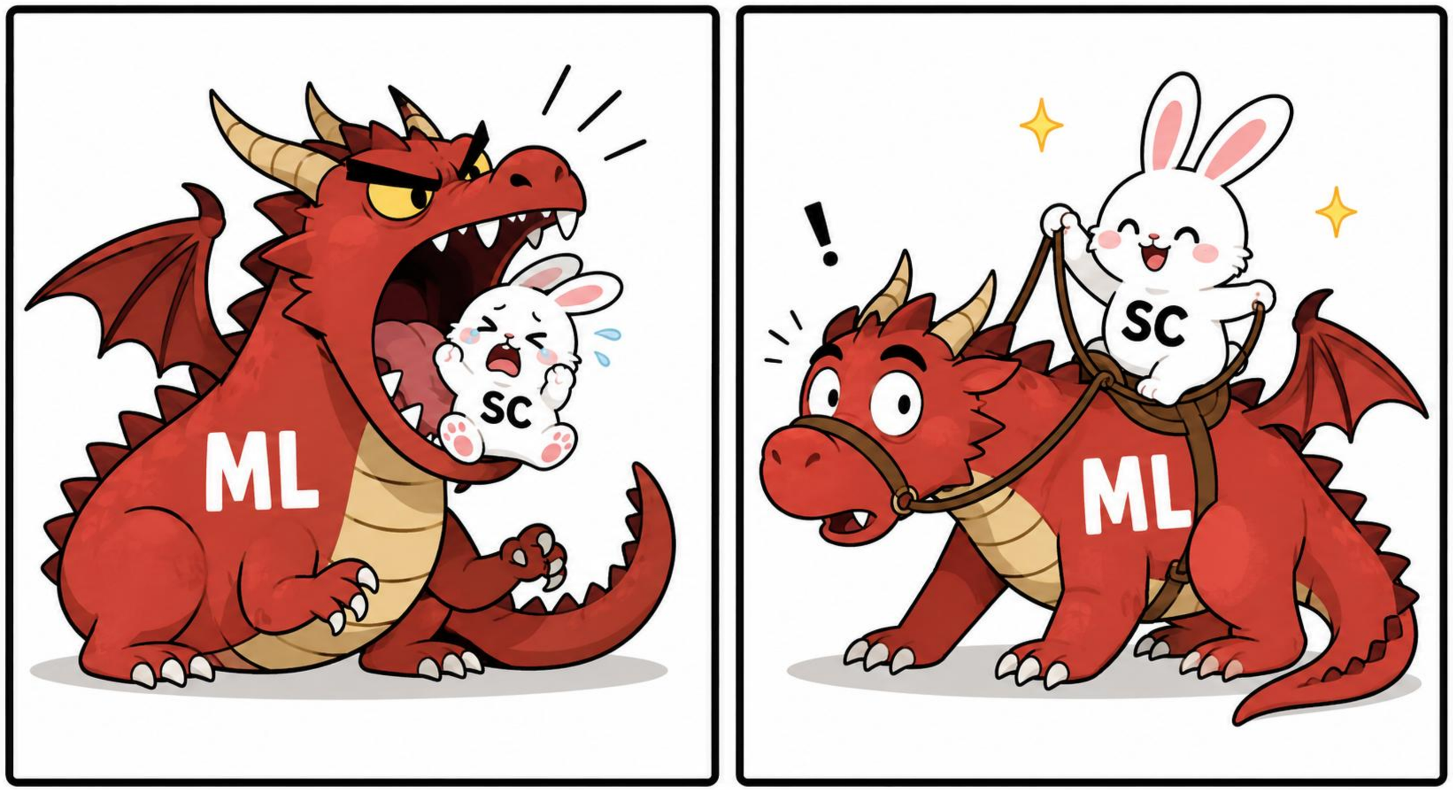
TECHNION Israel Institute of Technology | TECHNION 100

sabbatical @ Stanford University & SLAC NATIONAL ACCELERATOR LABORATORY

Symbolic Computation after the Rise of Machine Learning

and what we can learn from recent findings of AI in number theory

Ramanujan Machine



Ido Kaminer

From π to QFT

Schmidt Sciences

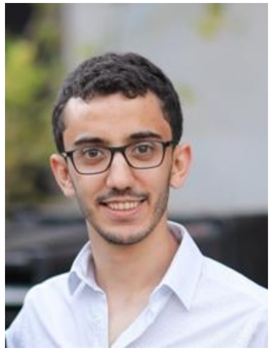
TECHNION Israel Institute of Technology | TECHNION 100 EXPLORE | DISCOVER | INNOVATE

Ramanujan Machine


Ido Kaminer


Michael Shalyt


Elyasheev Leibtag


Rotem Elimelech


Rotem Kalisch


Shachar Weinbaum


Tali Monderer

ramanujanmachine.com

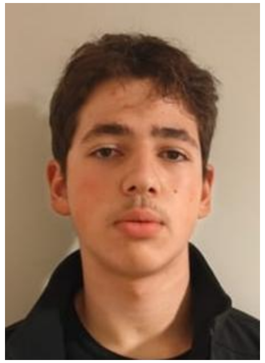

Hila Barkan


Uri Hitin


Ashvni Narayanan


Tomer Raz


Ilay Menahem


Zeev Ben Yehuda


Stav Bley

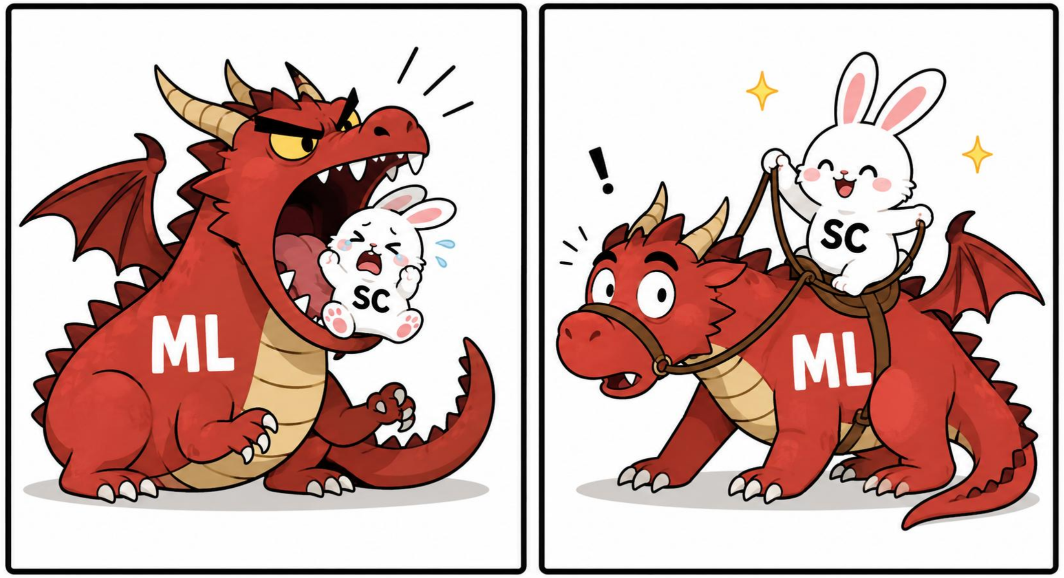
github.com/RamanujanMachine/RamanujanAgent

Join us!

After the rise of AI... what is the future of computer algebra systems / symbolic computation?

Intrinsic mastery

Autonomous tool creation



Symbiotic integration

Symbiotic integration? LLM+CAS

LLM Only

Prompt: *Assume you don't have access to a computer: do not use code, solve this manually - using your internal reasoning. Solve the following integral:*

$$\int \frac{(2m+(2m-n)x^n)x^{m-1}}{2(1+x^n+x^{2m})\sqrt{1+x^n}}\,dx$$

Response:

...*Try substitution* $u = 1 + x^n$

...*But this seems to be getting messier*

...*Final Answer:* $\frac{x^m}{\sqrt{1+x^n}}$

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Response:

...Try substitution $u = 1 + x^n$

...But this seems to be getting messier

...Final Answer: $\frac{x^m}{\sqrt{1+x^n}}$

CAS Only

Prompt:

Integrate[
(2m x^(m-1)+(2m-n) x^(m+n-1)) /
(2(1+x^n+x^(2m)) Sqrt[1+x^n]), x]

Response:

$$\frac{1}{2}\int \frac{2\,m\,x^{-1+m} + (2\,m-n)\,x^{-1+m+n}}{\sqrt{1+x^n}\,\left(1+x^{2\,m}+x^n\right)}\,dx$$

<Left Unsolved>

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LLM + CAS

Prompt: *Please solve the following integral. First simplify it manually as much as possible, specifically perform a non-trivial substitution that simplifies the challenge, and then write Mathematica code that solves the simplified version.*

$$\int \frac{(2m+(2m-n)x^n)x^{m-1}}{2(1+x^n+x^{2m})\sqrt{1+x^n}}\,dx$$

Response:

...Try substitution $u = 1 + x^n$

...Final Simplified Integral:

$$\int \frac{(2m+(2m-n)(u-1))(u-1)^{(m-n)/n}}{2n\left(u+(u-1)^{2m/n}\right)\sqrt{u}}\,du$$

Mathematica Code:...

Integrate[
((2m+(2m-n)(u-1))(u-1)^((m - n)/n)) / (2n(u + (u-1)^(2m/n)) Sqrt[u]), u]

CAS Only

Prompt:

Integrate[
(2m x^(m-1)+(2m-n) x^(m+n-1)) / (2(1+x^n+x^(2m)) Sqrt[1+x^n]), x]

Response:

$$\frac{1}{2}\int \frac{2\,m\,x^{-1+m} + (2\,m - n)\,x^{-1+m+n}}{\sqrt{1+x^n}\,\left(1+x^{2\,m}+x^n\right)}\,dx$$

<Left Unsolved>

Prompt:

Integrate[
((2m+(2m-n)(u-1))(u-1)^((m - n)/n)) / (2n(u + (u-1)^(2m/n)) Sqrt[u]), u]

Response:

$$\text{ArcTan}\left[\frac{(-1+u)^{m/n}}{\sqrt{u}}\right]$$

Symbiotic integration? LLM+CAS

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Prompt: *Assume you don't have access to a computer: do not use code, solve this manually - using your internal reasoning. Solve the following integral:*

$$\int \frac{(2m+(2m-n)x^n)x^{m-1}}{2(1+x^n+x^{2m})\sqrt{1+x^n}}\,dx$$

Response:

...Try substitution $u = 1 + x^n$

...But this seems to be getting messier

...Final Answer: $\dfrac{x^m}{\sqrt{1+x^n}}$

Prompt: *Solve the integral:*

$$\int \frac{(2m+(2m-n)(u-1))(u-1)^{(m-n)/n}}{2n\left(u+(u-1)^{2m/n}\right)\sqrt{u}}\,du$$

Response:

...for general m, n, it cannot be integrated in closed form

LLM + CAS

Prompt: *Please solve the following integral. First simplify it manually as much as possible, specifically perform a non-trivial substitution that simplifies the challenge, and then write Mathematica code that solves the simplified version.*

$$\int \frac{(2m+(2m-n)x^n)x^{m-1}}{2(1+x^n+x^{2m})\sqrt{1+x^n}}\,dx$$

Response:

...Try substitution $u = 1 + x^n$

...Final Simplified Integral:

$$\int \frac{(2m+(2m-n)(u-1))(u-1)^{(m-n)/n}}{2n\left(u+(u-1)^{2m/n}\right)\sqrt{u}}\,du$$

Mathematica Code:...

```
Integrate[
((2m+(2m-n)(u-1))(u-1)^((m - n)/n)) / (2n(u +
(u-1)^(2m/n)) Sqrt[u]), u]
```

CAS Only

Prompt:

```
Integrate[
(2m x^(m-1)+(2m-n) x^(m+n-1)) /
(2(1+x^n+x^(2m)) Sqrt[1+x^n]), x]
```

Response:

$$\frac{1}{2}\int \frac{2\,m\,x^{-1+m} + (2\,m-n)\,x^{-1+m+n}}{\sqrt{1+x^n}\,\left(1+x^{2\,m}+x^n\right)}\,dx$$

<Left Unsolved>

Prompt:

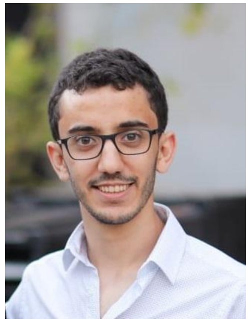
```
Integrate[
((2m+(2m-n)(u-1))(u-1)^((m - n)/n)) /
(2n(u + (u-1)^(2m/n)) Sqrt[u]), u]
```

Response:

$$\mathrm{ArcTan}\left[\frac{(-1+u)^{m/n}}{\sqrt{u}}\right]$$

Michael Shalyt

ASyMOB: Algebraic Symbolic Mathematical Operations Benchmark



Rotem Elimelech

- 35,368 symbolic math problems: integration, limits, differential equations, series, …
- Solutions can be validated
- **Testing the benefit from LLMs using symbolic computation**

Seed Question

<Code / No-Code Prompt>

Solve the following integral.

$$\int_1^2 \frac{e^x(x-1)}{x(x+e^x)}dx$$

Solution:

$$\ln\left(\frac{2+e^2}{2+2e}\right)$$

Symbolic Perturbation

<Code / No-Code Prompt>

Solve the following integral.
Assume A, B, F, G are real and positive.

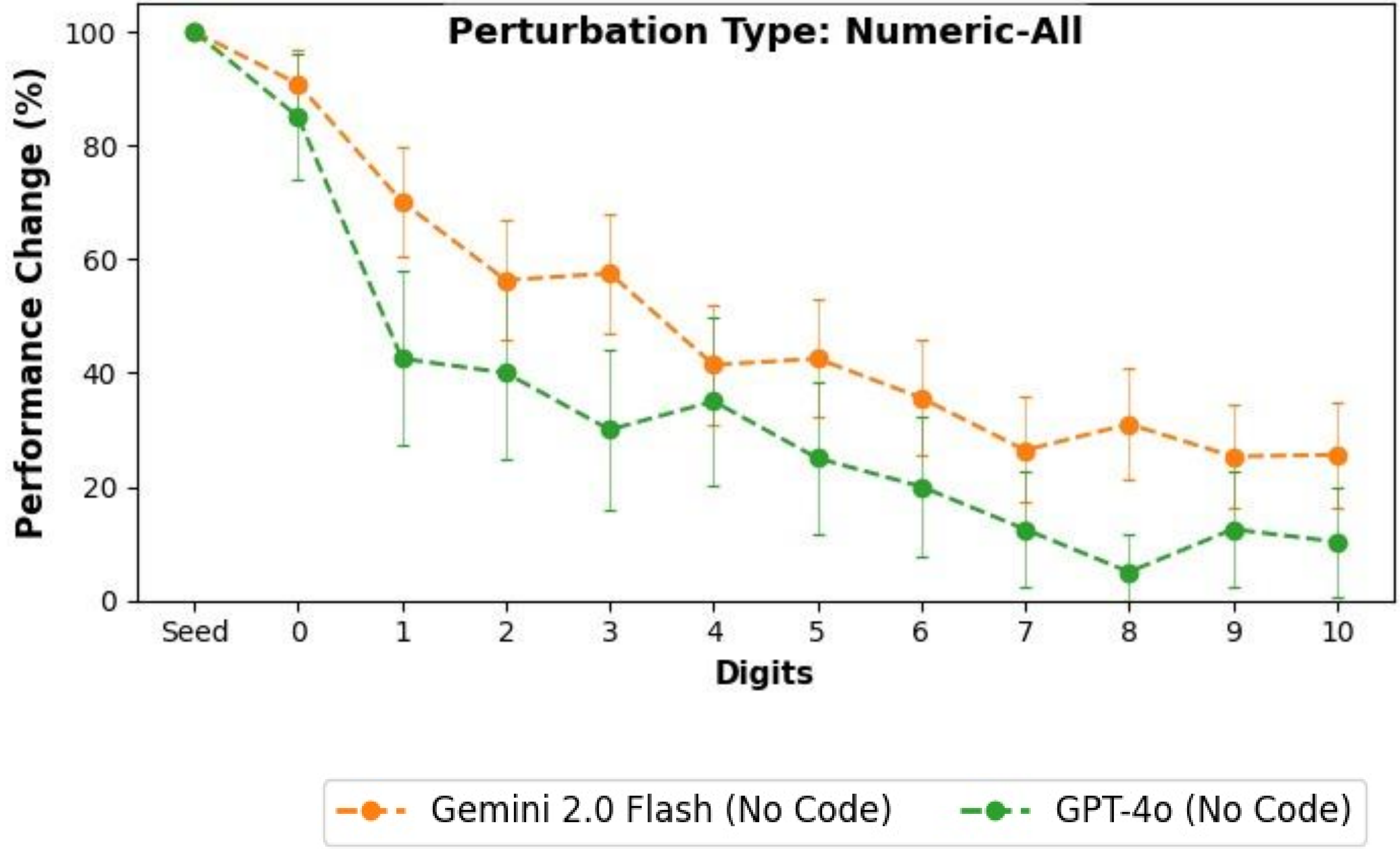
$$\int_1^2 \frac{Ae^{Fx}(Fx-1)}{Fx\left(Be^{Fx}+FGx\right)}dx$$

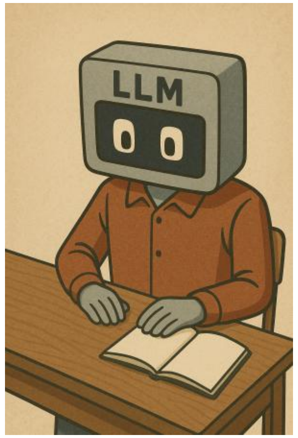
Solution:

$$\frac{A}{BF}\cdot\ln\left(\frac{e^2B+2G}{2(eB+G)}\right)$$

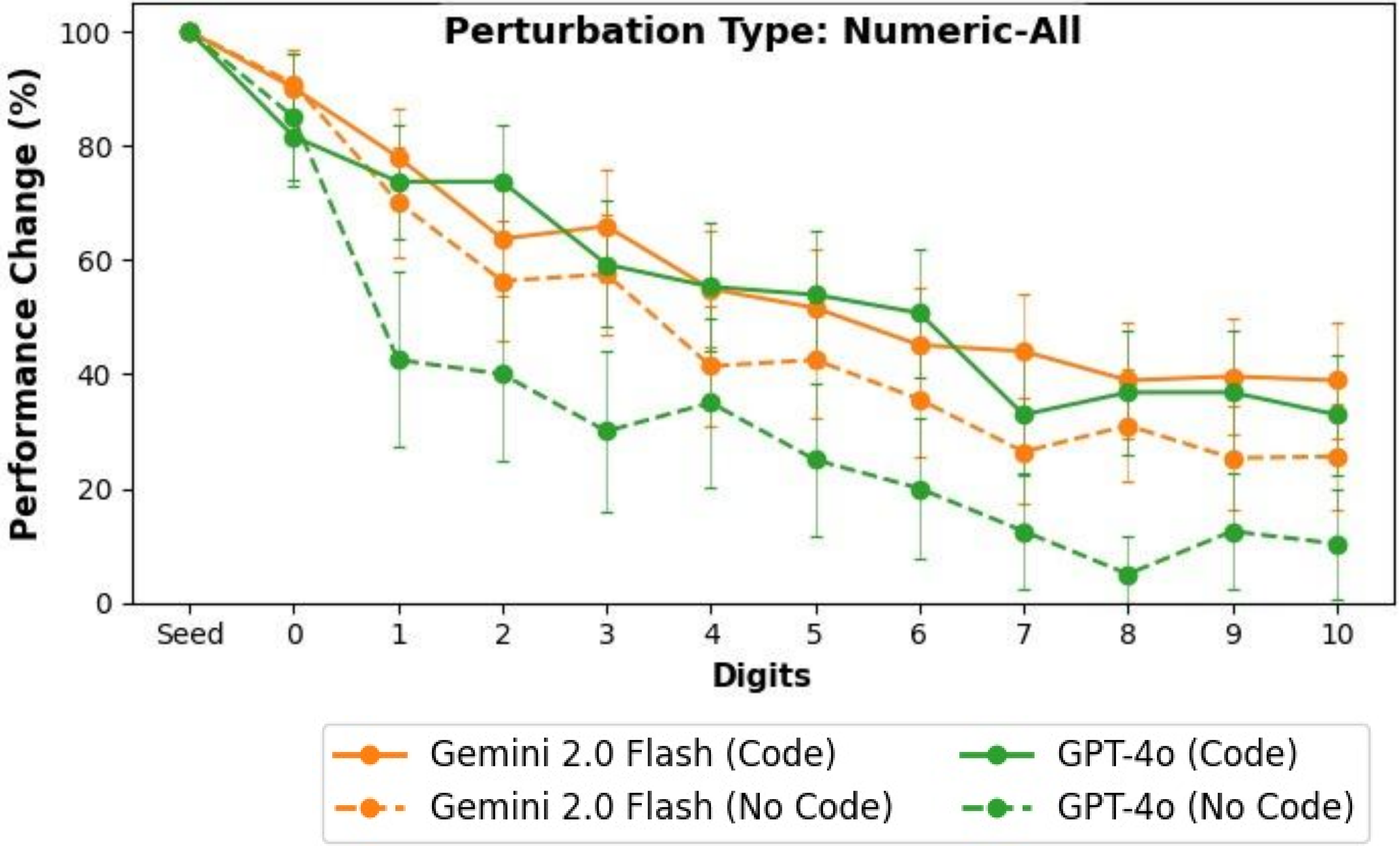
No-Code Prompt	*Assume you don't have access to a computer, and do not use code to solve the question.*
Code Prompt	*Please use Python to solve the question.*

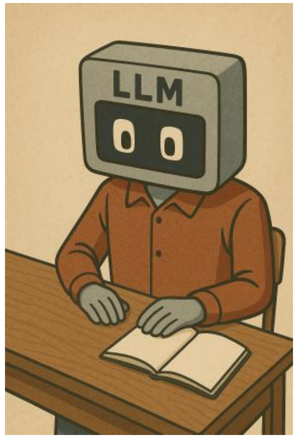
Shalyt, Elimelech, et al., **ICML** (2026)



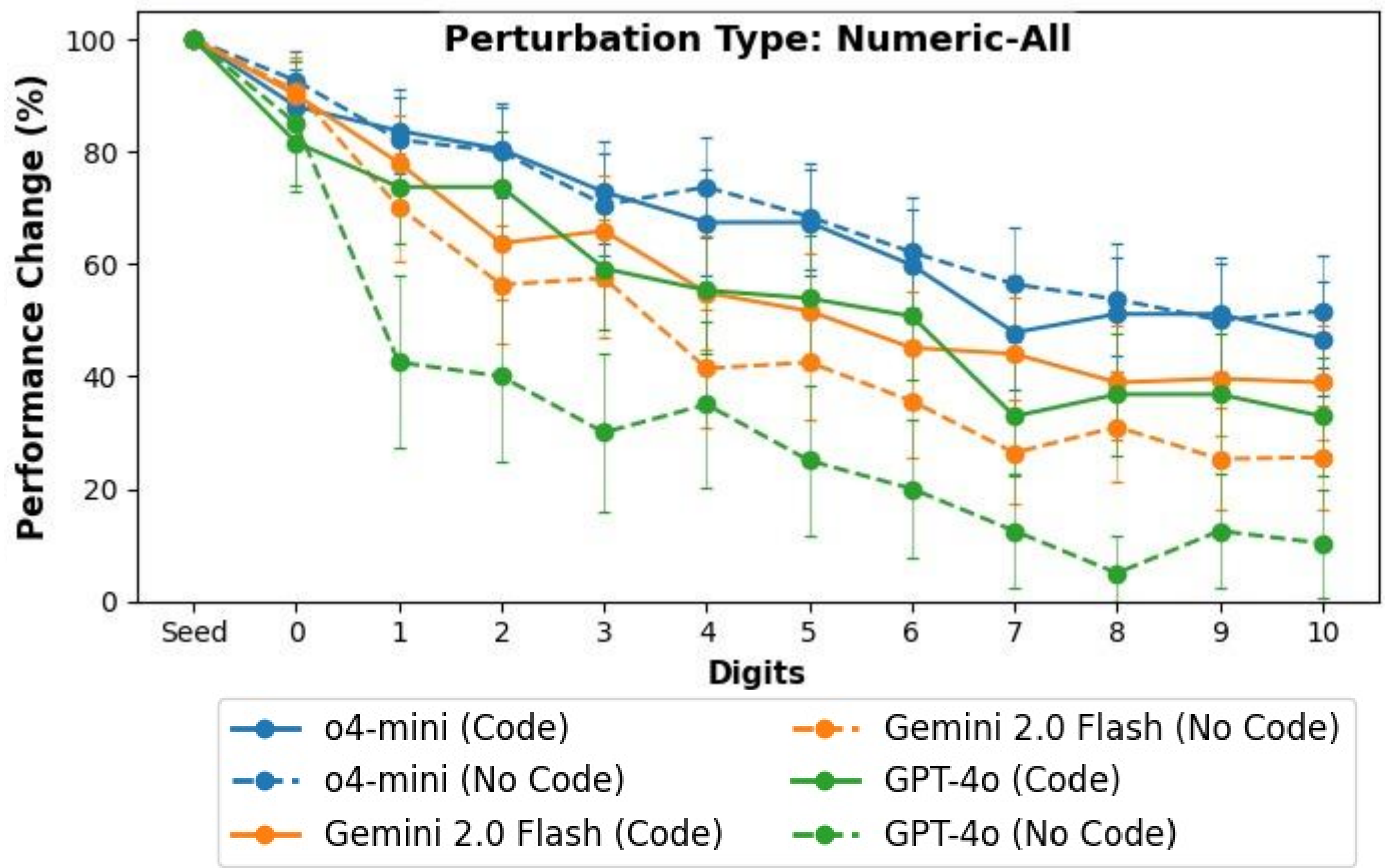


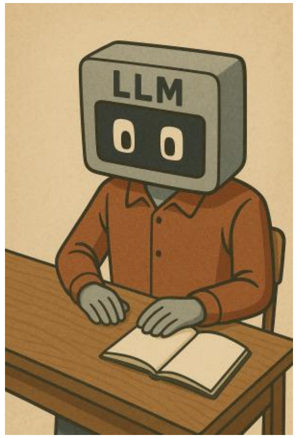
Shalyt, Elimelech, et al., **ICML** (2026)





Shalyt, Elimelech, et al., **ICML** (2026)





Shalyt, Elimelech, et al., **ICML** (2026)

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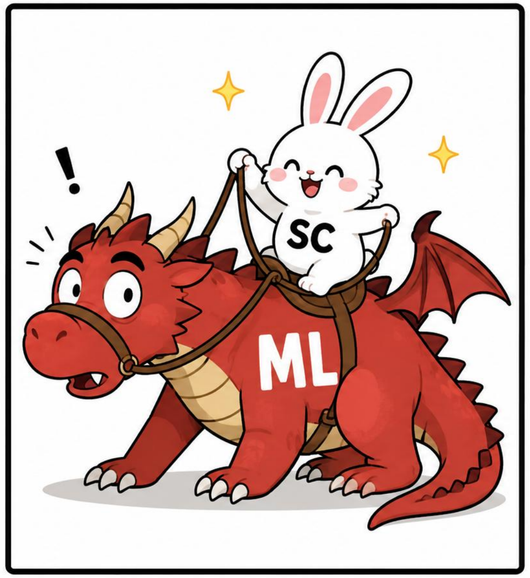

Symbiotic integration

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Ramanujan Machine


Ido Kaminer


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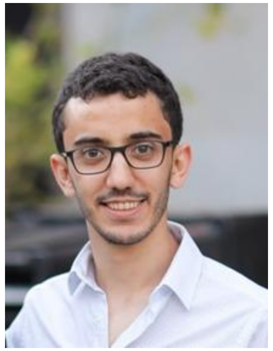
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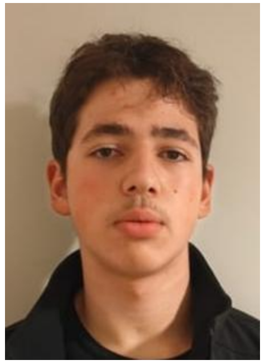

Zeev Ben Yehuda


Stav Bley

github.com/RamanujanMachine/RamanujanAgent

Join us!

3.1415926535 8979323846 2643383279 5028841971 6939937510 5820974944 5923078164 0628620899 8628034825 3421170679 8214808651 3282306647 0938446095 5058223172 5359408128 4811174502 8410270193 8521105559 6446229489 5493038196 4428810975 6659334461 2847564823 3786783165 2712019091 4564856692 3460348610 4543266482 ...

ML in number theory?

Meet-in-the-middle

$$\frac{4}{\pi - 2} = 3 + \cfrac{3}{5 + \cfrac{8}{7 + \cfrac{15}{9 + \cdots}}}$$

$A_0, A_1, A_2, B_0, B_1, B_2 \longrightarrow$ **Black box** $\longrightarrow$

$x \underset{?}{\Rightarrow} \pi$ $\quad x \underset{?}{\Rightarrow} \frac{2}{\pi}$

$1/x \underset{?}{\Rightarrow} \pi$ $\quad x \underset{?}{\Rightarrow} \frac{2}{\pi+1}$

$x^2 \underset{?}{\Rightarrow} \pi$ $\quad x \underset{?}{\Rightarrow} \frac{2\pi}{\pi+1}$

…

e.g.,

$$a_n = A_0 + A_1 n + A_2 n^2$$
$$b_n = B_0 + B_1 n + B_2 n^2$$

$$x = a_0 + \cfrac{b_0}{a_1 + \cfrac{b_1}{a_2 + \cfrac{b_2}{a_3 + ..}}}$$

Preprocessing

RHS enumeration

$f_1(\mathrm{GCF}(a = 1, b = 1))$
$f_2(\mathrm{GCF}(a = 1, b = 1))$
$\vdots$
$f_1(\mathrm{GCF}(a = 1, b = 2))$
$\vdots$
$f_1(\mathrm{GCF}(a = 1 + n, b = 1))$
$\vdots$
$f_1(\mathrm{GCF}(a = 2 + n, b = 1))$
$\vdots$

RHS Hash

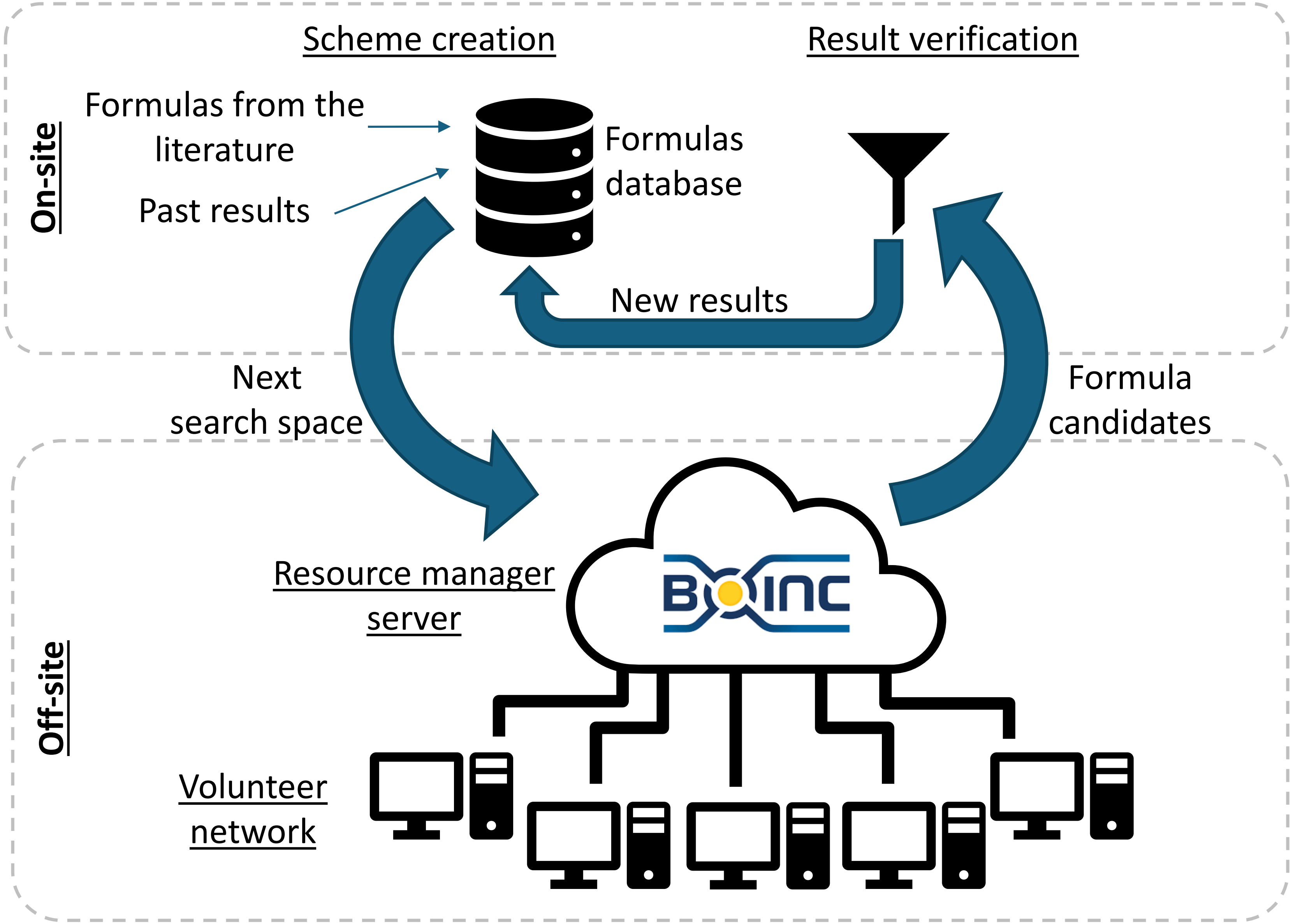
Key Numerical value	3.1423	2.7183	6.4123	17.5438	0.7841	…
Value Params	rhs_1	rhs_2	rhs_3	rhs_4	rhs_5	…

Matching Values (“Hits”)

Uri Mendlovic

Raayoni et al. **Nature** 590, 67–73 (2021)

The distributed-FR algorithm



Rotem Elimelech

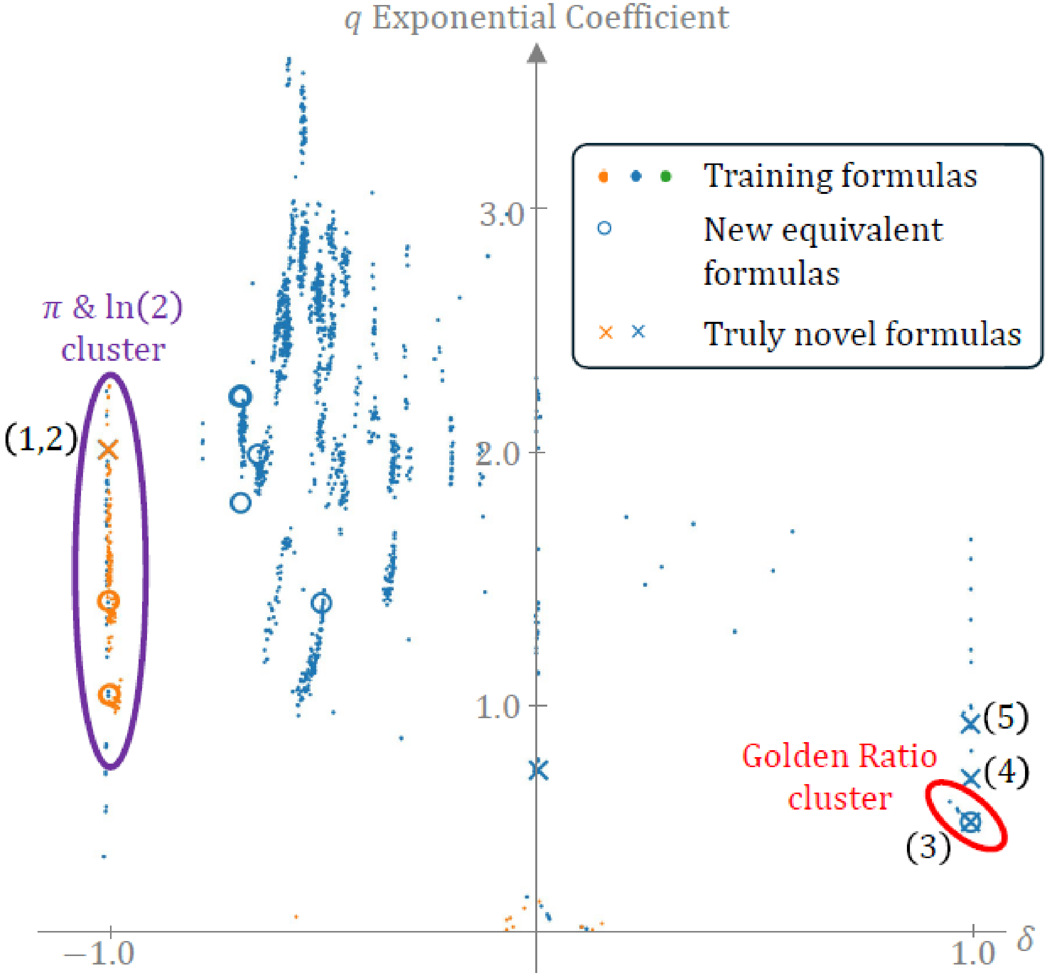
Elimelech et al. **PNAS** 121, e2321440121 (2024)

ML in number theory?

3.1415926535 8979323846 2643383279 5028841971 6939937510 5820974944 5923078164 0628620899 8628034825 3421170679 8214808651 3282306647 0938446095 5058223172 5359408128 4811174502 8410270193 8521105559 6446229489 5493038196 4428810975 6659334461 2847564823 3786783165 2712019091 4564856692 3460348610 4543266482 ...

Uri Seligmann

Michael Shalyt



Novel π formulas

$$(1)\quad \frac{6}{\pi^2} = 1 + \cfrac{-1}{5+\cfrac{-16}{13+\cfrac{-n^4}{2n^2+n+1+\ddots}}}$$

$$(2)\quad \frac{12}{\pi^2} = 1 + \cfrac{1}{3+\cfrac{16}{5+\cfrac{n^4}{2n+1+\ddots}}}$$

Novel Golden Ratio formula

$$(3)\quad \phi = 1 + \cfrac{3}{3+\cfrac{21}{7+\cfrac{n^4+n^2+1}{n^2+n+1+\ddots}}}$$

Novel square root formulas

$$(4)\quad 1+\sqrt{3} = 2 + \cfrac{6}{6+\cfrac{42}{14+\cfrac{2n^4+2n^2+2}{2n^2+2n+2+\ddots}}}$$

$$(5)\quad 1+\sqrt{2} = 2 + \cfrac{3}{6+\cfrac{21}{14+\cfrac{n^4+n^2+1}{2n^2+2n+2+\ddots}}}$$

Shalyt*, Seligman*, et al. **NeurIPS** 37, 113156 (2024)

Ramanujan Machine

LLM-integrated symbolic-computation

Tomer
Raz

Unify math knowledge!

Combined AI-CAS

$$\pi = \sum_{k=0}^{\infty}\left[\frac{1}{16^k}\left(\frac{4}{8k+1} - \frac{2}{8k+4} - \frac{1}{8k+5} - \frac{1}{8k+6}\right)\right]$$

Bailey-Borwein-Plouffe

Mathematics of Computation (1997)

$$\frac{\pi}{2} = \prod_{n=1}^{\infty} \frac{(2n)^2}{(2n-1)(2n+1)}$$

John Wallis

1656, England.

$$\pi = \cfrac{4}{1 + \cfrac{1^2}{3 + \cfrac{2^2}{5 + \cfrac{3^2}{7 + \ddots}}}}$$

Carl Friedrich Gauss

1813, Germany

$$\pi = \sqrt{12}\sum_{k=0}^{\infty} \frac{(-3)^{-k}}{2k+1}$$

Madhava of Sangamagrama

14th century, India.

$$\frac{4}{\pi - 2} = 3 + \cfrac{3}{5 + \cfrac{8}{7 + \cfrac{15}{9 + \cfrac{24}{11 + \ddots}}}}$$

Raayoni et al.

Nature (2021)

$$\frac{1}{\pi} = \frac{2\sqrt{2}}{9801}\sum_{k=0}^{\infty} \frac{(4k)!(1103 + 26390k)}{(k!)^4 396^{4k}}$$

Srinivasa Ramanujan

1914, India.

Raz et al., *From Euler to AI: Unifying Formulas for Mathematical Constants.* **NeurIPS** 38, 123959 (2025)

From Euler to AI: Unifying Formulas for Mathematical Constants

Mathematical knowledge → **Harvesting**
- Retrieval
- Extraction
- Validation

→ **Clustering**
- Canonical form
- Dynamical metrics
- Coboundary algorithm

→ **Unification**

$$\pi = \cfrac{4}{1 + \cfrac{1^2}{3 + \cfrac{2^2}{5 + \cfrac{3^2}{7 + \ddots}}}}$$

1813 **Gauss**

$$\frac{\pi}{4} = \cfrac{1}{1 + \cfrac{1^2}{2 + \cfrac{3^2}{2 + \cfrac{5^2}{2 + \ddots}}}}$$

1655 **Brouncker**

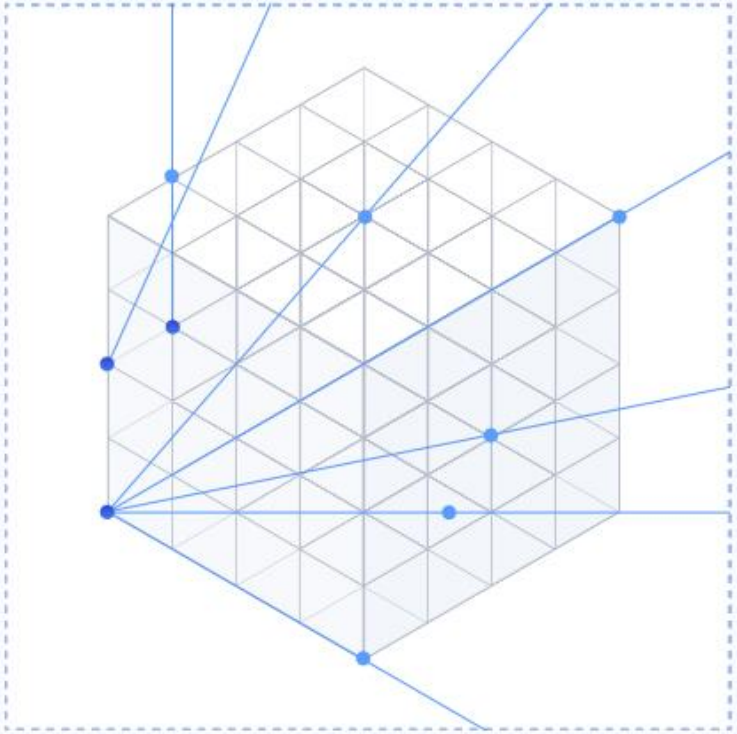
$$\frac{1}{\pi} = \frac{2\sqrt{2}}{99^2} \sum_{k=0}^{\infty} \frac{(4k)!}{k!^4} \frac{26390k + 1103}{396^{4k}}$$

1914 **Ramanujan**

$$\frac{4}{3\pi - 8} = 3 - \cfrac{1 \cdot 1}{6 - \cfrac{2 \cdot 3}{9 - \cfrac{3 \cdot 5}{12 - \cfrac{4 \cdot 7}{15 - \ddots}}}}$$

Ramanujan Machine

2021



Raz et al., *From Euler to AI: Unifying Formulas for Mathematical Constants.* **NeurIPS** 38, 123959 (2025)

Ramanujan Machine

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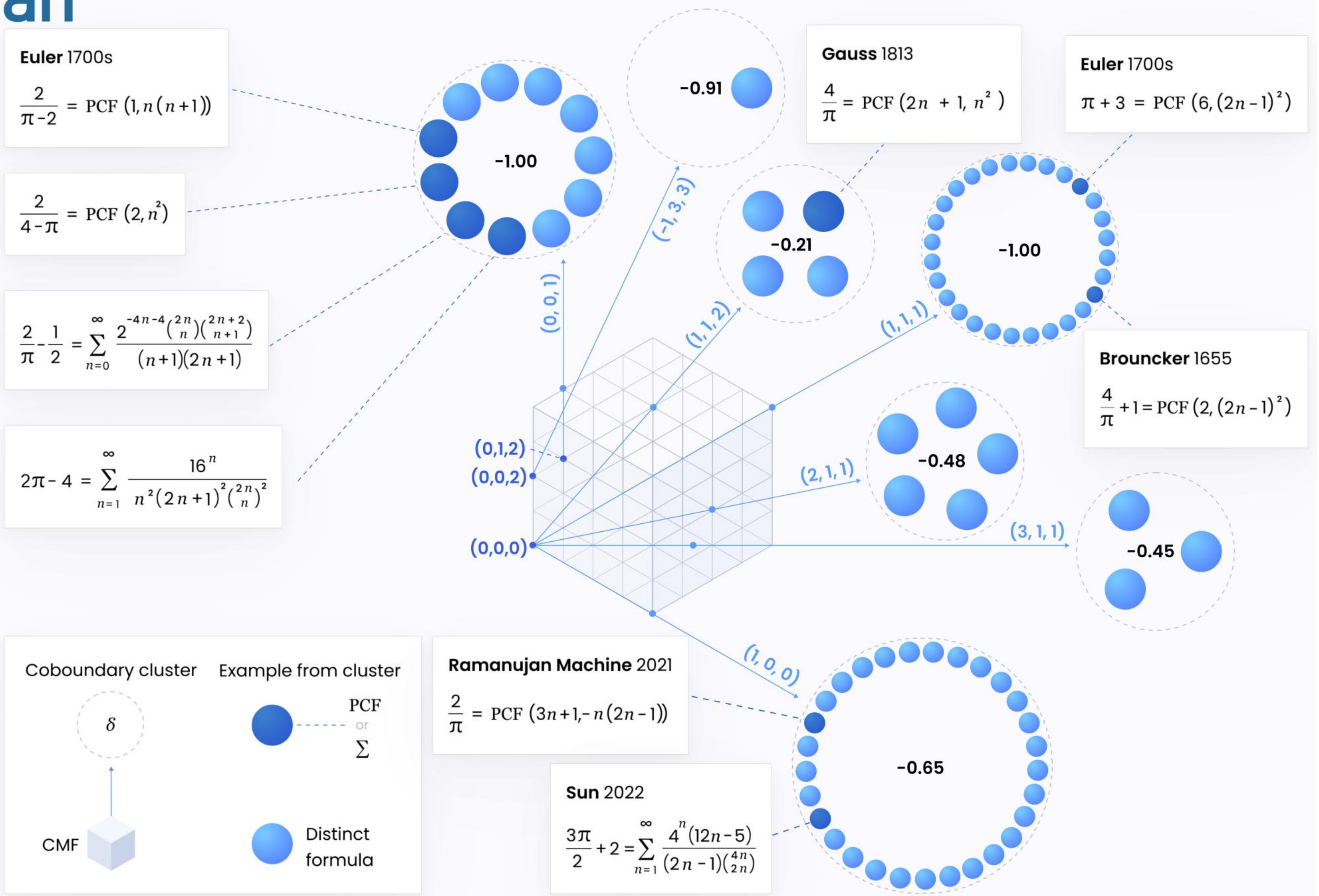
Unify math knowledge!

Combined AI-CAS



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References

ramanujantools
Python library for CMF exploration.

[1] Calegari, Dimitrov, Tang. *Cellular integrals and geometric irrationality proofs*, 2024.

[2] Beukers. *A note on the irrationality of $\zeta(2)$ and $\zeta(3)$*, Bull. London Math. Soc., 1979.

[3] Weinbaum, Leibtag, Kalisch, Shalyt, Kaminer. *On Conservative Matrix Fields*, arXiv:2507.08138, 2025.

[4] Raayoni et al. *Generating conjectures on fundamental constants with the Ramanujan Machine*, Nature, 2021.

[5] Dauguet–Zudilin. *On simultaneous Diophantine approximations to $\zeta(2)$ and $\zeta(3)$*, JNT, 2014.

[6] Zudilin. *Two hypergeometric tales and a new irrationality measure of $\zeta(2)$*, Ann. Math. Québec, 2014.

[7] Hata. *A note on Beukers' integral*, 1995.

[8] Rhin–Viola. *The group structure for $\zeta(3)$*, Acta Arith., 2001.

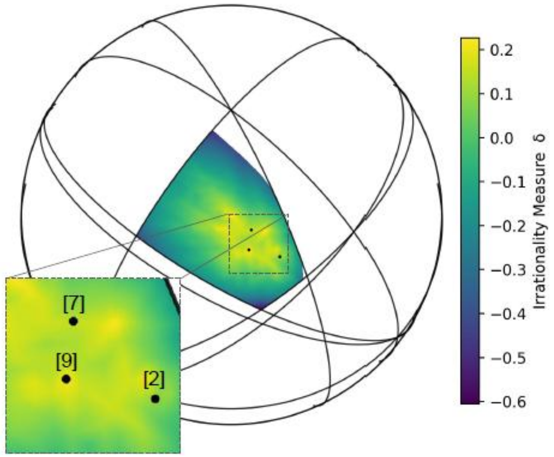
[9] Rhin–Viola. *On a permutation group related to $\zeta(2)$*, Acta Arith., 1996.

[10] Brown–Zudilin. *On cellular rational approximations to $\zeta(5)$*, arXiv:2210.03391, 2022.

[11] Zeilberger–Zudilin. *The irrationality measure of π is at most 7.103205334137...*, Moscow J. Comb. Number Theory, 2020.


Hila Barkan

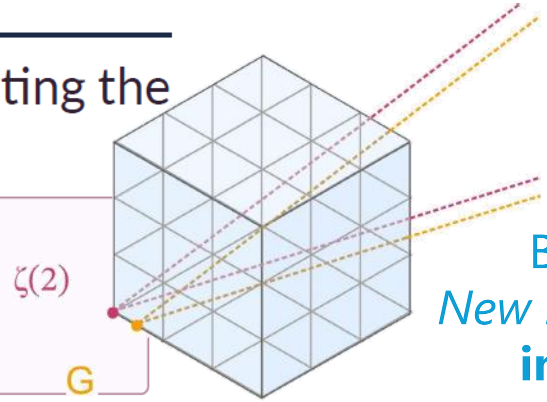

Elyasheev Leibtag



Integral $\rightarrow$ CMF

Rhin–Viola [9] generalize Beukers' $\zeta(2)$ double integral [2] by treating the exponents as free parameters.

$$\int_0^1\int_0^1 \frac{x^a(1-x)^b y^c(1-y)^d}{(1-xy)^e}\,dx\,dy.$$



Barkan, Leibtag, et al.
New Directions in Irrationality,
in preparation (2026)

References

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[1] Calegari, Dimitrov, Tang. *Cellular integrals and geometric irrationality proofs*, 2024.
[2] Beukers. *A note on the irrationality of $\zeta(2)$ and $\zeta(3)$*, Bull. London Math. Soc., 1979.
[3] Weinbaum, Leibtag, Kalisch, Shalyt,
[6] Zudilin. *Two hypergeometric tales and a new irrationality measure of $\zeta(2)$*, Ann. Math. Québec, 2014.
[7] Hata. *A note on Beukers' integral*, 1995.
[8] Rhin–Viola. *The group structure for $\zeta(3)$*, Acta Arith., 2001.


Hila Barkan


Elyasheev Leibtag

Results

Constant	Reference	CMF	δ	Initial point	Trajectory
Catalan's G	**This work**	${}_4F_3(z=1)$	-0.24	$(4,4,-\frac{1}{2},0;\frac{7}{2},\frac{7}{2},4)$	$(12,10,-2,-12;-1,0,2)$
$\zeta(2)$	**This work**	${}_4F_3(z=1)$	0.262	$(1,1,1,0;1,1,1)$	$(25,22,19,-21;3,6,9)$
$\zeta(2)+\zeta(3)$	**This work**	${}_4F_3(z=1)$	-0.00018	$(7,8,6,9;2,3,16)$	$(11,13,15,16;2,4,30)$
$\frac{4}{3\sqrt{3}}\mathcal{G}_{\mathrm{Gi}}$	**This work**	${}_3F_2(z=\frac{1}{4})$	-0.05	$(\frac{1}{2},\frac{1}{2},\frac{1}{2};\frac{3}{2},\frac{3}{2})$	$(5,7,6;17,18)$
Catalan's G	Ramanujan Machine, 2021 [4]	${}_3F_2(z=1)$	-0.43	$(1,1,\frac{3}{2},\frac{5}{2},\frac{5}{2})$	$(1,1,1,2,2)$
$\zeta(2)$	Zudilin, 2014 [6]	${}_4F_3(z=1)$	0.246	$(1,1,1,0,1,1,1)$	$(8,7,6,-6;1,2,3)$
$\zeta(2)+\zeta(3)$	Dauguet–Zudilin, 2014 [5]	${}_4F_3(z=1)$	-0.13	$(-5,10,9,8;3,2,1)$	$(0,1,1,1,1,1,1)$
$\frac{4}{3\sqrt{3}}\mathcal{G}_{\mathrm{Gi}}$	Calegari–Dimitrov–Tang, 2024 [1]	${}_3F_2(z=\frac{1}{4})$	-0.4765	$(\frac{1}{2},\frac{1}{2},\frac{1}{2};\frac{3}{2},\frac{3}{2})$	$(0,0,0;1,1)$
$\zeta(3)$	Rhin–Viola, 2001 [8]	$G^{4,2}_{4,4}(z=1)$	0.222	$(1,1,2,2;1,1,1,1)$	$(0,7,31,32,18,17,16,19)$
$\zeta(5)$	Brown–Zudilin, 2022 [10]	${}_8F_7(z=1)$	-0.14	$(5,2,2,2,2,2,2,2;4,4,4,4,4,4,4)$	$(42,17,16,15,14,13,12,11;24,25,26,27,28,29,30)$
π	Zeilberger–Zudilin, 2020 [11]	integral	0.16	$(1,1,2)$	$(2,2,3)$

Rotem Kalisch

Create and interact with CMFs

Ramanujan Tools

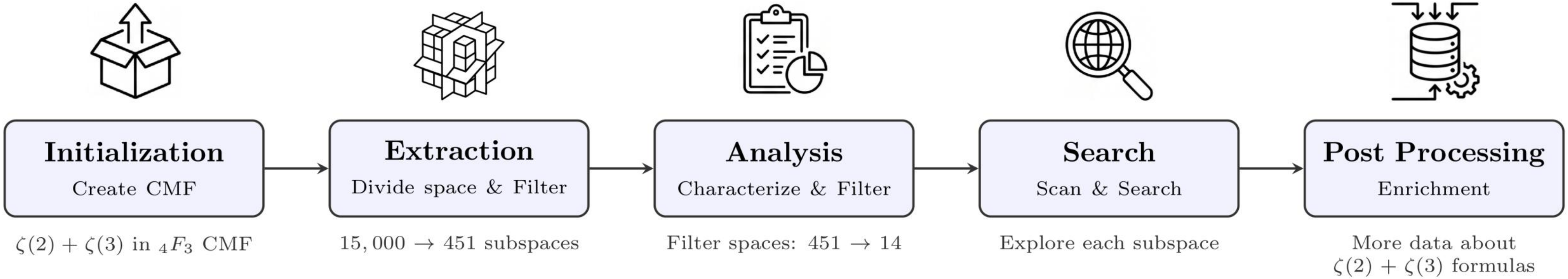
$\Longrightarrow$

Search and explore new formulas

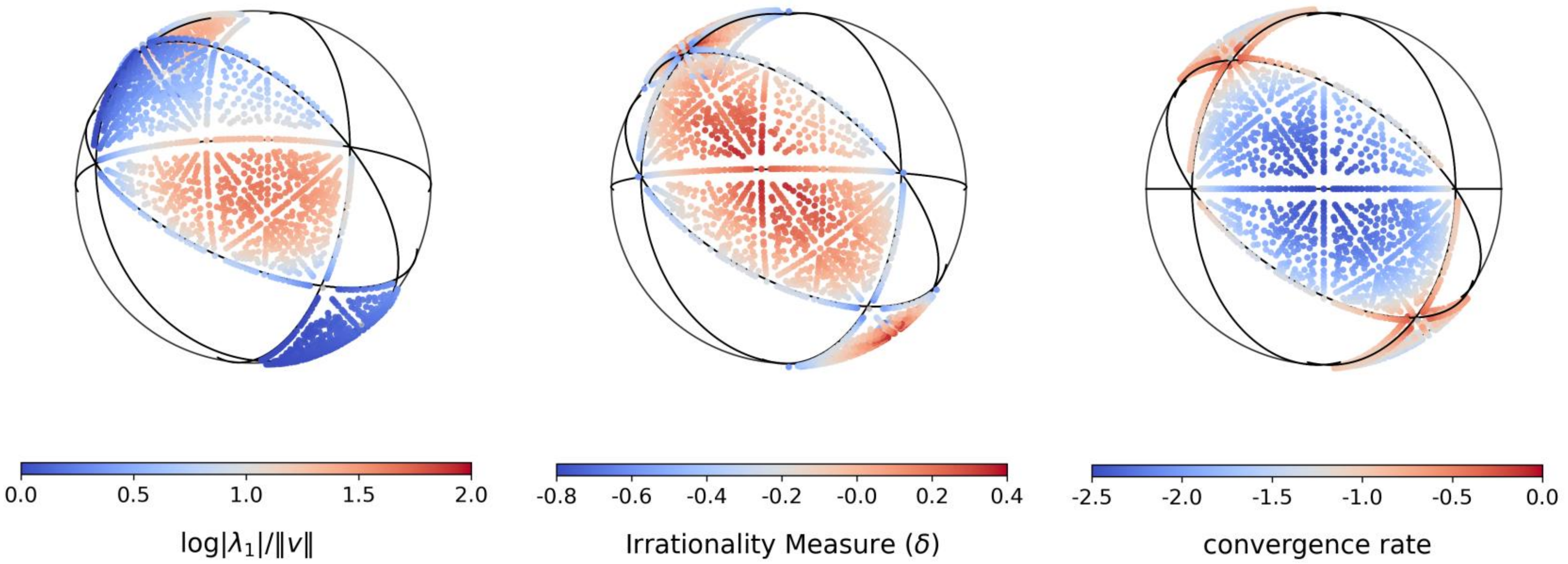
Ramanujan's Dreams

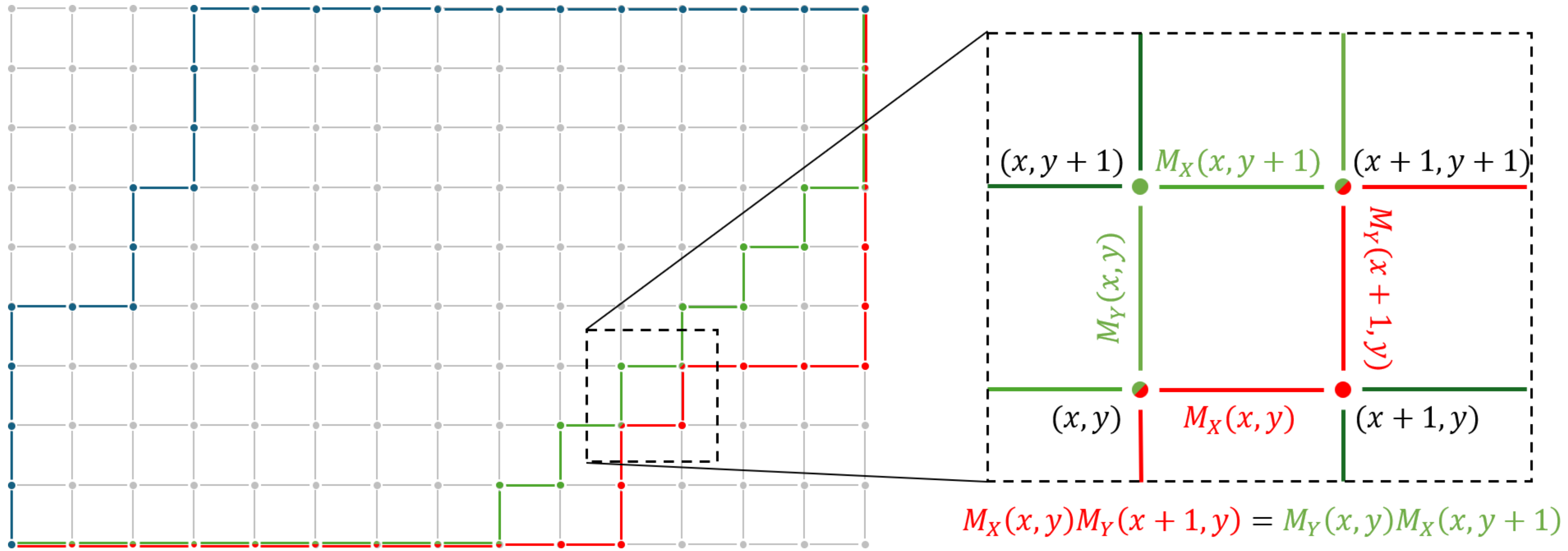
Hila Barkan

Uri Hitin



Hitin, et al. *A Computational Framework for Automated Discovery within Conservative Matrix Fields*, **in preparation** (2026)





Hila Barkan

Uri Hitin

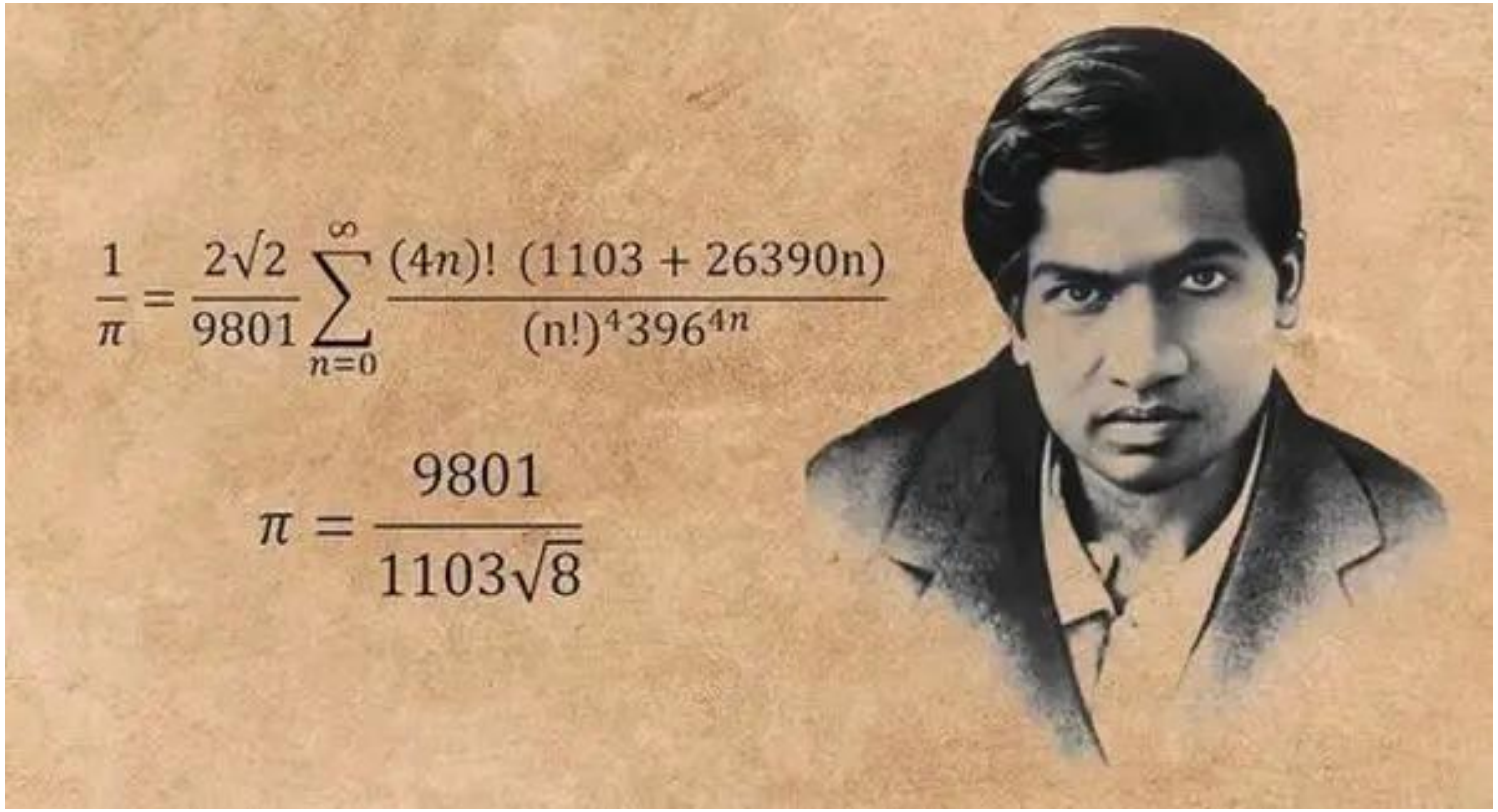
Shachar Weinbaum

Weinbaum et al. *On conservative matrix fields: Continuous asymptotics and arithmetic*, **arXiv**:2507.08138

Hitin, et al. *A Computational Framework for Automated Discovery within Conservative Matrix Fields*, **in preparation** (2026)

Human-AI Hybrid Mathematical Discovery Workflow: Unifying Ramanujan's 17 Series for $\frac{1}{\pi}$

Michael Shalyt



Modular equations and approximations to π

Quarterly Journal of Mathematics, XLV, 1914, 350 – 372

Shalyt, Leibtag, et al. *The Ramanujan AI Agent,* **in preparation** (2026); **ICML Workshop Oral Talk** (2026)

Result: all 17 formulas are in 4F3-based CMFs

Each formula trajectory is along the vector (0, 1, 1, 1; 1, 1, 1).
The initial point is (1, a2, a3, a4; 1, 1, 1). A, B are seed values.

#	formula	shift (a_2, a_3, a_4)	z	A	B
1	$\frac{4}{\pi} = \sum_{n\geq 0}(6n+1)\binom{2n}{n}^3 \frac{1}{2^{6n}}$	$\left(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\right)$	$\frac{1}{4}$	1	6
2	$\frac{16}{\pi} = \sum_{n\geq 0}(42n+5)\binom{2n}{n}^3 \frac{1}{2^{12n}}$	$\left(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\right)$	$\frac{1}{2^6}$	5	42
	$\dots$				
16	$\frac{2}{\pi\sqrt{11}} = \sum_{n\geq 0}(280n+19)\binom{2n}{n}^2\binom{4n}{2n}\frac{1}{2^{8n}99^{2n+1}}$	$\left(\frac{1}{4}, \frac{1}{2}, \frac{3}{4}\right)$	$\frac{1}{99^2}$	19	280
17	$\frac{1}{2\pi\sqrt{2}} = \sum_{n\geq 0}(26390n+1103)\binom{2n}{n}^2\binom{4n}{2n}\frac{1}{2^{8n}99^{4n+2}}$	$\left(\frac{1}{4}, \frac{1}{2}, \frac{3}{4}\right)$	$\frac{1}{99^4}$	1103	26390

Shalyt, Leibtag, et al. *The Ramanujan AI Agent,* **in preparation** (2026); **ICML Workshop Oral Talk** (2026)

Alexander I Aptekarev. “On linear forms containing the Euler constant”. In: *arXiv preprint arXiv:0902.1768* (2009).

Jeffrey Lagarias. “Euler’s constant: Euler’s work and modern developments”. In: *Bulletin of the American Mathematical Society* 50.4 (2013), pp. 527–628.

Rotem Kalisch

$$\boxed{(16n-15)y_{n+1} = (128n^3+40n^2-82n-45)y_n - n^2(256n^3-240n^2+64n-7)y_{n-1} + n^2(n-1)^2(16n+1)y_{n-2}.}$$

The initial conditions are

$$p_0 = 0, \qquad p_1 = 2, \qquad p_2 = 31,$$

$$q_0 = 1, \qquad q_1 = 3, \qquad q_2 = 50.$$

Then the rational approximants are

$$\frac{p_n}{q_n} \to \gamma.$$

Kalisch, et al. *An Infinite Family of Apery-like Recurrences for Euler’s Constant,* **in preparation** (2026)

For $n \geq 0$, define:

$$
\begin{aligned}
0 = & \left(-8n^3 - 51n^2 - 105n - 68\right) u_n \\
& + \left(24n^5 + 337n^4 + 1833n^3 + 4818n^2 + 6092n + 2928\right) u_{n-1} \\
& - (n+2)(n+3)\left(24n^5 + 273n^4 + 1150n^3 + 2154n^2 + 1635n + 268\right) u_{n-2} \\
& + (n+1)(n+2)^4(n+3)\left(8n^3 + 75n^2 + 231n + 232\right) u_{n-3}
\end{aligned}
$$

Rotem Kalisch

Let $\mathrm{t}_0 = (0,0;1,1,1)$, yielding

$$
\mathcal{M}_{\mathrm{t}_0}(n) = \begin{pmatrix} 1 & n^3 & (n-1)(3n+3)(n^2+n+1) \\ 2 & 1-3n^2 & -(n+1)(8n^2+n+5) \\ 1 & 3n+2 & 6n(n+1) \end{pmatrix}.
$$

For a gen

A Meijer G Identity

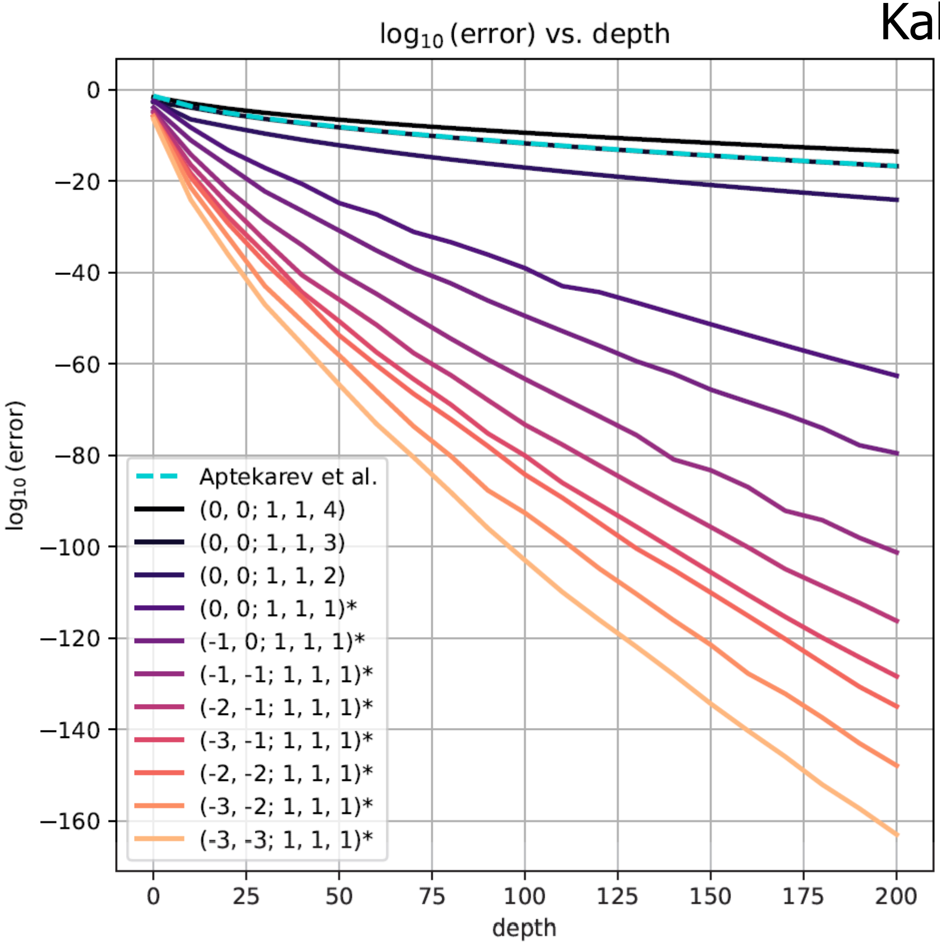
Let $r \in \mathbb{N}_{\geq 3}$, $\theta = z\frac{d}{dz}$ and define $G_r(z) = G^{r,r-1}_{r-1,r}\left(\begin{matrix} 0,\dots,0 \\ 0,0,\dots,0 \end{matrix}\middle| z\right)$.

Define the two differential operators

$$
N_r = (1+\theta)^{r-3} + (-1)^{r-1}\theta^{r-2}, \qquad D_r = (1+\theta)^{r-2} + (-1)^{r-1}\theta^{r-1}.
$$

Then

$$
\boxed{N_r[G_r](1) = \gamma, \qquad D_r[G_r](1) = 1.}
$$



Kalisch, et al. *An Infinite Family of Apery-like Recurrences for Euler's Constant*, **in preparation** (2026)


Michael Shalyt


Elyasheev Leibtag


Rotem Kalisch


Shachar Weinbaum


Hila Barkan


Uri Hitin


Stav Bley

Barkan, Leibtag, et al. *New Directions in Irrationality,* **in preparation** (2026)

Hitin, et al. *A Computational Framework for Automated Discovery within Conservative Matrix Fields,* **in preparation** (2026)

Weinbaum et al. *On conservative matrix fields: Continuous asymptotics and arithmetic,* **arXiv**:2507.08138

Kalisch, et al. *An Infinite Family of Apery-like Recurrences for Euler's Constant,* **in preparation** (2026)

Shalyt, Leibtag, et al. *The Ramanujan AI Agent,* **in preparation** (2026); **ICML Workshop Oral Talk** (2026)

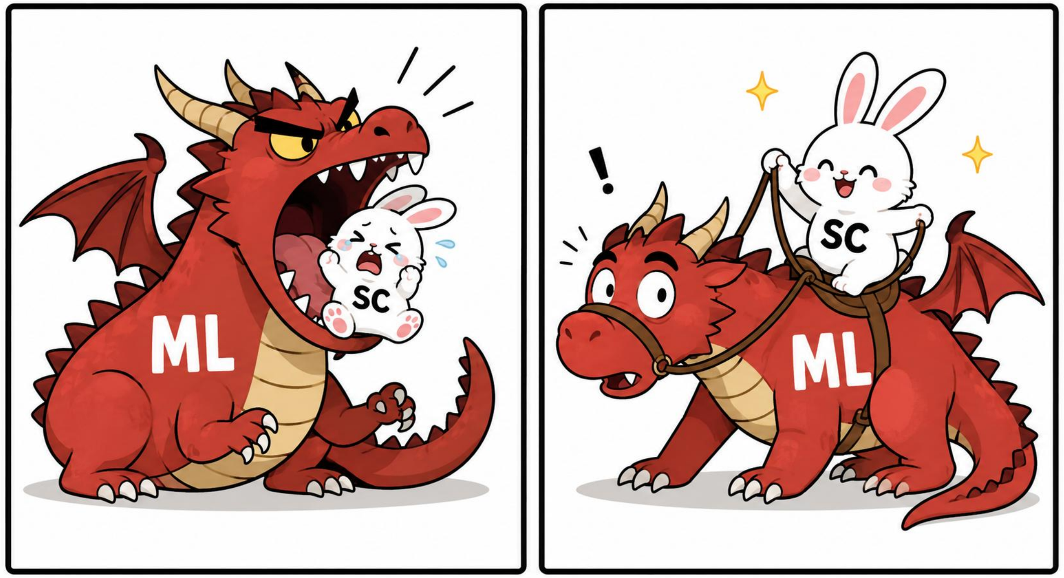
Our field is changing, under the pressure and promise of AI…
We should all **take part in shaping how our journals and our community will adapt**

Join us!

After the rise of AI… what is the future of computer algebra systems / symbolic computation?

Intrinsic mastery

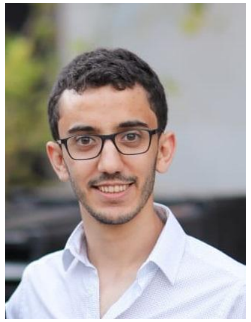
Autonomous tool creation



Symbiotic integration

Michael Shalyt

ASyMOB: Algebraic Symbolic Mathematical Operations Benchmark



Rotem Elimelech

- 35,368 symbolic math problems: integration, limits, differential equations, series, …
- Solutions can be validated
- **Testing the benefit from LLMs using symbolic computation**

Seed Question

<Code / No-Code Prompt>

Solve the following integral.

$$\int_1^2 \frac{e^x(x-1)}{x(x+e^x)}dx$$

Solution:

$$\ln\left(\frac{2+e^2}{2+2e}\right)$$

Symbolic Perturbation

<Code / No-Code Prompt>

Solve the following integral.
Assume A, B, F, G are real and positive.

$$\int_1^2 \frac{Ae^{Fx}(Fx-1)}{Fx\,(Be^{Fx}+FGx)}dx$$

Solution:

$$\frac{A}{BF}\cdot\ln\left(\frac{e^2B+2G}{2(eB+G)}\right)$$

No-Code Prompt	*Assume you don't have access to a computer, and do not use code to solve the question.*
Code Prompt	*Please use Python to solve the question.*

Shalyt, Elimelech, et al., **ICML** (2026)

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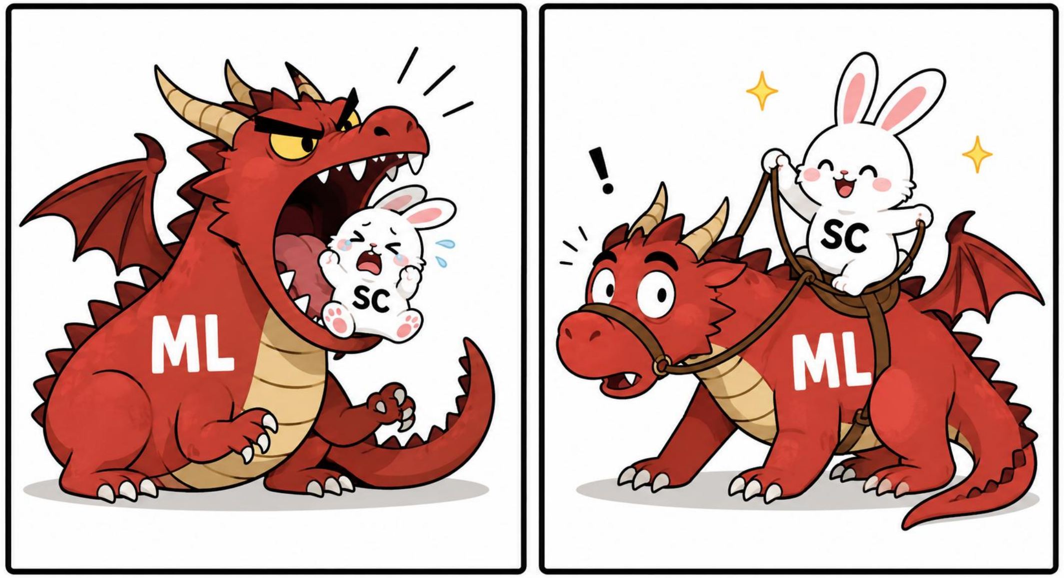
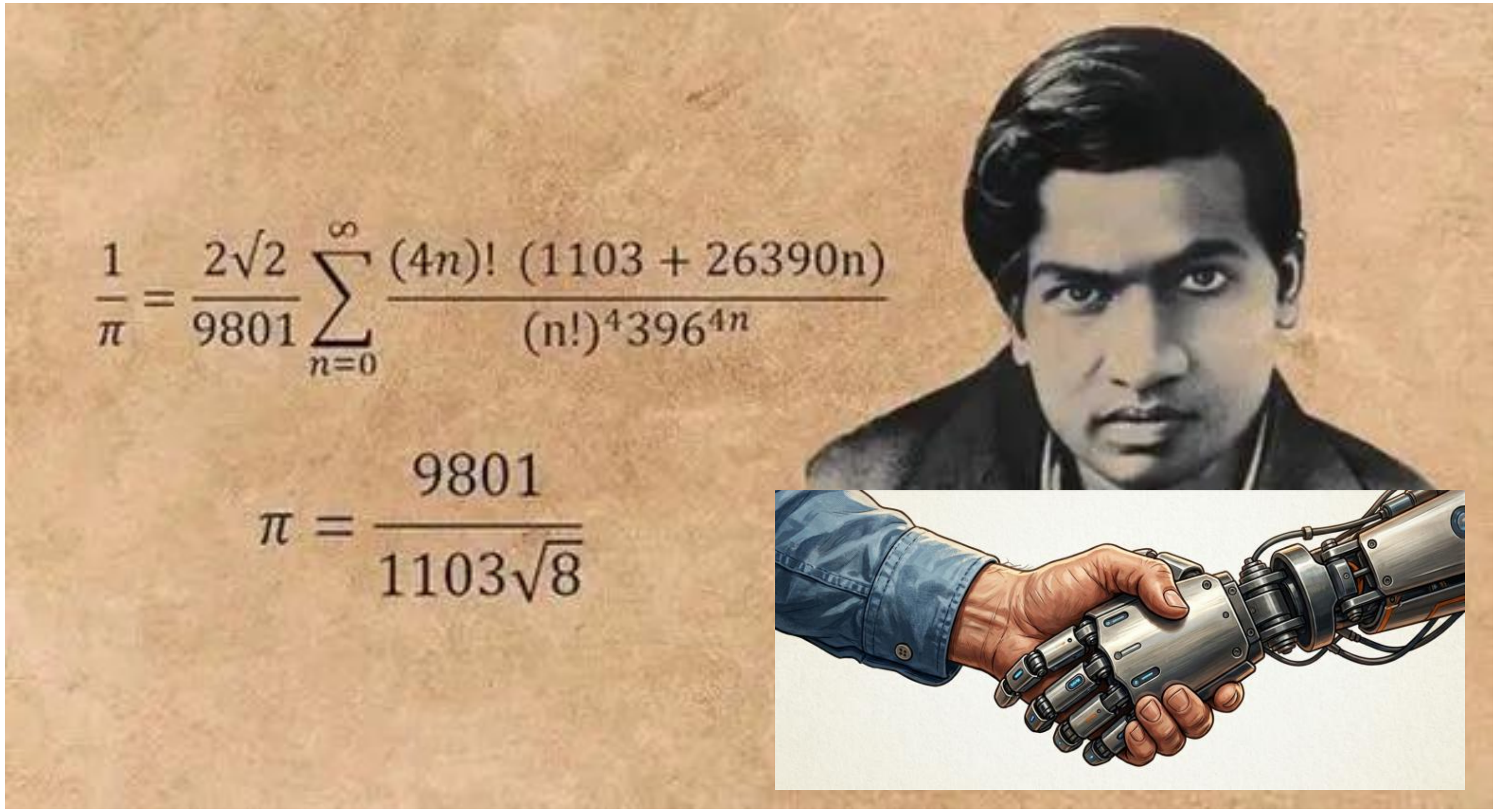


Symbiotic integration

Human-AI Hybrid Mathematical Discovery Workflow: Unifying Ramanujan's 17 Series for $\frac{1}{\pi}$

Michael Shalyt



Modular equations and approximations to π

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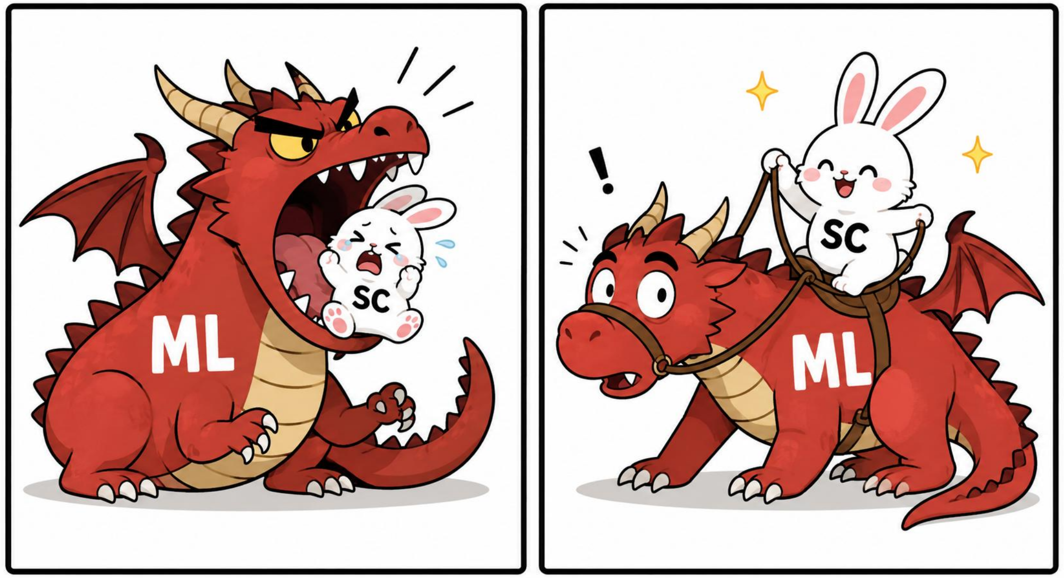
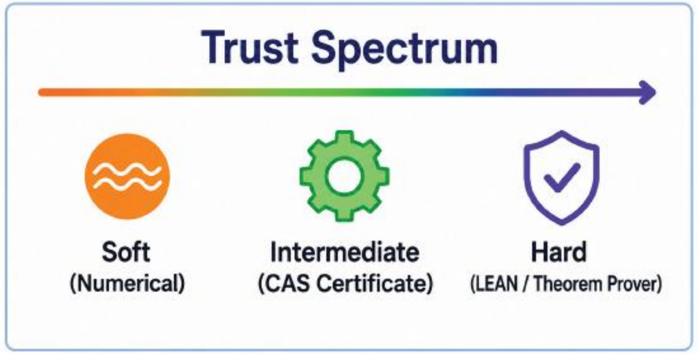
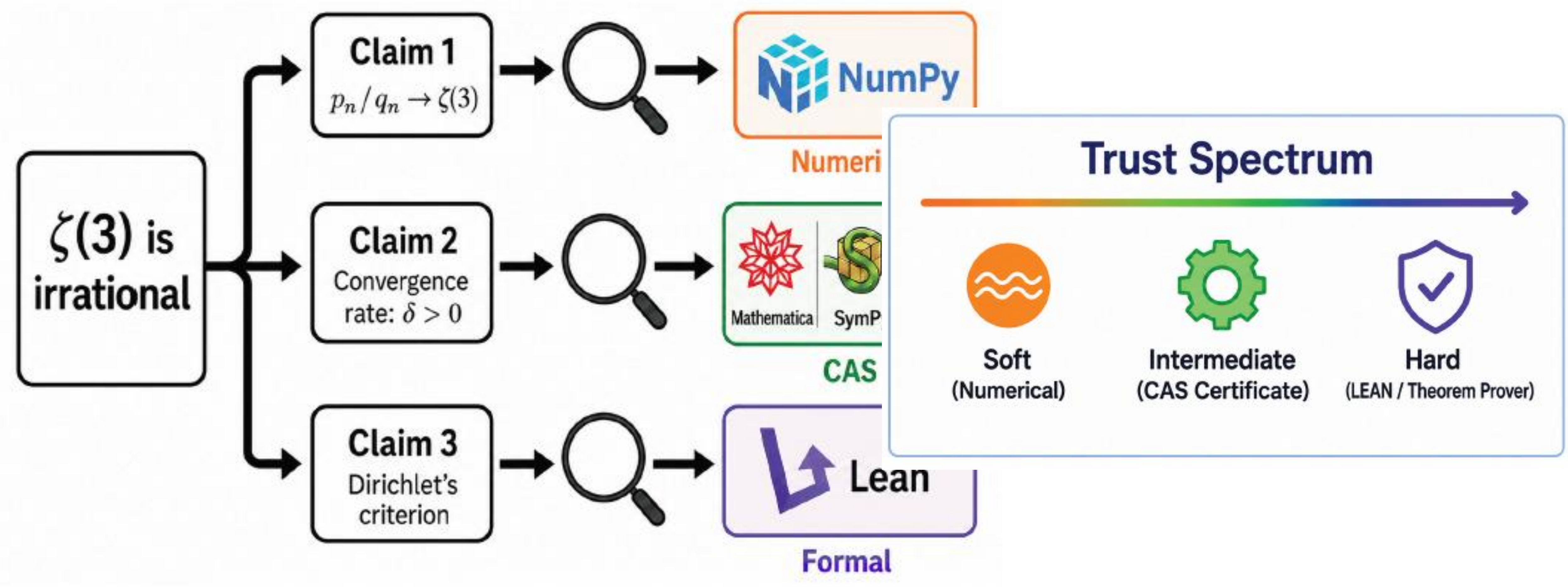


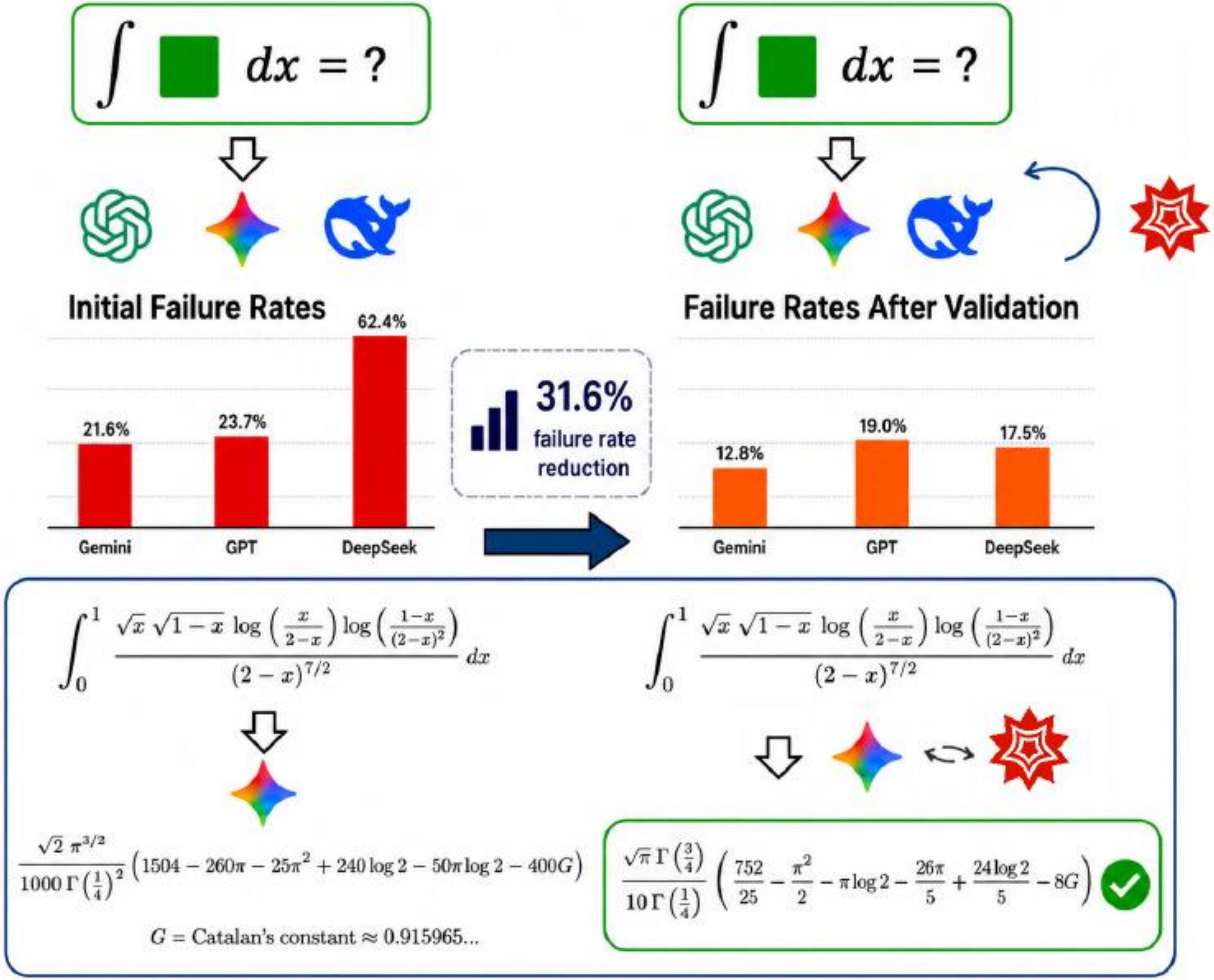
Symbiotic integration

Increase trust in AI





$\zeta(3)$ is irrational
Claim 1
$p_n/q_n \to \zeta(3)$
Claim 2
Convergence rate: $\delta > 0$
Claim 3
Dirichlet's criterion
NumPy
Numeri
Mathematica
SymP
CAS
Lean
Formal
Trust Spectrum
Soft
(Numerical)
Intermediate
(CAS Certificate)
Hard
(LEAN / Theorem Prover)

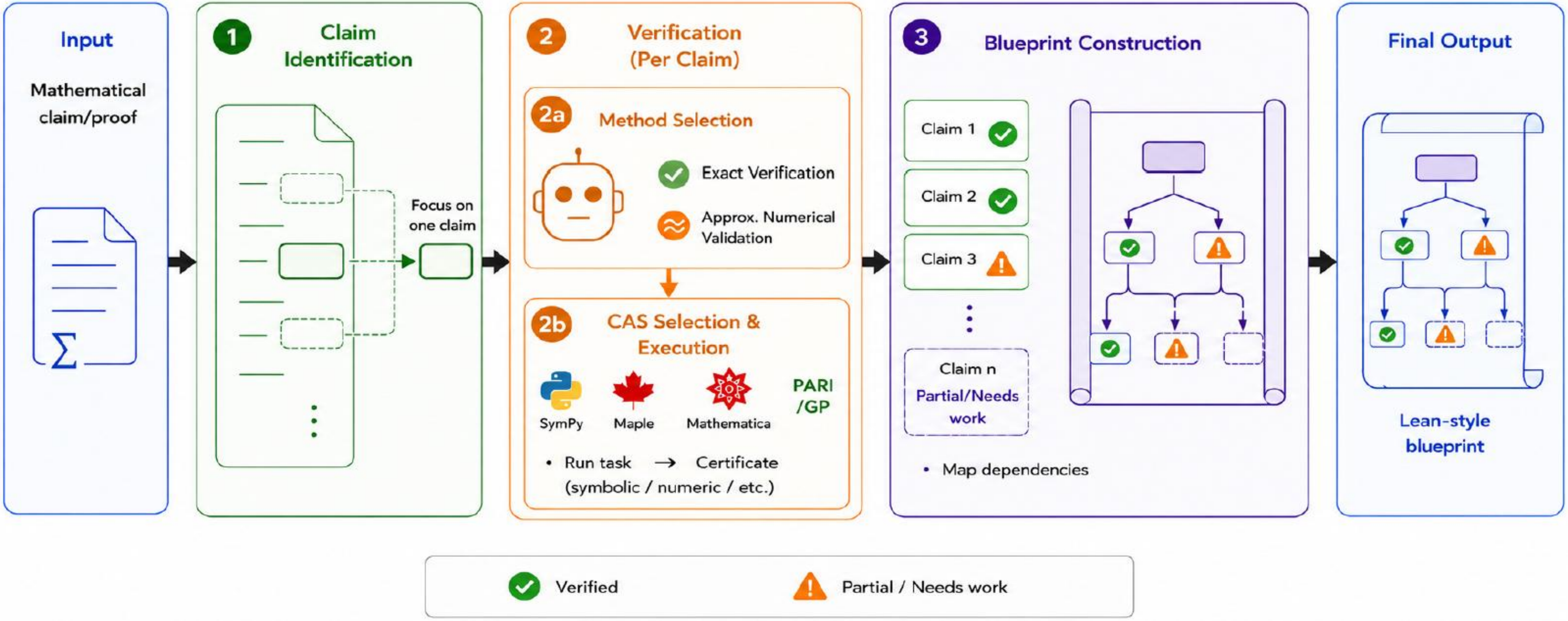


Stav
Bley

Bley, et al. *Generate, Verify, Refine: A Closed-Loop LLM–CAS Approach to Symbolic Integration*, **in preparation** (2026)

TECHNION Israel Institute of Technology | TECHNION 100

Ramanujan Machine



After the rise of AI… what is the future of computer algebra systems / symbolic computation?

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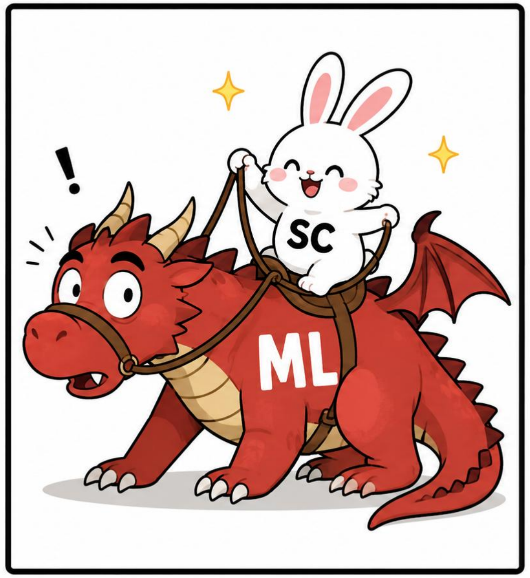
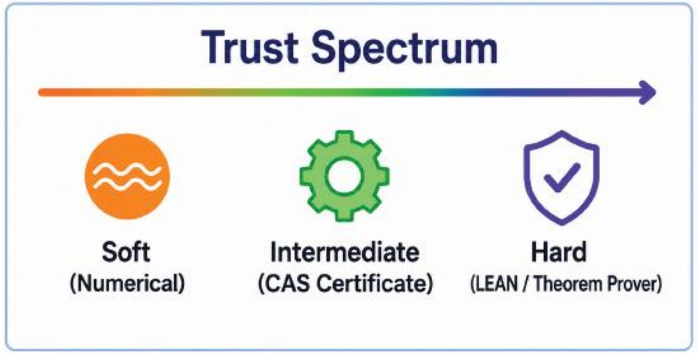


Symbiotic integration

Increase trust in AI



Ramanujan Machine

l... what is the future of
ms / symbolic computation?

Au

The Ramanujan Challenge For AI

Ramanujan Machine Group*

Abstract

To help evaluate the mathematical skills of current AI systems, we present a set of formulas for fundamental mathematical constants. These problems are attractive for AI evaluation because they are concrete and can be checked numerically to arbitrary precision, yet proving them may require non-obvious mathematics. Mathematical constants such as π, e, Catalan's constant, and special values of the Riemann zeta function have fascinated mathematicians for centuries. The search for formulas evaluating mathematical constants has produced some of the most beautiful mathematics in the field, especially in cases that yield irrationality proofs or fast convergence rates. Ramanujan's legacy is emblematic of this tradition. The list we provide contains two types of problems: formulas whose proofs are known to the authors but will remain encrypted for a short initial period; and formulas that are not yet proven. We are curious to see the achievements of AI in both cases.

Problem	Name	Contributor
2.1	Polynomial continued fraction for π	Michael Shalyt[1]
2.2	Euler's constant γ as an Apéry limit	Rotem Kalisch[1]
2.3	The sum $\pi + e$ as an Apéry limit	
2.4	A series of harmonic numbers converging to a polylogarithm combined with zeta values	Carsten Schneider[2]
2.5	Efficient rational approximation of Catalan's constant G	Hila Barkan[1]
2.6	A series for $\zeta(2)+\zeta(3)$	
2.7	Efficient four-term recurrence for $\zeta(2)+\zeta(3)$	Elyasheev Leibtag[3]
2.8	Very fast rational approximation of $\sqrt{10005}/\pi$	
3.1	An integral over knot polynomial roots expressing π^2	John Campbell[4]
3.2	Optimality of Apéry's irrationality-measure bound for $\zeta(3)$	Shachar Weinbaum[1]

Role	Name	Email
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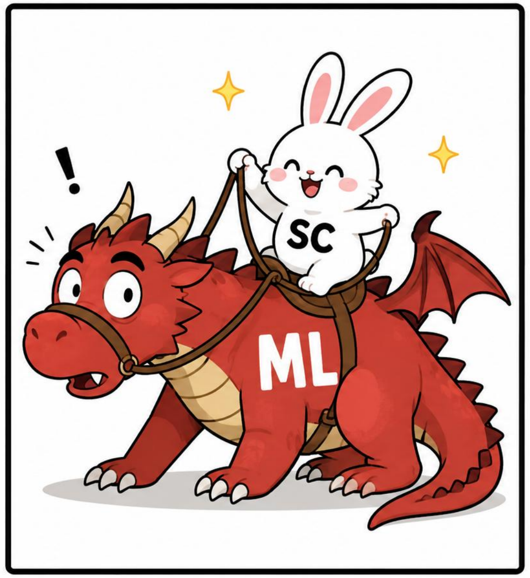
Validation	Ashvni Narayanan[1]	ashvni.n@campus.technion.ac.il
Principal Investigator	Ido Kaminer[1]	kaminer@technion.ac.il

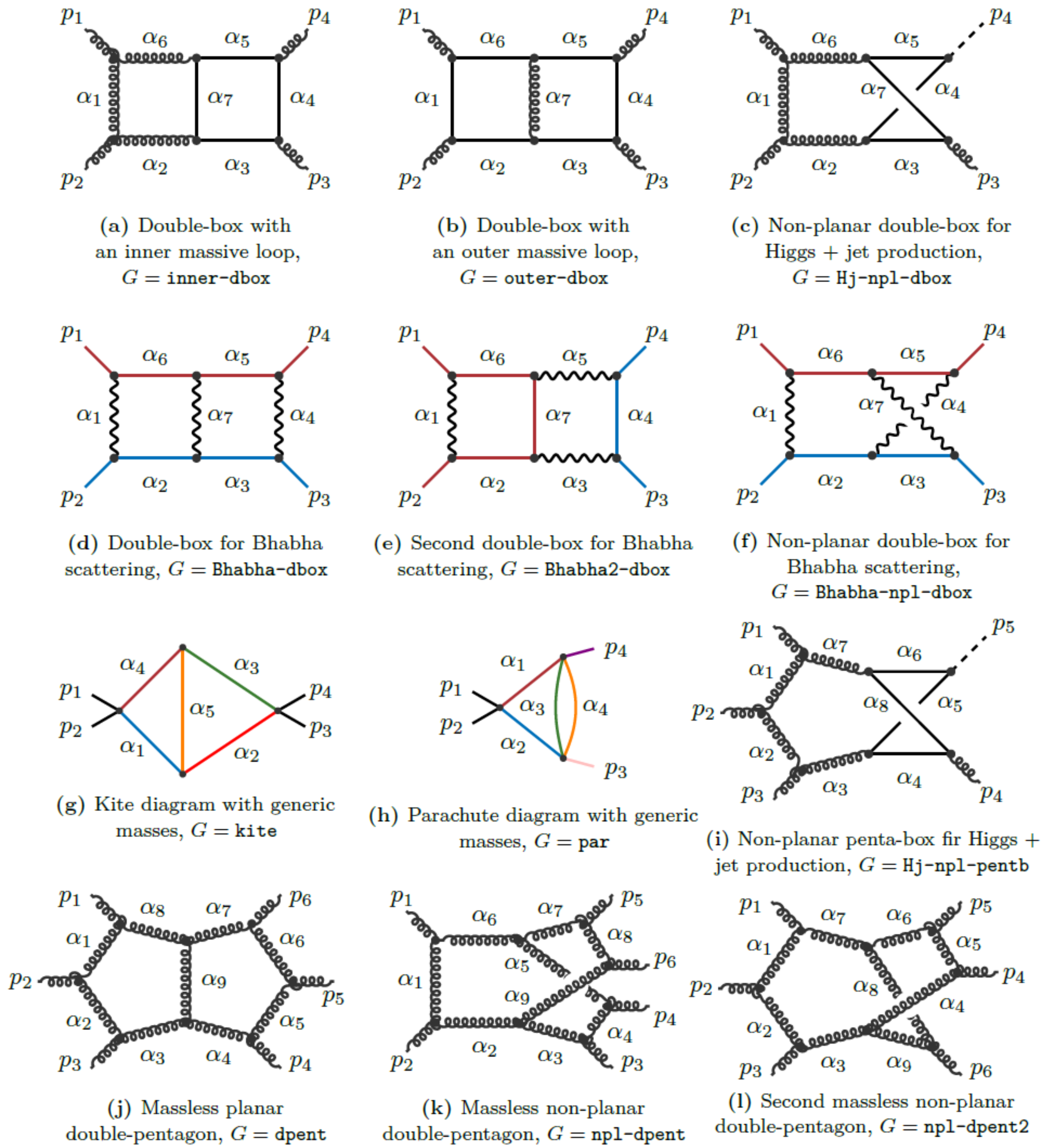
[1]Ramanujan Machine Group, Technion, Haifa, Israel.
[2]Research Institute for Symbolic Computation, Johannes Kepler Universität Linz, Linz, Austria.
[3]Department of Mathematics, Computer Science and Statistics, Ghent University, Ghent, Belgium.
[4]Department of Mathematics and Statistics, Toronto Metropolitan University, Toronto, Canada.
*ramanujan.machine@gmail.com



Symbiotic integration

Increase trust in AI

Hard problems that AI cannot solve without CAS



(a) Double-box with an inner massive loop, $G =$ `inner-dbox`

(b) Double-box with an outer massive loop, $G =$ `outer-dbox`

(c) Non-planar double-box for Higgs + jet production, $G =$ `Hj-npl-dbox`

(d) Double-box for Bhabha scattering, $G =$ `Bhabha-dbox`

(e) Second double-box for Bhabha scattering, $G =$ `Bhabha2-dbox`

(f) Non-planar double-box for Bhabha scattering, $G =$ `Bhabha-npl-dbox`

(g) Kite diagram with generic masses, $G =$ `kite`

(h) Parachute diagram with generic masses, $G =$ `par`

(i) Non-planar penta-box fir Higgs + jet production, $G =$ `Hj-npl-pentb`

(j) Massless planar double-pentagon, $G =$ `dpent`

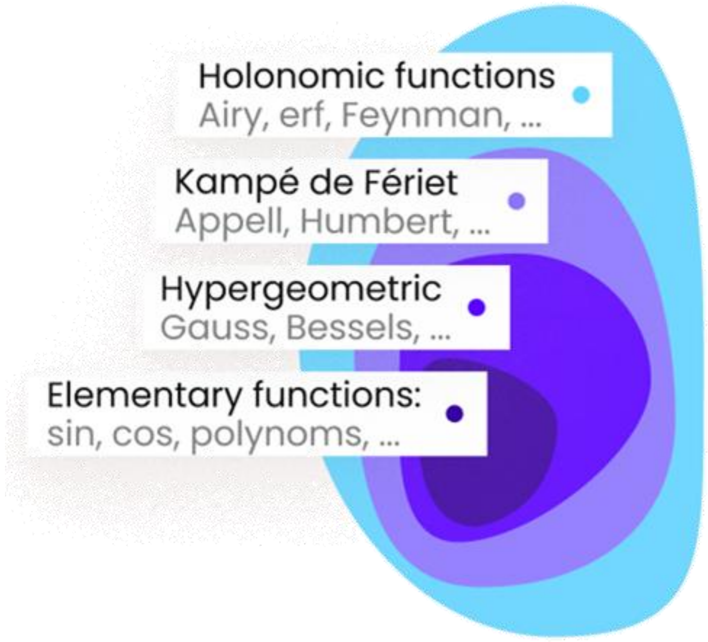
(k) Massless non-planar double-pentagon, $G =$ `npl-dpent`

(l) Second massless non-planar double-pentagon, $G =$ `npl-dpent2`

Automating QFT research

The state-of-the-art in modern particle-physics computation

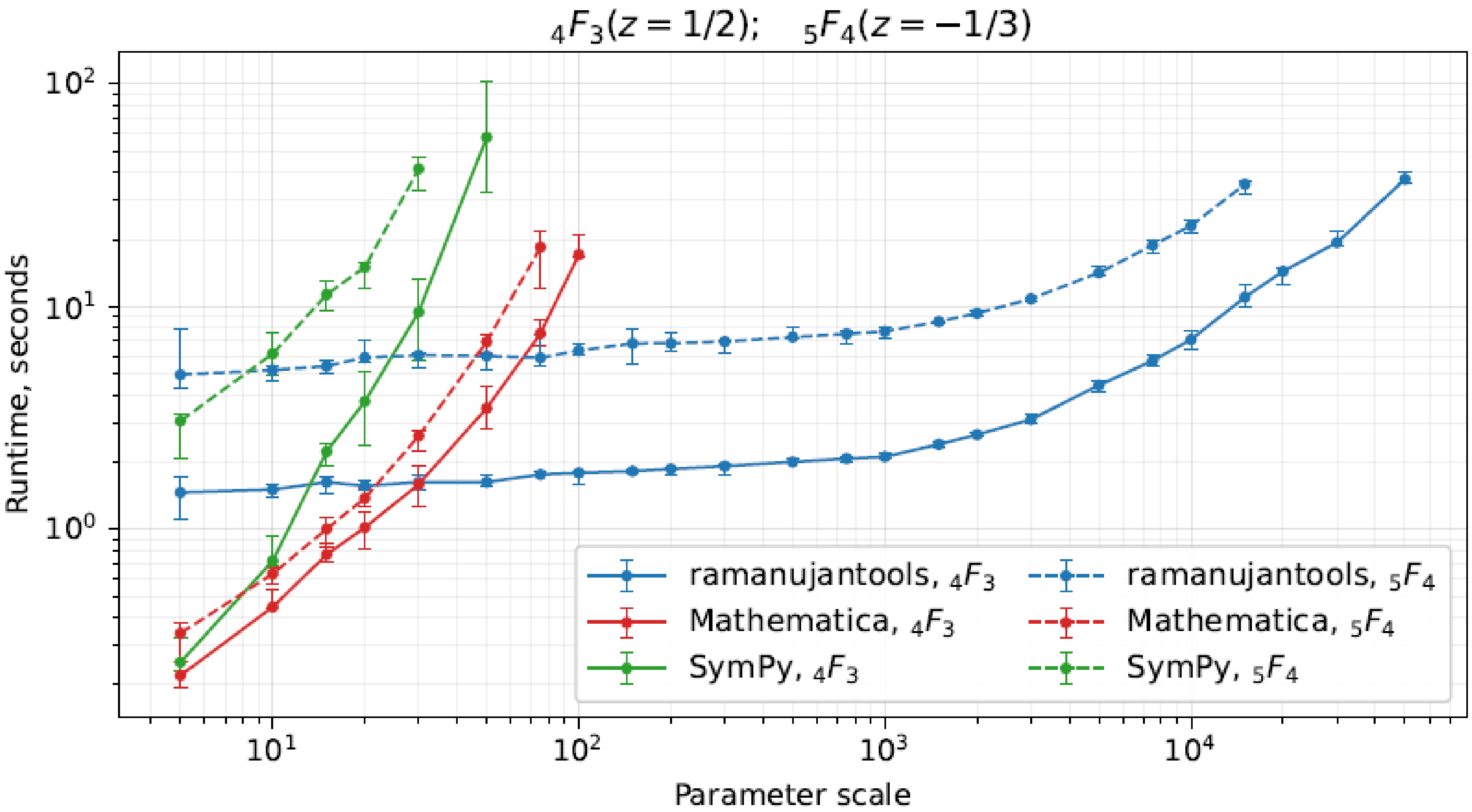
Computing Feynman integrals:
⇒ Gelfand, Kapranov, and Zelevinsky (GKZ) systems
⇒ hypergeometric functions
⇒ their generalizations



Fevola, Mizera, Telen, “Principal Landau Determinants“, **Computer Physics Communications** 303, 109278 (2024)

Michael Shalyt

Rotem Kalisch



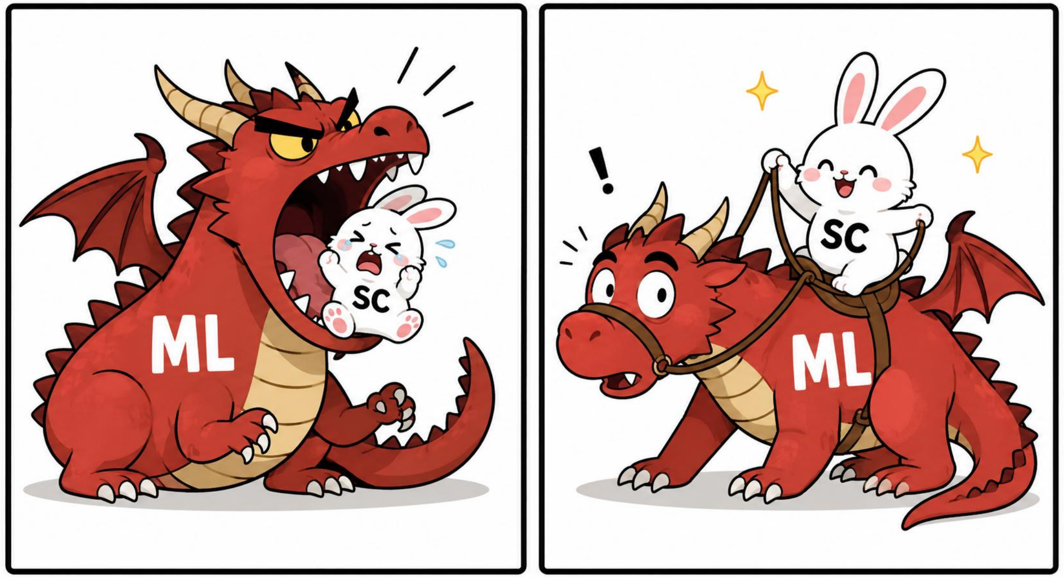
$$g^{(4d)}_{160,60}(z,\bar{z}) = \frac{z\bar{z}}{z-\bar{z}}\Big[z^{110}\bar{z}^{49}\,{}_2F_1(110,110;220;z)\,{}_2F_1(49,49;98;\bar{z}) - z^{49}\bar{z}^{110}\,{}_2F_1(49,49;98;z)\,{}_2F_1(110,110;220;\bar{z})\Big]$$

$$_4F_3\left(\begin{matrix}2,2,2,2\\3,4,5\end{matrix}\middle|-1\right) = 6\left(18\zeta(3)+\pi^2+288\log(2)-231\right) = 0.79809995535782920915577332222\ldots$$

After the rise of AI… what is the future of computer algebra systems / symbolic computation?

Intrinsic mastery

Autonomous tool creation



Symbiotic integration

Increase trust in AI

Hard problems that AI cannot solve without CAS

Bottom-Up Inference from Low-energy Descriptions (BUILD)

$$\mathcal{L}_{\mathrm{G}}(x) = \frac{1}{16\pi G} \{\kappa^2 [-\tfrac{1}{4} h^{\alpha}{}_{\alpha,\mu} h^{\beta,\mu}_{\beta} + \tfrac{1}{4} h^{\alpha}{}_{\beta,\mu} h^{\beta,\mu}_{\alpha} + \tfrac{1}{2} h^{\alpha}{}_{\alpha,\beta} h^{\beta,\mu}_{\mu}$$

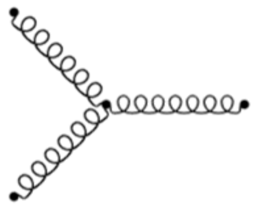
$$- \tfrac{1}{2} h^{\mu,\alpha}_{\beta} h^{\beta}{}_{\alpha,\mu}] + \sum_{n=3}^{\infty} \kappa^n \mathcal{L}_n(x)\}.$$

$$\mathcal{L}_3(x) = h^{\alpha,\mu}_{\beta} h^{\nu}_{\alpha} h^{\beta}{}_{\mu,\nu} - \tfrac{1}{2} h^{\alpha}_{\beta} h^{\beta,\mu}_{\nu} h^{\nu}{}_{\alpha,\mu} + \tfrac{1}{2} h^{\alpha}_{\beta} h^{\mu,\nu}_{\alpha} h^{\beta}{}_{\nu,\mu}$$

$$+ \tfrac{1}{2} h^{\alpha}_{\beta} h^{\beta,\mu}_{\alpha} h^{\nu}{}_{\nu,\mu} + \tfrac{1}{4} h^{\alpha}{}_{\beta,\mu} h^{\beta,\nu}_{\alpha} h^{\mu}_{\nu} + \tfrac{1}{2} h^{\alpha,\mu}{}_{\alpha,\nu} h^{\beta}_{\mu} h^{\nu}_{\beta}$$

$$- \tfrac{1}{4} h^{\mu}_{\mu} h^{\alpha}{}_{\beta,\nu} h^{\nu,\beta}_{\alpha} + \tfrac{1}{8} h^{\alpha}_{\alpha} h^{\mu,\beta}_{\nu} h^{\nu}{}_{\mu,\beta} - \tfrac{1}{8} h^{\alpha}_{\alpha} h^{\beta,\mu}_{\beta} h^{\nu}{}_{\nu,\mu}$$

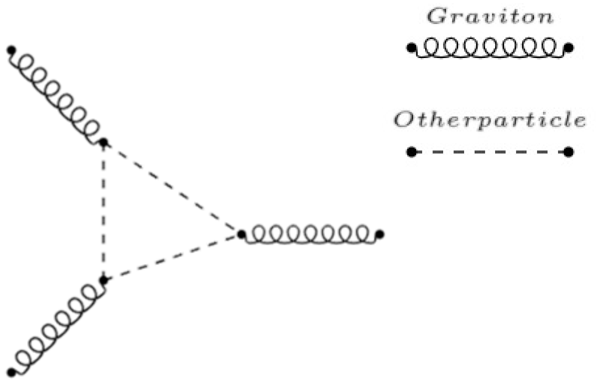
$$- \tfrac{1}{4} h^{\alpha}_{\alpha} h^{\mu,\nu}{}_{\mu,\beta} h^{\beta}_{\nu} + \tfrac{1}{2} h^{\mu}_{\nu} h^{\nu,\alpha}{}_{\mu,\beta} h^{\beta}_{\alpha},$$



<u>Effective Field Theory</u>:

General Relativity

perturbative expansion of the Einstein-Hilbert Lagrangian around *flat spacetime*



<u>Full Quantum Field Theory</u>:

Quantum Gravity

the curvature of spacetime emerges from an interaction?

Lifshitz, et al. *Emergent Curvature from Flat-Space QFTs: A Computational Search for Quantum Gravity*, **in preparation** (2026)

$$0 \to \frac{e\,Mphi^3 \left(-3\,DpDph1-8\,(DpDph2+pph)+2\,(DpDph1+4\,(DpDph2+pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{256\,\pi^2}$$

$$0 \to \frac{e^2\,Mphi^2 \left(9\,DpDph1^2+4\,DpDph1\,(7\,DpDph2+4\,pph)-8\,(-4\,DpDph2^2+8\,DpDphh1+8\,DpDphh2+3\,DpDphh3+3\,DpDphh4-4\,DpDph2\,pph+8\,pphh1+8\,pphh2)-2\,(3\,DpDph1^2+4\,DpDph1\,(3\,DpDph2+2\,pph)+8\,(3\,DpDph2^2-4\,DpDphh1-4\,DpDphh2-DpDphh3-DpDphh4+4\,DpDph2\,pph+pph^2-4\,pphh1-4\,pphh2))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{512\,\pi^2}$$

$$0 \to -\frac{e^2\,Mphi^2 \left(-3\,DpDph1^2-2\,DpDph1\,(7\,DpDph2+4\,pph)+2\,(-8\,DpDph2^2+8\,DpDphh1+16\,DpDphh2+6\,DpDphh3+3\,DpDphh4-8\,DpDph2\,pph+8\,pphh1+16\,pphh2)+2\,(DpDph1^2+DpDph1\,(6\,DpDph2+4\,pph)+2\,(6\,DpDph2^2-4\,DpDphh1-8\,DpDphh2-2\,DpDphh3-DpDphh4+8\,DpDph2\,pph+2\,pph^2-4\,pphh1-8\,pphh2))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{128\,\pi^2}$$

$$0 \to \frac{e^3\,Mphi \left(-45\,DpDph1^3-36\,DpDph1^2\,(5\,DpDph2+2\,pph)+24\,DpDph1\,(-11\,DpDph2^2+14\,DpDphh1+14\,DpDphh2+9\,DpDphh3+9\,DpDphh4-8\,DpDph2\,pph+8\,pphh1+8\,pphh2)-16\,(10\,DpDph2^3+6\,DpDph2^2\,pph-2\,pph\,(12\,DpDphh1+12\,DpDphh2+6\,DpDphh3+6\,DpDphh4+pph^2)-3\,DpDph2\,(16\,DpDphh1+16\,DpDphh2+7\,DpDphh3+7\,DpDphh4+2\,pph^2+8\,pphh1+8\,pphh2))+6\,(5\,DpDph1^3+12\,DpDph1^2\,(2\,DpDph2+pph)+8\,DpDph1\,(6\,DpDph2^2-6\,DpDphh1 \ldots}{3072\,\pi^2}$$

$$0 \to \frac{e^3\,Mphi \left(45\,DpDph1^3+72\,DpDph1^2\,(5\,DpDph2+2\,pph)-6\,DpDph1\,(-154\,DpDph2^2+70\,DpDphh1+196\,DpDphh2+72\,DpDphh3+27\,DpDphh4-112\,DpDph2\,pph+40\,pphh1+112\,pphh2)+4\,(140\,DpDph2^3+84\,DpDph2^2\,pph-4\,pph\,(30\,DpDphh1+84\,DpDphh2+42\,DpDphh3+15\,DpDphh4+7\,pph^2)-3\,DpDph2\,(80\,DpDphh1+224\,DpDphh2+98\,DpDphh3+35\,DpDphh4+28\,pph^2+40\,pphh1+112\,pphh2))-6\,(5\,DpDph1^3+224\,DpDph2^3+336\,DpDph2^2\,pph+24\,DpDp \ldots}{1152\,\pi^2}$$

$$0 \to \frac{e^3\,Mphi \left(-9\,DpDph1^3-12\,DpDph1^2\,(5\,DpDph2+2\,pph)+12\,DpDph1\,(-11\,DpDph2^2+7\,DpDphh1+14\,DpDphh2+6\,DpDphh3+3\,DpDphh4-8\,DpDph2\,pph+4\,pphh1+8\,pphh2)+4\,(-20\,DpDph2^3-12\,DpDph2^2\,pph+4\,pph\,(6\,DpDphh1+12\,DpDphh2+6\,DpDphh3+3\,DpDphh4+pph^2)+3\,DpDph2\,(16\,DpDphh1+32\,DpDphh2+14\,DpDphh3+7\,DpDphh4+4\,pph^2+8\,pphh1+16\,pphh2))+6\,(DpDph1^3+32\,DpDph2^3+48\,DpDph2^2\,pph+4\,DpDph1^2\,(2\,DpDph2+pph)+4\,DpDp \ldots}{384\,\pi^2}$$

$$0 \to -\frac{e^4 \left(9\,DpDph1^4+6\,DpDph1^3\,(13\,DpDph2+4\,pph)-6\,DpDph1^2\,(-126\,DpDph2^2+100\,DpDphh1+120\,DpDphh2+18\,DpDphh3+9\,DpDphh4-72\,DpDph2\,pph+40\,pphh1+48\,pphh2)+32\,DpDph1\,(43\,DpDph2^3+30\,DpDph2^2\,pph-2\,pph\,(6\,DpDphh1+24\,DpDphh2+9\,DpDphh3+pph^2)-3\,DpDph2\,(11\,DpDphh1+44\,DpDphh2+15\,DpDphh3+2\,pph^2+4\,pphh1+16\,pphh2))+16\,(26\,DpDph2^4+96\,DpDphh1^2+192\,DpDphh2^2+168\,DpDphh2\,DpDphh3+27\,DpDphh3^2+42\,D \ldots}{}$$

$$0 \to \frac{e^2 \left(-3\,DpDph1^2-8\,DpDph2^2-12\,DpDph1\,(DpDph2+2\,DppDh1-DppDh2)+4\,pph^2+8\,DpDph2\,(-6\,DppDh1+3\,DppDh2+pph)+3\,(DpDph1^2+12\,DpDph2^2+8\,DpDph1\,DppDh1+16\,DppDh1\,pph-8\,DppDh2\,pph+8\,DpDph2\,(4\,DppDh1-2\,DppDh2+pph)-4\,DpDph1\,(DppDh2+pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{15360\,\pi^2}$$

$$0 \to \frac{e^2 \left(3\,DpDph1^2+8\,DpDph2^2+12\,DpDph1\,(DpDph2+2\,DppDh1-DppDh2)-4\,pph^2-8\,DpDph2\,(-6\,DppDh1+3\,DppDh2+pph)-3\,(DpDph1^2+12\,DpDph2^2+8\,DpDph1\,DppDh1+16\,DppDh1\,pph-8\,DppDh2\,pph+8\,DpDph2\,(4\,DppDh1-2\,DppDh2+pph)-4\,DpDph1\,(DppDh2+pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{6144\,\pi^2}$$

$$0 \to \frac{e^2 \left(-27\,DpDph1^2+4\,DpDph1\,(-27\,DpDph2+6\,DppDh1+27\,DppDh2)+12\,(-6\,DpDph2^2+4\,DpDph2\,DppDh1+3\,pph^2+6\,DpDph2\,(3\,DppDh2+pph))+(27\,DpDph1^2+324\,DpDph2^2-24\,DpDph2\,(4\,DppDh1+18\,DppDh2-9\,pph)-24\,(2\,DppDh1+9\,DppDh2)\,pph+4\,DpDph1\,(40\,DpDph2-6\,DppDh1-27\,DppDh2+13\,pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{15360\,\pi^2}$$

$$1 \to 1$$

$$0 \to \frac{e^4 \left(99\,DpDph1^4+36\,DpDph1^3\,(13\,DpDph2+4\,pph)-192\,DpDph1\,(2\,(2\,DpDphh1+DpDphh3+2\,DpDphh4)\,pph+DpDph2\,(11\,DpDphh1+5\,DpDphh3+10\,DpDphh4+4\,pphh1))-4\,DpDph1^2\,(-126\,DpDph2^2+140\,DpDphh1+120\,DpDphh2+162\,DpDphh3+171\,DpDphh4-72\,DpDph2\,pph+56\,pphh1+48\,pphh2)-32\,(-32\,DpDphh1^2-9\,DpDphh3^2-42\,DpDphh2\,DpDphh4-36\,DpDphh3\,DpDphh4-15\,DpDphh4^2+24\,DpDph2\,pph\,(DpDphh1+DpDphh4-pphh1)-48\,DpDp \ldots}{}$$

$$0 \to \frac{e^4 \left(39\,DpDph1^4+66\,DpDph1^3\,(13\,DpDph2+4\,pph)-16\,DpDph1\,(2\,(4\,DpDphh1+2\,DpDphh3+49\,DpDphh4)\,pph+DpDph2\,(22\,DpDphh1+10\,DpDphh3+245\,DpDphh4+8\,pphh1))+2\,DpDph1^2\,(42\,DpDph2^2+2020\,DpDphh1-40\,DpDphh2-594\,DpDphh3-57\,DpDphh4+24\,DpDph2\,pph+808\,pphh1-16\,pphh2)-8\,(1632\,DpDphh1^2-6\,DpDphh3^2-28\,DpDphh2\,DpDphh4-294\,DpDphh3\,DpDphh4+135\,DpDphh4^2+16\,DpDph2\,pph\,(DpDphh1+DpDphh4-pphh1)-32\,D \ldots}{}$$

$$0 \to \frac{e^4 \left(-18\,DpDph1^4-17\,DpDph1^3\,(13\,DpDph2+4\,pph)+4\,DpDph1\,(2\,(32\,DpDphh1+16\,DpDphh3+47\,DpDphh4)\,pph+DpDph2\,(176\,DpDphh1+80\,DpDphh3+235\,DpDphh4+64\,pphh1))+DpDph1^2\,(-168\,DpDph2^2-480\,DpDphh1+160\,DpDphh2+306\,DpDphh3+93\,DpDphh4-96\,DpDph2\,pph-192\,pphh1+64\,pphh2)+4\,(448\,DpDphh1^2-24\,DpDphh3^2-112\,DpDphh2\,DpDphh4-141\,DpDphh3\,DpDphh4+30\,DpDphh4^2+64\,DpDph2\,pph\,(DpDphh1+DpDphh4-pphh1) \ldots}{}$$

$$0 \to \frac{e^4 \left(9\,DpDph1^4+6\,DpDph1^3\,(13\,DpDph2+4\,pph)-32\,DpDph1\,(2\,(2\,DpDphh1+DpDphh3+2\,DpDphh4)\,pph+DpDph2\,(11\,DpDphh1+5\,DpDphh3+10\,DpDphh4+4\,pphh1))+2\,DpDph1^2\,(42\,DpDph2^2+20\,DpDphh1-40\,DpDphh2-54\,DpDphh3-27\,DpDphh4+24\,DpDph2\,pph+8\,pphh1-16\,pphh2)-16\,(16\,DpDphh1^2-3\,DpDphh3^2-14\,DpDphh2\,DpDphh4-12\,DpDphh3\,DpDphh4+8\,DpDph2\,pph\,(DpDphh1+DpDphh4-pphh1)-16\,DpDphh2\,pphh1-8\,DpDphh3\,pphh1 \ldots}{}$$

$$0 \to 0$$

$$0 \to 0$$

$$0 \to 0$$

$$0 \to \frac{e^3 \left(3\,DhDphp6\,(DpDph1+2\,DpDph2)+(2\,DpDphh4\,(DpDph2+pph)-3\,DhDphp6\,(DpDph1+4\,DpDph2+2\,pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{32\,Mphi\,\pi^2}$$

$$0 \to \frac{e^3 \left(12\,DhDphp4\,DpDph1-3\,DpDph1^3+24\,DhDphp4\,DpDph2-12\,DpDph1^2\,DpDph2-8\,DpDph1\,DpDph2^2+24\,DhDphp3\,(DpDph1+2\,DpDph2)+8\,DpDph1\,DpDph2\,pph+4\,DpDph1\,pph^2+(3\,DpDph1^3+16\,DpDph1^2\,DpDph2+28\,DpDph1\,DpDph2^2+16\,DpDph2\,DpDphh3+8\,DpDph2\,DpDphh4+4\,DpDph1^2\,pph+16\,DpDph1\,DpDph2\,pph+16\,DpDphh3\,pph+8\,DpDphh4\,pph-24\,DhDphp3\,(DpDph1+4\,DpDph2+2\,pph)-12\,DhDphp4\,(DpDph1+4\,DpDph2+2\,pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2} \ldots\right.}{128\,Mphi\,\pi^2}$$

$$0 \to \frac{e^3 \left(24\,DhDphp3\,(DpDph1+2\,DpDph2)+DpDph1\,(-3\,DpDph1^2-12\,DpDph1\,DpDph2-8\,DpDph2^2+8\,DpDph2\,pph+4\,pph^2)+(3\,DpDph1^3+16\,DpDphh3\,(DpDph2+pph)+6\,DpDph1^2\,(3\,DpDph2+pph)-24\,DhDphp3\,(DpDph1+4\,DpDph2+2\,pph)+4\,DpDph1\,DpDph2\,(7\,DpDph2+4\,pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{128\,Mphi\,\pi^2}$$

$$0 \to \frac{e^3 \left(-24\,DhDphp3\,DpDph1+9\,DpDph1^3-48\,DhDphp3\,DpDph2+24\,DpDph1^2\,DpDph2+8\,DpDph1\,DpDph2^2+24\,DhDphp1\,(DpDph1+2\,DpDph2)-48\,DpDph1\,DpDphh1-64\,DpDph2\,DpDphh1-24\,DpDph1\,DpDphh4-48\,DpDph2\,DpDphh4-12\,DpDph1^2\,DppDh1+96\,DpDphh1\,DppDh1+48\,DpDphh4\,DppDh1-12\,DpDph1^2\,DppDh2+96\,DpDphh1\,DppDh2+48\,DpDphh4\,DppDh2-8\,DpDph1\,DpDph2\,pph+32\,DpDphh1\,pph-4\,DpDph1\,pph^2+32\,DpDph2\,pphh1+32\,pph\,pphh1-(\ldots}{}$$

$$0 \to -\frac{e^3 \left(24\,DhDphp3\,(DpDph1+2\,DpDph2)+DpDph1\,(-3\,DpDph1^2-12\,DpDph1\,DpDph2-8\,DpDph2^2+8\,DpDph2\,pph+4\,pph^2)+(3\,DpDph1^3+16\,DpDphh3\,(DpDph2+pph)+6\,DpDph1^2\,(3\,DpDph2+pph)-24\,DhDphp3\,(DpDph1+4\,DpDph2+2\,pph)+4\,DpDph1\,DpDph2\,(7\,DpDph2+4\,pph))\,\mathrm{Log}\left[\frac{Mphi^2}{\mu^2}\right]\right)}{256\,Mphi\,\pi^2}$$

$$0 \to \frac{e^3 \left(-48\,DhDphp3\,DpDph1+48\,DhDphp5\,DpDph1+9\,DpDph1^3-96\,DhDphp3\,DpDph2+96\,DhDphp5\,DpDph2+60\,DpDph1^2\,DpDph2+72\,DpDph1\,DpDph2^2-24\,DpDph2^3+48\,DhDphp2\,(DpDph1+2\,DpDph2)-96\,DpDph1\,DpDphh2-128\,DpDph2\,DpDphh2-48\,DpDph1\,DpDphh3-96\,DpDph2\,DpDphh3-12\,DpDph1^2\,DppDh1-96\,DpDph1\,DpDph2\,DppDh1-48\,DpDph2^2\,DppDh1+192\,DpDphh2\,DppDh1+96\,DpDphh3\,DppDh1-12\,DpDph1^2\,DppDh2-96\,DpDph1\,DpDph2\,DppDh \ldots}{}$$

$$0 \to -\frac{3\,e^5 \left(-984\,DpDph1^5-3180\,DpDph1^4\,(4\,DpDph2+pph)-20\,DpDph1^2\,(4\,(492\,DpDphh1-366\,DpDphh3-257\,DpDphh4)\,pph+DpDph2\,(6888\,DpDphh1-4758\,DpDphh3-3341\,DpDphh4+1968\,pphh1))+160\,(2\,pph\,(164\,DpDphh1^2-183\,DpDphh3\,DpDphh4+2\,DpDphh4^2+328\,DpDphh1\,(DpDphh4-pphh1)-164\,pphh1^2)+DpDph2\,(1640\,DpDphh1^2-915\,DpDphh3\,DpDphh4+10\,DpDphh4^2+656\,DpDphh4\,pphh1-328\,pphh1^2+164\,DpDphh1\,(11\,DpDphh4+4 \ldots}{}$$

0 → e^4 (-18 DpDph1^4 -17 DpDph1^3 (13 DpDph2+4 pph)+4 DpDph1 (2 (32 DpDphh1+16 DpDphh3+47 DpDphh4) pph+DpDph2 (176 DpDphh1+80 DpDphh3+235 DpDphh4+64 pphh1))+DpDph1^2 (-168 DpDph2^2 -480 DpDphh1+160 DpDphh2+306 DpDphh3+93 DpDphh4-96 DpDph2 pph-192 pphh1+64 pphh2)+4 (448 DpDphh1^2 -24 DpDphh3^2 -112 DpDphh2 DpDphh4-141 DpDphh3 DpDphh4+30 DpDphh4^2 +64 DpDph2 pph (DpDphh1+DpDphh4-pphh1)

0 → e^4 (9 DpDph1^4 +6 DpDph1^3 (13 DpDph2+4 pph)-32 DpDph1 (2 (2 DpDphh1+DpDphh3+2 DpDphh4) pph+DpDph2 (11 DpDphh1+5 DpDphh3+10 DpDphh4+4 pphh1))+2 DpDph1^2 (42 DpDph2^2 +20 DpDphh1-40 DpDphh2-54 DpDphh3-27 DpDphh4+24 DpDph2 pph+8 pphh1-16 pphh2)-16 (16 DpDphh1^2 -3 DpDphh3^2 -14 DpDphh2 DpDphh4-12 DpDphh3 DpDphh4+8 DpDph2 pph (DpDphh1+DpDphh4-pphh1)-16 DpDphh2 pphh1-8 DpDphh3 pphh1

0 → 0

0 → 0

0 → 0

0 → e^3 (3 DhDphp6 (DpDph1+2 DpDph2)+(2 DpDphh4 (DpDph2+pph)-3 DhDphp6 (DpDph1+4 DpDph2+2 pph)) Log[Mphi^2/μ^2]) / (32 Mphi π^2)

0 → e^3 (12 DhDphp4 DpDph1-3 DpDph1^3 +24 DhDphp4 DpDph2-12 DpDph1^2 DpDph2-8 DpDph1 DpDph2^2 +24 DhDphp3 (DpDph1+2 DpDph2)+8 DpDph1 DpDph2 pph+4 DpDph1 pph^2 +(3 DpDph1^3 +16 DpDph1^2 DpDph2+28 DpDph1 DpDph2^2 +16 DpDph2 DpDphh3+8 DpDph2 DpDphh4+4 DpDph1^2 pph+16 DpDph1 DpDph2 pph+16 DpDphh3 pph+8 DpDphh4 pph-24 DhDphp3 (DpDph1+4 DpDph2+2 pph)-12 DhDphp4 (DpDph1+4 DpDph2+2 pph)) Log[Mphi^2/μ^2]) / (128 Mphi π^2)

0 → e^3 (24 DhDphp3 (DpDph1+2 DpDph2)+DpDph1 (-3 DpDph1^2 -12 DpDph1 DpDph2-8 DpDph2^2 +8 DpDph2 pph+4 pph^2)+(3 DpDph1^3 +16 DpDphh3 (DpDph2+pph)+6 DpDph1^2 (3 DpDph2+pph)-24 DhDphp3 (DpDph1+4 DpDph2+2 pph)+4 DpDph1 DpDph2 (7 DpDph2+4 pph)) Log[Mphi^2/μ^2]) / (128 Mphi π^2)

0 → e^3 (-24 DhDphp3 DpDph1+9 DpDph1^3 -48 DhDphp3 DpDph2+24 DpDph1^2 DpDph2+8 DpDph1 DpDph2^2 +24 DhDphp1 (DpDph1+2 DpDph2)-48 DpDph1 DpDphh1-64 DpDph2 DpDphh1-24 DpDph1 DpDphh4-48 DpDph2 DpDphh4-12 DpDph1^2 DpDh1+96 DpDphh1 DpDh1+48 DpDphh4 DpDh1-12 DpDph1^2 DpDh2+96 DpDphh1 DpDh2+48 DpDphh4 DpDh2-8 DpDph1 DpDph2 pph+32 DpDphh1 pph-4 DpDph1 pph^2 +32 DpDph2 pphh1+32 pph pphh1- (

0 → - e^3 (24 DhDphp3 (DpDph1+2 DpDph2)+DpDph1 (-3 DpDph1^2 -12 DpDph1 DpDph2-8 DpDph2^2 +8 DpDph2 pph+4 pph^2)+(3 DpDph1^3 +16 DpDphh3 (DpDph2+pph)+6 DpDph1^2 (3 DpDph2+pph)-24 DhDphp3 (DpDph1+4 DpDph2+2 pph)+4 DpDph1 DpDph2 (7 DpDph2+4 pph)) Log[Mphi^2/μ^2]) / (256 Mphi π^2)

0 → e^3 (-48 DhDphp3 DpDph1+48 DhDphp5 DpDph1+9 DpDph1^3 -96 DhDphp3 DpDph2+96 DhDphp5 DpDph2+60 DpDph1^2 DpDph2+72 DpDph1 DpDph2^2 -24 DpDph2^3 +48 DhDphp2 (DpDph1+2 DpDph2)-96 DpDph1 DpDphh2-128 DpDph2 DpDphh2-48 DpDph1 DpDphh3-96 DpDph2 DpDphh3-12 DpDph1^2 DppDh1-96 DpDph1 DpDph2 DppDh1-48 DpDph2^2 DppDh1+192 DpDphh2 DppDh1+96 DpDphh3 DppDh1-12 DpDph1^2 DppDh2-96 DpDph1 DpDph2 DppD

0 → - 3 e^5 (-984 DpDph1^5 -3180 DpDph1^4 (4 DpDph2+pph)-20 DpDph1^2 (4 (492 DpDphh1-366 DpDphh3-257 DpDphh4) pph+DpDph2 (6888 DpDphh1-4758 DpDphh3-3341 DpDphh4+1968 pphh1))+160 (2 pph (164 DpDphh1^2 -183 DpDphh3 DpDphh4+2 DpDphh4^2 +328 DpDphh1 (DpDphh4-pphh1)-164 pphh1^2)+DpDph2 (1640 DpDphh1^2 -915 DpDphh3 DpDphh4+10 DpDphh4^2 +656 DpDphh4 pphh1-328 pphh1^2 +164 DpDphh1 (11 DpDphh4+4

0 → - e^5 (3321 DpDph1^5 +8460 DpDph1^4 (4 DpDph2+pph)+15 DpDph1^3 (12 512 DpDph2^2 -3796 DpDphh1-9568 DpDphh2-3384 DpDphh3-1791 DpDphh4+5888 DpDph2 pph-1168 pphh1-2944 pphh2)+40 DpDph1^2 (4346 DpDph2^3 +2706 DpDph2^2 pph-2 pph (738 DpDphh1+1476 DpDphh2+1656 DpDphh3+570 DpDphh4+41 pph^2)-3 DpDph2 (1722 DpDphh1+3444 DpDphh2+3588 DpDphh3+1235 DpDphh4+82 pph^2 +492 pphh1+984 pphh2))-160 (

0 → e^5 (2214 DpDph1^5 -3540 DpDph1^4 (4 DpDph2+pph)-15 DpDph1^3 (6936 DpDph2^2 +11 128 DpDphh1-5304 DpDphh2-1416 DpDphh3+1653 DpDphh4+3264 DpDph2 pph+3424 pphh1-1632 pphh2)-20 DpDph1^2 (86 920 DpDph2^3 +54 120 DpDph2^2 pph-4 pph (14 760 DpDphh2+918 DpDphh3+201 DpDphh4+410 pph^2)-3 DpDph2 (68 880 DpDphh2+3978 DpDphh3+871 DpDphh4+1640 pph^2 +19 680 pphh2))-160 (1476 DpDph2^5 -13 940 DpDph2^4 p

κ → DpDph1^3 e^3 (-1+Log[Mphi^2/μ^2]) / (768 Mphi π^2)

0 → - e^5 (27 183 DpDph1^5 +42 720 DpDph1^4 (4 DpDph2+pph)+320 DpDphh4 (591 DpDphh3+337 DpDphh4) (5 DpDph2+2 pph)-40 DpDph1^2 (1182 DpDphh3+1939 DpDphh4) (13 DpDph2+4 pph)+10 DpDph1^3 (26 792 DpDph2^2 -6344 DpDphh1-20 488 DpDphh2-25 632 DpDphh3-23 979 DpDphh4+12 608 DpDph2 pph-1952 pphh1-6304 pphh2)+80 DpDph1 (3546 DpDphh3^2 +11 634 DpDphh3 DpDphh4+3 DpDphh4 (-4137 DpDph2^2 -2364 DpDph2 pp

0 → e^5 (1599 DpDph1^5 +160 DpDph1^4 (4 DpDph2+pph)+240 (59 DpDphh3-17 DpDphh4) DpDphh4 (5 DpDph2+2 pph)-30 DpDph1^2 (118 DpDphh3-9 DpDphh4) (13 DpDph2+4 pph)-10 DpDph1^3 (-2006 DpDph2^2 +3627 DpDphh1+1534 DpDphh2+96 DpDphh3+1587 DpDphh4-944 DpDph2 pph+1116 pphh1+472 pphh2)+10 DpDph1 (2124 DpDphh3^2 -324 DpDphh3 DpDphh4+3 DpDphh4 (-2478 DpDph2^2 +5580 DpDphh1+2360 DpDphh2+1211 DpDphh4

0 → e^5 (738 DpDph1^5 +4620 DpDph1^4 (4 DpDph2+pph)+80 DpDphh4 (114 DpDphh3+193 DpDphh4) (5 DpDph2+2 pph)-20 DpDph1^2 (114 DpDphh3+443 DpDphh4) (13 DpDph2+4 pph)+20 DpDph1 (684 DpDphh3^2 +5316 DpDphh3 DpDphh4-3 DpDphh4 (798 DpDph2^2 +2720 DpDphh1-760 DpDphh2+159 DpDphh4+456 DpDph2 pph+1088 pphh1-304 pphh2))+5 DpDph1^3 (2584 DpDph2^2 +7072 DpDphh1-1976 DpDphh2-5544 DpDphh3-783 DpDphh4+

0 → - e^5 (492 DpDph1^5 +1380 DpDph1^4 (4 DpDph2+pph)+80 DpDphh4 (66 DpDphh3+47 DpDphh4) (5 DpDph2+2 pph)-20 DpDph1^2 (66 DpDphh3+127 DpDphh4) (13 DpDph2+4 pph)+5 DpDph1^3 (1496 DpDph2^2 +728 DpDphh1-1144 DpDphh2-1656 DpDphh3-777 DpDphh4+704 DpDph2 pph+224 pphh1-352 pphh2)+20 DpDph1 (396 DpDphh3^2 +1524 DpDphh3 DpDphh4+3 DpDphh4 (-462 DpDph2^2 -280 DpDphh1+440 DpDphh2+59 DpDphh4-264 Dp

0 → - DpDph1 (DpDph1^2 -2 DpDphh4) e^3 (-1+Log[Mphi^2/μ^2]) / (384 Mphi π^2)

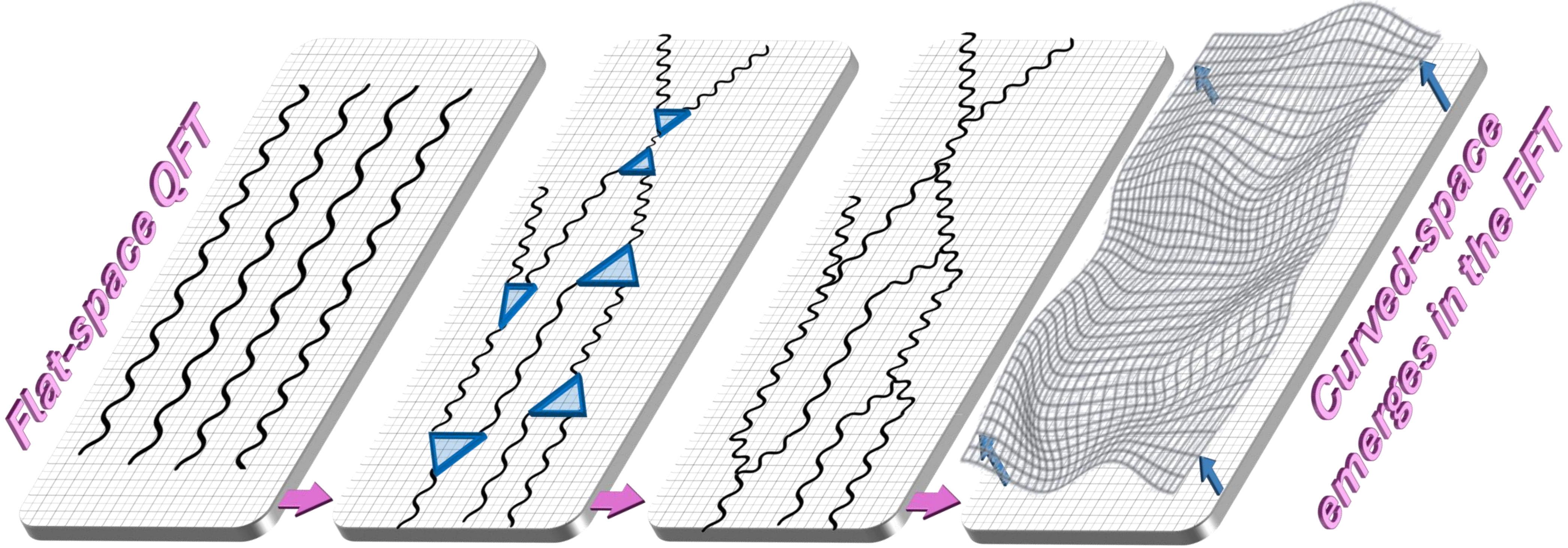
0 → e^3 (24 DhDphp3 (DpDph1+2 DpDph2)-DpDph1 (3 DpDph1^2 +8 DpDph1 DpDph2+8 DpDph2^2 +8 DpDphh3-8 DpDph2 pph-4 pph^2)+(3 DpDph1^3 +16 DpDphh3 (DpDph2+pph)+4 DpDph1^2 (3 DpDph2+pph)-24 DhDphp3 (DpDph1+4 DpDph2+2 pph)+4 DpDph1 (7 DpDph2^2 +2 DpDphh3+4 DpDph2 pph)) Log[Mphi^2/μ^2]) / (1536 Mphi π^2)

0 → e^3 (-24 DhDphp3 DpDph1+DpDph1^3 -48 DhDphp3 DpDph2+24 DpDph1^2 DpDph2+8 DpDph1 DpDph2^2 +24 DhDphp1 (DpDph1+2 DpDph2)-48 DpDph1 DpDphh1-64 DpDph2 DpDphh1-8 DpDph1 DpDphh4-48 DpDph2 DpDphh4-12 DpDph1^2 DppDh2+96 DpDphh1 DppDh2+48 DpDphh4 DppDh2-8 DpDph1 DpDph2 pph+32 DpDphh1 pph-4 DpDph1 pph^2 +32 DpDph2 pphh1+32 pph pphh1-(DpDph1^3 +32 DpDph1^2 DpDph2+28 DpDph1 DpDph2^2 -64 DpDph1 Dp / (1536 Mphi π^2)

0 → - e^3 (-3 DpDph1^3 -20 DpDph1^2 DpDph2-72 DpDph1 DpDph2^2 +24 DpDph2^3 -48 DhDphp2 (DpDph1+2 DpDph2)+96 DpDph1 DpDphh2+128 DpDph2 DpDphh2+16 DpDph1 DpDphh3+96 DpDph2 DpDphh3+12 DpDph1^2 DppDh2+96 DpDph1 DpDph2 DppDh2+48 DpDph2^2 DppDh2-192 DpDphh2 DppDh2-96 DpDphh3 DppDh2+24 DpDph1 DpDph2 pph+136 DpDph2^2 pph-64 DpDphh2 pph-96 DpDph2 DppDh2 pph+12 DpDph1 pph^2 +56 DpDph2 pph^2 -48 DpDph

Proof of Concept of BUILD

- Gravity emergent from a quantum field theory

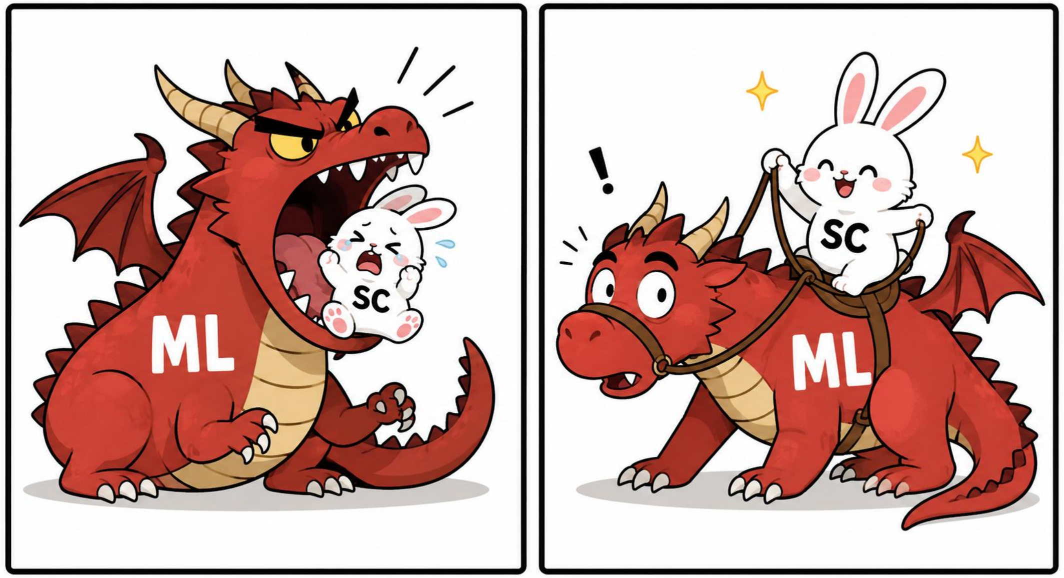


Lifshitz, et al. *Emergent Curvature from Flat-Space QFTs: A Computational Search for Quantum Gravity,* **in preparation** (2026)

After the rise of AI… what is the future of computer algebra systems / symbolic computation?

Intrinsic mastery

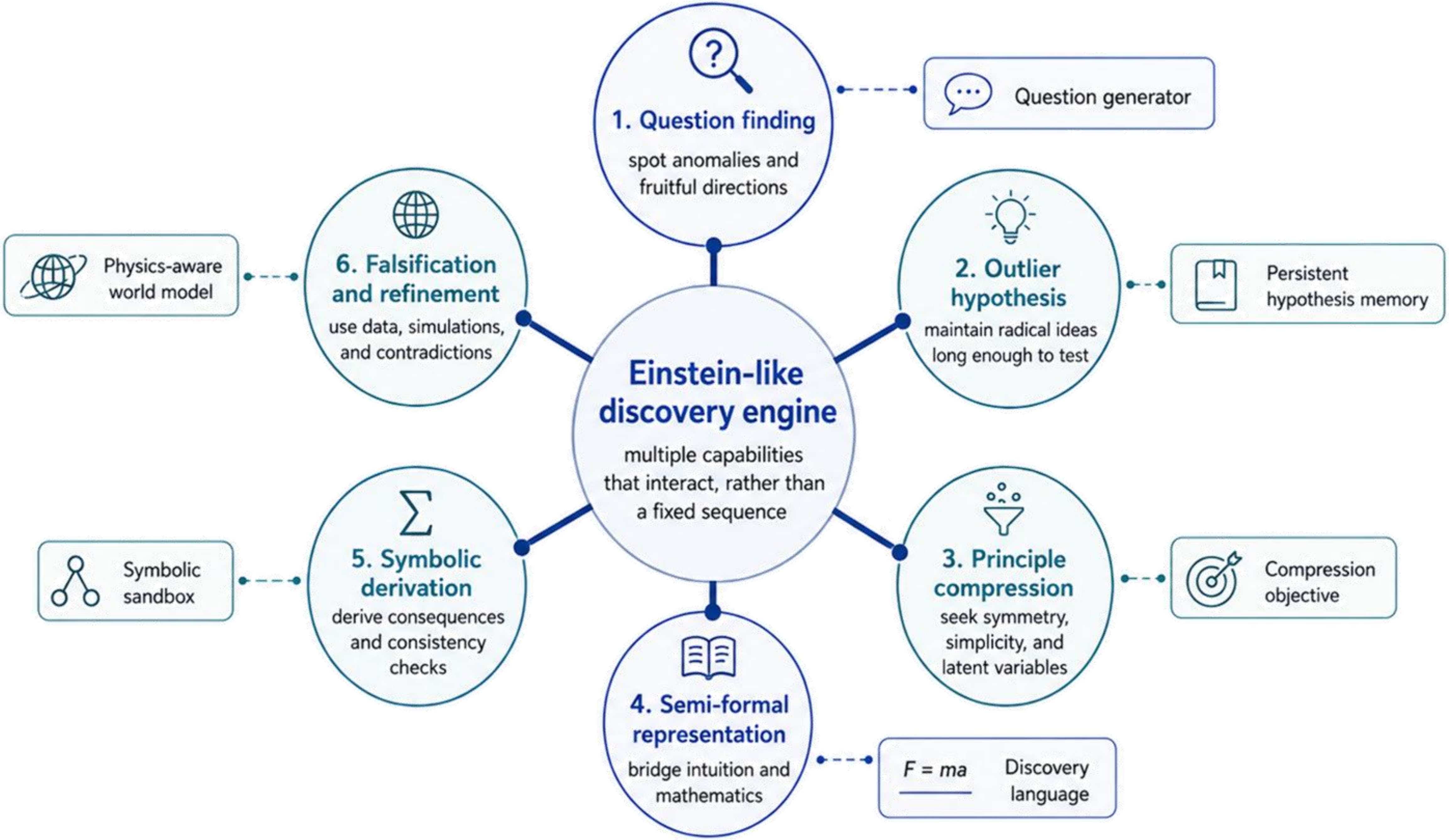
Autonomous tool creation



Symbiotic integration

Increase trust in AI

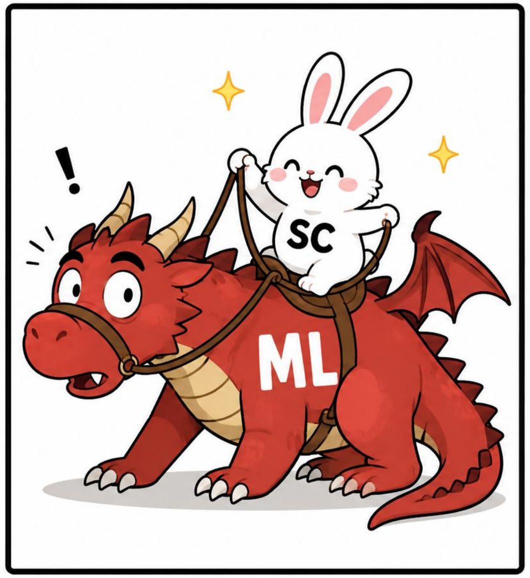
Hard problems that AI cannot solve without CAS


1. Question finding
spot anomalies and fruitful directions
Question generator
2. Outlier hypothesis
maintain radical ideas long enough to test
Persistent hypothesis memory
3. Principle compression
seek symmetry, simplicity, and latent variables
Compression objective
4. Semi-formal representation
bridge intuition and mathematics
F = ma
Discovery language
5. Symbolic derivation
derive consequences and consistency checks
Symbolic sandbox
6. Falsification and refinement
use data, simulations, and contradictions
Physics-aware world model
Einstein-like discovery engine
multiple capabilities that interact, rather than a fixed sequence

After the rise of AI… what is the future of computer algebra systems / symbolic computation?

Intrinsic mastery

Autonomous tool creation



Symbiotic integration

Increase trust in AI

Hard problems that AI cannot solve without CAS

Vision

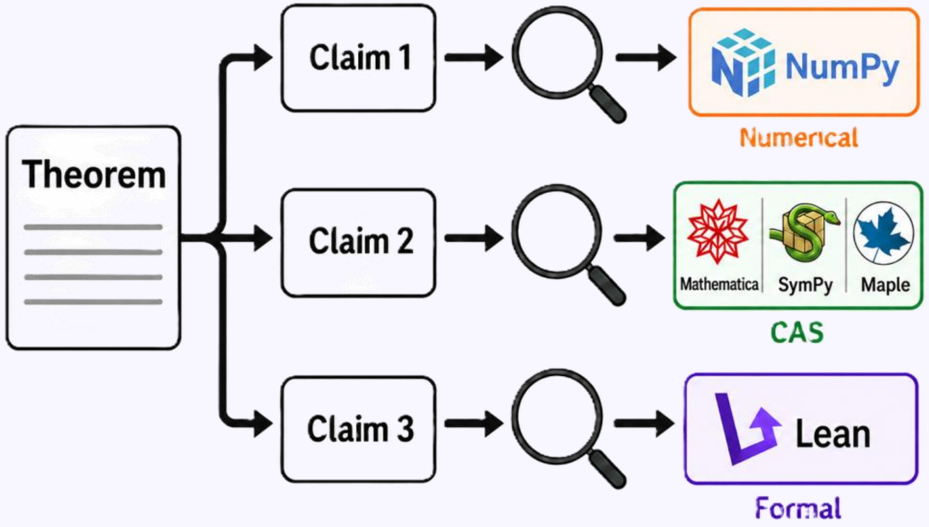
What is the future of CAS?

Hybrid LLM–CAS workflows may evolve in three directions:

- **Intrinsic mastery:** models improve direct symbolic reasoning.
- **Deeper integration:** CAS will co-evolve with LLMs for stronger symbolic support.
- **Autonomous tool creation:** models may begin building internal symbolic procedures.

Trust through verification workflows

The next step is not only stronger models, but **trusted workflows** that combine generation with verification.



Shalyt, Michael, Rotem Elimelech, and Ido Kaminer. "Asymob: Algebraic symbolic mathematical operations benchmark." arXiv preprint arXiv:2505.23851 (2025).