

Congkai (Kelvin) Peng

Combinatorics and Optimization, University of Waterloo | PhD applicant for Fall 2027

kelvinpeng2004@outlook.com · svah-x.ca · github.com/SVAH-X · linkedin.com/in/k2peng · Waterloo, ON, Canada

RESEARCH INTERESTS

Reasoning in latent space and through recurrence (looped transformers, recursive reasoners); interpretability of model internals through causal interventions; controlled tasks that separate what a model computes from what it outputs.

EDUCATION

University of Waterloo

Sept. 2023 – Aug. 2027 (expected)

Bachelor of Mathematics, Combinatorics and Optimization

Waterloo, ON

Selected coursework: Graph Theory, Nonlinear Optimization, Number Theory, Computational Mathematics; Neural Networks (in progress); Quantum Information Processing (Winter 2027).

PUBLICATIONS AND MANUSCRIPTS

[1] Congkai Peng, Taoli Cheng. *Probing the Emergent Global Workspace of Reasoning Models on Structured Reasoning Tasks*. Under review at ICLR 2027.

Short version accepted at the NeurIPS 2026 Workshop on Mathematical Reasoning and AI (MATH-AI) as *Verifiable Mathematical Reasoning as a Probe of Emergent Global Workspaces* (T. Cheng, C. Peng). [PDF] [Workshop OpenReview]

Research problem. Do reasoning models that were never given a workspace module develop one, a small internal state that later computation repeatedly reads and rewrites? If so, where does it live and what does it carry?

Key findings. In a recursive latent reasoner (GRAM), a puzzle-specific 16-dimensional span, 0.04% of the state, is causally necessary: removing it cuts validity from 95.3% to 37.9% while clue retention stays at or above 99.7%. The recursion repairs single-step damage, so only sustained removal is fatal. Directions fitted to one sampled trajectory change *which* solution is returned more than *whether* one is (70.4% stay valid, 15.0% unchanged). In Qwen3-32B the same edit has no effect through layer 52 and collapses validity at layer 56 (71% to 14%).

Innovation. Puzzles with many valid answers let every intervention be scored as same answer, different valid answer, or invalid. This separates answer identity from validity, which final-answer accuracy cannot do.

My contributions.

- **Designed the experiments:** three lens-conditioning levels (corpus, per puzzle, per sampled trajectory), single-step versus sustained removal, rank- and norm-matched controls, and paired noise replay; wrote down the pass/fail criteria before each round.
- **Reproduced GRAM** (version 13 of my implementation) for all GRAM experiments, on n -queens and on a cubic-graph edge-coloring task I designed.
- **Ran all experiments and led the writing.**

[2] Jiucheng Zang, Congkai Peng, Yankai Wei, Peng Cheng (all authors contributed equally). *When Wrong Answers Remain Unsettled: Failure Dynamics in Recurrent Reasoners*. Under review at ICLR 2027.

Research problem. When a weight-shared recurrent reasoner returns a wrong answer, has it settled on that answer, or would more computation still change it?

Key findings. In HRM on Sudoku-Extreme, wrong answers are far less persistent than solved ones under continued recurrence (0.18 pooled versus 0.95), and perturbation size barely matters. Solved answers stay more persistent across six settings, but HRM's spectral and timescale patterns do not carry over to TRM or GRAM-guided TRM.

Innovation. Measures answer persistence directly against an unperturbed continuation, separating persistence, local geometry and reselection gains.

My contributions.

- **Proposed and ran the GRAM analysis (App. T):** tested whether the paper's endpoint analyses carry over to a stochastic recurrent reasoner, using my n -queens and edge-coloring GRAM models; found that the sampler is load-bearing (collapsing it to its conditional mean drops solve rates from 0.964 to 0.466 and from 0.720 to 0.005).
- **Introduced the leading-Ritz (finite-Krylov) framing** of the paper's spectral estimates and added reorthogonalization and Ritz residuals to its Arnoldi solver.
- **Wrote the GRAM guidance module and n -queens generators** used in the GRAM-guided TRM and 12×12 settings, and restructured the related-work section.

RESEARCH EXPERIENCE

Shanghai Academy of AI for Science (SAIS)

Research Intern, Latent Reasoning

May 2026 – present

Shanghai, China

- **Set the direction through literature review:** wrote reviews of LLM failures on compositional reasoning, of search, recursion and verification for combinatorial reasoning, and of 3-edge-coloring and the Berge–Fulkerson conjecture as AI tasks; these led to the project’s use of multi-solution tasks.
- **Rebuilt a model without the authors’ code:** starting from a community reproduction of GRAM (Baek et al., 2026), iterated to version 13 by fixing label construction, posterior conditioning and KL scaling; it reaches 95.0% single-draw validity and 97.2% solution coverage on the 773-puzzle 8-queens evaluation split.
- **Designed tasks:** a 3-edge-coloring task on 3,848 cubic graphs (GRAM: 67.0% validity, 87.9% solution coverage) and a certificate-search benchmark used to evaluate GPT-5.5, Claude Opus 4.8 and Qwen3-32B.
- **Turned a negative result into a better design:** the first round’s corpus-level lens had no effect. I traced this to per-puzzle causal directions being nearly orthogonal (the averaged Jacobian keeps about $1/N$ of the per-example mass) and rebuilt the study around per-puzzle and per-trajectory lenses, which gave the main results of [1].
- **Kept every result reproducible:** commit-pinned multi-GPU pipelines, bit-exact replay checks and puzzle-cluster bootstrap intervals; tracked Jacobians over 60 training checkpoints.

Project: emergent global workspace in recursive and autoregressive reasoners | Supervisor: Taoli Cheng, AI Scientist, SAIS

Residual Routing and Recurrent Reasoning (collaboration)

Apr. 2026 – Sept. 2026

Research contributor

Remote

- **Proposed the move to GRAM:** after fixed-width multi-stream residual routing (mHC) failed, proposed letting the model learn how many streams to use through GRAM’s stochastic latent routing; the project adopted it.
- **Moved the test to the right task:** implemented GRAM guidance and recursion-axis attention residuals on TRM, and moved the GRAM experiments from single-solution Sudoku to multi-solution n -queens.
- **Led a fidelity audit of GRAM implementations:** showed that solution coverage was capped at 0.41 by single-canonical labels, that pooled label encoding made the posterior blind to the label, and that the KL weight scaled with the GPU count; defined metrics for the effective number of solution modes.
- **Carried the work into paper [2]:** proposed and ran its GRAM analysis (App. T).

Collaborators: Jiucheng Zang, Yankai Wei, Peng Cheng

SELECTED PROJECTS

TopoAdamW: topology-guided learning-rate control github.com/SVAH-X/topoadamw · PyPI: [topoadamw](https://pypi.org/project/topoadamw) 2025

- Designed a learning-rate controller that probes the local loss landscape (sharpness probe or a persistence-image CNN on GUDHI) and rescales AdamW’s step; +1.4–1.5 points on CIFAR-10/100 at 14–22% overhead.

Geometry Dash world-model agent github.com/SVAH-X/gd_agent: DreamerV3-style prototype in JAX with a custom 60 Hz environment and an inverse-dynamics labeler. 2025

TEACHING AND OPEN EDUCATIONAL MATERIALS

Two free, code-first courses written from my study notes: **PyTorch Deep Learning** (10 chapters, tensors to vision transformers) and **Reinforcement Learning and World Models** (4 parts, DQN to Isaac Lab). github.com/SVAH-X

HONORS AND AWARDS

Euclid Mathematics Contest (CEMC): 1st in British Columbia; Honour Roll, about the top 1% 2021 – 2022

Canadian Senior Mathematics Contest (CEMC): Honour Roll 2022

SKILLS

Programming and ML: Python, C/C++, SQL, Bash, LaTeX; PyTorch, JAX, Hugging Face, vLLM, DeepSpeed, Slurm, Docker.

Methods: Jacobian lenses and activation interventions, CKA/Procrustes alignment, cluster bootstrap, TDA. **Languages:** English, Mandarin (native).