FRTI64 · AI LEARNING PATH

AI 学习路径指南 · 资料汇编

AI Learning Path Guide · Resource Compilation

144 条资源 · 14 个学习阶段 · 242 份 PDF 留档 / 144 resources · 14 stages · 242 archived PDFs

指南原稿 / Source guide	《AI学习路径指南》PDF，32 页（Gemini 多轮问答打印稿） / “AI Learning Path Guide” PDF, 32 pages (printed Gemini conversation)
资源条目 / Resources	144 条（18 种类型，覆盖指南 14 个阶段） / 144 entries, 18 types, 14 stages
已核验可访问 / Verified accessible	133 条；11 条出版社反爬但书目元数据已补齐 / 133; 11 blocked by publishers but metadata recovered
开放获取 / Open access	46 条 / 46 entries
PDF 留档 / Archived PDFs	242 份 / 229.34 MiB（主库 32 + OCW 131 + 剑桥 72 + 其它 7） / 242 files / 229.34 MiB
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网页检索版 / Web index	https://frti64.top/ai-resources/

数据来源：《AI学习路径指南》PDF（32 页，Gemini 多轮问答打印稿）与其原始 HTML 导出；网页检索版：https://frti64.top/ai-resources/

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一、概览 / 1. Overview

指标 / Metric	数值 / Value
资源总数 / Total resources	144
已抓取 / Crawled OK	133 / 144
抓取失败但元数据已补 / Blocked, metadata recovered	11
开放获取 / Open access	46
PDF 留档 / Archived PDFs	242 份 / 229.34 MiB
覆盖阶段 / Stages	S1-S14（14 个 / 14 stages）
网页检索版 / Web index	https://frti64.top/ai-resources/

二、指南主线 / 2. Learning Roadmap

阶段 / Stage	名称 / Name	覆盖内容 / Focus
S1	一、核心知识底座 Core Knowledge Foundation	数理/编程/机器学习与深度学习核心 Build the mathematical, programming, and machine-learning foundation that every specialization builds on.
S2	二、主流细分方向 Main Specialization Tracks	大模型算法、AI 应用工程、多模态具身、AI 基础设施、垂直行业 Choose one of five specialization tracks and understand the stack and typical outcomes of each.
S3	三、渐进式学习路径 Progressive Learning Path	夯实基础→经典 ML→Transformer→实战项目→论文闭环 Follow a staged path from fundamentals through classical ML and Transformers to real projects and a paper loop.
S4	顶会论文与高薪研发岗 Top-Conference Papers and High-Paying R&D Jobs	选题/方法论/面试三维能力/12-18 个月节奏 Turn empirical research into top-conference papers and high-paying R&D job offers on a 12-18 month timeline.
S5	低算力顶会课题 Low-Compute Top-Conference Projects	五个低算力课题与饱和度分析 Pick a publishable low-compute project and judge its competition level by saturation.
S6	以研代学 / 30 天计划 Research-Driven Learning / 30-Day Plan	最小技术栈、代码驱动读论文、PyTorch+Transformer+LoRA 30 天 Learn by doing research: a minimal toolchain, code-driven paper reading, and a 30-day PyTorch + Transformer + LoRA plan.
S7	证明型选手的理论赛道 Theory Track for Proof-Oriented Students	优化几何/RLHF 理论/注意力理论/可信 AI For students strong in proofs: four theory directions that need little compute.
S8	数学诊断题 Math Diagnostic Problems	5 道顶会级数学推导诊断题 Locate gaps in your math toolkit with five top-conference-level derivations and a self-assessment scale.
S9	AI 理论推荐教材 Recommended AI Theory Textbooks	高维概率、矩阵分析、凸优化、信息论、前沿讲义 Read the theory textbooks and lecture notes most used in AI papers: high-dimensional probability, matrix analysis, convex optimization, and information theory.
S10	数学基础教材 Foundational Mathematics Textbooks	线代/分析/概率/泛函/数值优化 Strengthen proof skills with core linear algebra, analysis, probability, functional analysis, and numerical optimization texts.
S11	开放获取教材 Open-Access Textbooks	作者官网免费 PDF 的教材与讲义 Access free, legally downloadable versions of the foundational math textbooks from author and university sites.
S12	配套习题集 Companion Problem Sets	带官方解答的证明/放缩习题集 Practice proof and inequality techniques with problem sets that include official solutions.
S13	纯数学教材 Pure Mathematics Textbooks	实分析/抽象代数/测度概率/微分几何与最优传输 Train pure mathematics across real and functional analysis, algebra and representation theory, measure-theoretic probability, and differential geometry and optimal transport.
S14	开源纯数学与题库 Open-Source Pure Math & Problem Banks	开放获取纯数学教材 + MIT OCW/剑桥 Tripos/arXiv 题库 Use open pure-math textbooks and problem banks (MIT OCW, Cambridge Tripos, arXiv lecture notes) for self-study.

说明：阶段名称取自《AI学习路径指南》原文（S1-S14），原文为中文；英文为对照翻译。

三、分阶段资料清单 / 3. Resources by Stage

按指南 14 个阶段编排；同一资料可能出现在多个阶段，编号唯一。 / Grouped by the guide’s 14 stages; IDs are unique.

S1 一、核心知识底座

> 数理/编程/机器学习与深度学习核心

Build the mathematical, programming, and machine-learning foundation that every specialization builds on.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
P001	**Attention Is All You Need** 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	Transformer 与自注意力机制原始论文，现代生成式 AI 基石 The original paper on Transformer and self-attention; the foundation of modern generative AI.	https://arxiv.org/abs/1706.03762
T001	**Python**	平台 Platform	免费 Free	编程基石：核心语法、面向对象，AI 全部生态的语言底座 Programming foundation: core syntax and object-oriented design, the language base of the entire AI ecosystem.	https://www.python.org/
T002	**NumPy**	库 Library	免费 Free	脱离 for 循环手写向量化矩阵运算与损失函数 Hand-write vectorized matrix operations and loss functions without for loops.	https://numpy.org/
T003	**Pandas**	库 Library	免费 Free	数据科学栈的数据清洗与分析入口 The entry point for data cleaning and analysis in the data-science stack.	https://pandas.pydata.org/
T004	**Scikit-learn**	库 Library	免费 Free	跑通分类/回归/聚类/交叉验证的经典机器学习基线 Run classic machine-learning baselines: classification, regression, clustering, and cross-validation.	https://scikit-learn.org/
T005	**XGBoost**	库 Library	免费 Free	表数据经典强基线，理解梯度提升 A classic strong baseline for tabular data; learn gradient boosting.	https://xgboost.readthedocs.io/
T006	**PyTorch**	框架 Framework	免费 Free	深度学习主框架：不依赖高层封装手写训练循环 The main deep-learning framework: hand-write training loops without relying on high-level wrappers.	https://pytorch.org/
T027	**Docker**	工具 Tool	免费 Free	容器化部署，复现实验环境 Containerized deployment to reproduce experimental environments.	https://www.docker.com/
T028	**Git**	工具 Tool	免费 Free	版本控制；开源贡献与技术信用的基础设施 Version control; the infrastructure for open-source contribution and technical credibility.	https://git-scm.com/
T007	**Hugging Face**	平台 Platform	免费 Free	模型/数据集/镜像源生态，单卡跑通开源模型的入口 Model, dataset, and mirror ecosystem; the entry point for running open models on a single GPU.	https://huggingface.co/

S2 二、主流细分方向

> 大模型算法、AI 应用工程、多模态具身、AI 基础设施、垂直行业

Choose one of five specialization tracks and understand the stack and typical outcomes of each.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T030	**MCP 协议**	网站 Website	免费 Free	Model Context Protocol：Agent 工具调用与上下文接入标准 Model Context Protocol: the standard for agent tool calls and context access.	https://modelcontextprotocol.io/
T014	**Megatron-LM**	框架 Framework	免费 Free	分布式训练：TP/PP/EP 并行与大规模预训练工程 Distributed training: TP/PP/EP parallelism and large-scale pretraining engineering.	https://github.com/NVIDIA/Megatron-LM
T015	**DeepSpeed**	框架 Framework	免费 Free	ZeRO 显存优化与分布式训练，面试高频考点 ZeRO memory optimization and distributed training; a frequent interview topic.	https://github.com/deepspeedai/DeepSpeed
T023	**CUDA**	平台 Platform	免费 Free	GPU 计算平台；底层推理加速/算子开发的必备技能 GPU computing platform; essential for low-level inference acceleration and kernel development.	https://developer.nvidia.com/cuda-toolkit
T024	**Triton**	框架 Framework	免费 Free	Python 写 GPU 算子：融合算子实现真实吞吐提升 Write GPU kernels in Python: fused kernels for real throughput gains.	https://github.com/triton-lang/triton
T025	**Isaac Sim**	框架 Framework	免费 Free	机器人仿真平台，具身智能/Sim2Real 迁移 Robot simulation platform for embodied AI and Sim2Real transfer.	https://developer.nvidia.com/isaac/sim
T026	**MuJoCo**	框架 Framework	免费 Free	物理仿真引擎，VLA/机器人策略研究 Physics simulation engine for VLA and robot-policy research.	https://github.com/google-deepmind/mujoco
T012	**vLLM**	框架 Framework	免费 Free	高吞吐推理引擎：评测加速、KV Cache 压缩实验平台 High-throughput inference engine: evaluation acceleration and a platform for KV Cache compression experiments.	https://github.com/vllm-project/vllm
T013	**SGLang**	框架 Framework	免费 Free	推理加速框架，与 vLLM 并列用于采样加速与吞吐测试 Inference acceleration framework used alongside vLLM for faster sampling and throughput tests.	https://github.com/sgl-project/sglang
T016	**veRL**	框架 Framework	免费 Free	RL 训练框架：提交 PR 建立开源技术信用、申请研究型实习 RL training framework: submit PRs to build open-source credibility and apply for research internships.	https://github.com/volcengine/verl
T017	**OpenRLHF**	框架 Framework	免费 Free	RLHF/RLVR 训练框架，后训练方向核心工具 RLHF/RLVR training framework; a core tool for the post-training direction.	https://github.com/OpenRLHF/OpenRLHF
T034	**Qwen（Qwen2.5 / Qwen3）**	模型 Model	免费 Free	开源模型家族：单卡实验与多模型家族验证的首选基座 Open model family: the preferred base for single-GPU experiments and multi-family validation.	https://github.com/QwenLM/Qwen3
T009	**PEFT**	库 Library	免费 Free	参数高效微调：LoRA/QLoRA 显存友好微调 Parameter-efficient fine-tuning: memory-friendly LoRA/QLoRA fine-tuning.	https://github.com/huggingface/peft
T035	**Llama（Llama-3）**	模型 Model	免费 Free	开源模型家族，多家族对比实验 Open model family for multi-family comparison experiments.	https://github.com/meta-llama/llama-models

S3 三、渐进式学习路径

> 夯实基础→经典 ML→Transformer→实战项目→论文闭环

Follow a staged path from fundamentals through classical ML and Transformers to real projects and a paper loop.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
P001	**Attention Is All You Need** 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	Transformer 与自注意力机制原始论文，现代生成式 AI 基石 The original paper on Transformer and self-attention; the foundation of modern generative AI.	https://arxiv.org/abs/1706.03762
T001	**Python**	平台 Platform	免费 Free	编程基石：核心语法、面向对象，AI 全部生态的语言底座 Programming foundation: core syntax and object-oriented design, the language base of the entire AI ecosystem.	https://www.python.org/
T002	**NumPy**	库 Library	免费 Free	脱离 for 循环手写向量化矩阵运算与损失函数 Hand-write vectorized matrix operations and loss functions without for loops.	https://numpy.org/
T004	**Scikit-learn**	库 Library	免费 Free	跑通分类/回归/聚类/交叉验证的经典机器学习基线 Run classic machine-learning baselines: classification, regression, clustering, and cross-validation.	https://scikit-learn.org/
T006	**PyTorch**	框架 Framework	免费 Free	深度学习主框架：不依赖高层封装手写训练循环 The main deep-learning framework: hand-write training loops without relying on high-level wrappers.	https://pytorch.org/
T007	**Hugging Face**	平台 Platform	免费 Free	模型/数据集/镜像源生态，单卡跑通开源模型的入口 Model, dataset, and mirror ecosystem; the entry point for running open models on a single GPU.	https://huggingface.co/
T031	**GitHub**	平台 Platform	免费 Free	端到端项目产出与复现代码公开的载体 Where end-to-end project outputs and reproduction code are published.	https://github.com/
C001	**Machine Learning Roadmap: Beginner to Expert (2026) - Coursera**	路线图 Roadmap	免费 Free	指南 Sources：Coursera 机器学习路线图课程 Guide source: Coursera's machine-learning roadmap course.	https://www.coursera.org/resources/ml-learni…
C002	**关于 AI 的学习路线图 - 凌杰 - 博客园**	博客 Blog	免费 Free	指南 Sources：中文 AI 学习路线图博客 Guide source: a Chinese AI learning-roadmap blog post.	https://www.cnblogs.com/owlman/p/19560606
C003	**A Machine Learning Roadmap for 2026, from Python to Papers**	博客 Blog	免费 Free	指南 Sources：从 Python 到论文的 2026 机器学习路线图 Guide source: a 2026 machine-learning roadmap from Python to papers.	https://www.tensortonic.com/guides/machine-l…
C004	**Machine Learning Roadmap for Beginners: 5 Essential Skills - IAICB**	博客 Blog	免费 Free	指南 Sources：初学者五项必备技能 Guide source: five essential skills for beginners.	https://www.iaicb.org/blog/machine-learning-…
C005	**查阅了十几篇学习资源后，我总结了这份AI学习路径 - mason's blog**	博客 Blog	免费 Free	指南 Sources：中文 AI 学习路径总结 Guide source: a Chinese AI learning-path summary.	https://mianshenglee.github.io/2019/09/06/ai…
C006	**学习路径总览：从零基础到找到第一份相关工作 - GitHub**	路线图 Roadmap	免费 Free	指南 Sources：GitHub 上的从零到就业学习路径总览 Guide source: a GitHub overview of the path from zero to a first job.	https://github.com/datawhalechina/dive-into-…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T032	arXiv	网站 Website	免费 Free	每日刷 cs.CL/cs.LG/cs.CV，精读 1-2 篇最新高赞论文 Daily scan of cs.CL/cs.LG/cs.CV; closely read 1-2 recent high-voted papers.	https://arxiv.org/
T008	Transformers（Hugging Face 库）	库 Library	免费 Free	AutoModel/AutoTokenizer 三件套，提取中间层激活与注意力矩阵 The AutoModel/AutoTokenizer trio for extracting intermediate activations and attention matrices.	https://github.com/huggingface/transformers

S4 顶会论文与高薪研发岗

> 选题/方法论/面试三维能力/12-18 个月节奏
>
> Turn empirical research into top-conference papers and high-paying R&D job offers on a 12-18 month timeline.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T014	Megatron-LM	框架 Framework	免费 Free	分布式训练：TP/PP/EP 并行与大规模预训练工程 Distributed training: TP/PP/EP parallelism and large-scale pretraining engineering.	https://github.com/NVIDIA/Megatron-LM
T015	DeepSpeed	框架 Framework	免费 Free	ZeRO 显存优化与分布式训练，面试高频考点 ZeRO memory optimization and distributed training; a frequent interview topic.	https://github.com/deepspeedai/DeepSpeed
T023	CUDA	平台 Platform	免费 Free	GPU 计算平台；底层推理加速/算子开发的必备技能 GPU computing platform; essential for low-level inference acceleration and kernel development.	https://developer.nvidia.com/cuda-toolkit
T031	GitHub	平台 Platform	免费 Free	端到端项目产出与复现代码公开的载体 Where end-to-end project outputs and reproduction code are published.	https://github.com/
T032	arXiv	网站 Website	免费 Free	每日刷 cs.CL/cs.LG/cs.CV，精读 1-2 篇最新高赞论文 Daily scan of cs.CL/cs.LG/cs.CV; closely read 1-2 recent high-voted papers.	https://arxiv.org/
P006	DeepSeek-V3 Technical Report 留档 1 份 / 1 archived	技术报告 Tech report	开放获取 Open access	精读顶级技术报告的 Limitations，找可迁移到低资源场景的机制 Closely read the Limitations sections of top technical reports to find mechanisms transferable to low-resource settings.	https://arxiv.org/abs/2412.19437
P007	DeepSeek-R1 留档 1 份 / 1 archived	技术报告 Tech report	开放获取 Open access	RLVR/长思维链推理的标志性技术报告 A landmark technical report on RLVR and long chain-of-thought reasoning.	https://arxiv.org/abs/2501.12948
P008	Qwen2.5 Technical Report 留档 1 份 / 1 archived	技术报告 Tech report	开放获取 Open access	开源模型技术报告：数据配比与后训练细节 Open-model technical report: data mixing and post-training details.	https://arxiv.org/abs/2412.15115
P009	Qwen3 Technical Report 留档 1 份 / 1 archived	技术报告 Tech report	开放获取 Open access	最新开源模型技术报告，跟踪前沿训练配方 The latest open-model technical report; track the frontier training recipe.	https://arxiv.org/abs/2505.09388
P010	GPT-4 Technical Report 留档 1 份 / 1 archived	技术报告 Tech report	开放获取 Open access	OpenAI 技术报告范式：能力评测与安全约束 OpenAI technical-report paradigm: capability evaluation and safety constraints.	https://arxiv.org/abs/2303.08774

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
P011	Anthropic Claude 3 Model Card 留档 1 份 / 1 archived	技术报告 Tech report	开放获取 Open access	Anthropic 技术报告/模型卡：可解释性与评测口径参考 Anthropic technical report/model card: reference for interpretability and evaluation protocols.	https://docs.anthropic.com/en/docs/resources…
P012	ByteDance Seed 技术报告 留档 1 份 / 1 archived（补档）	技术报告 Tech report	开放获取 Open access	Seed（字节）技术报告：Seed 系列模型训练与评测 Seed (ByteDance) technical report: training and evaluation of the Seed model family.	https://arxiv.org/abs/2505.07062
T012	vLLM	框架 Framework	免费 Free	高吞吐推理引擎：评测加速、KV Cache 压缩实验平台 High-throughput inference engine: evaluation acceleration and a platform for KV Cache compression experiments.	https://github.com/vllm-project/vllm
T013	SGLang	框架 Framework	免费 Free	推理加速框架，与 vLLM 并列用于采样加速与吞吐测试 Inference acceleration framework used alongside vLLM for faster sampling and throughput tests.	https://github.com/sgl-project/sglang
T016	veRL	框架 Framework	免费 Free	RL 训练框架：提交 PR 建立开源技术信用、申请研究型实习 RL training framework: submit PRs to build open-source credibility and apply for research internships.	https://github.com/volcengine/verl
T017	OpenRLHF	框架 Framework	免费 Free	RLHF/RLVR 训练框架，后训练方向核心工具 RLHF/RLVR training framework; a core tool for the post-training direction.	https://github.com/OpenRLHF/OpenRLHF
T029	LeetCode	网站 Website	免费 Free	算法题保持零 Bug 编写能力，面试硬性要求 Keep zero-bug coding speed on algorithm problems; a hard interview requirement.	https://leetcode.cn/
P002	Direct Preference Optimization (DPO) 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	DPO 原始推导：RLHF/GRPO 理论分析基石，面试手推 KL 正则闭式解 The original DPO derivation: a cornerstone of RLHF/GRPO theory analysis and a whiteboard interview classic on the closed-form KL-regularized solution.	https://arxiv.org/abs/2305.18290

S5 低算力顶会课题

> 五个低算力课题与饱和度分析

Pick a publishable low-compute project and judge its competition level by saturation.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T024	Triton	框架 Framework	免费 Free	Python 写 GPU 算子：融合算子实现真实吞吐提升 Write GPU kernels in Python: fused kernels for real throughput gains.	https://github.com/triton-lang/triton
T032	arXiv	网站 Website	免费 Free	每日刷 cs.CL/cs.LG/cs.CV，精读 1-2 篇最新高赞论文 Daily scan of cs.CL/cs.LG/cs.CV; closely read 1-2 recent high-voted papers.	https://arxiv.org/

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T012	vLLM	框架 Framework	免费 Free	高吞吐推理引擎：评测加速、KV Cache 压缩实验平台 High-throughput inference engine: evaluation acceleration and a platform for KV Cache compression experiments.	https://github.com/vllm-project/vllm
T013	SGLang	框架 Framework	免费 Free	推理加速框架，与 vLLM 并列用于采样加速与吞吐测试 Inference acceleration framework used alongside vLLM for faster sampling and throughput tests.	https://github.com/sgl-project/sglang
T034	Qwen（Qwen2.5 / Qwen3）	模型 Model	免费 Free	开源模型家族：单卡实验与多模型家族验证的首选基座 Open model family: the preferred base for single-GPU experiments and multi-family validation.	https://github.com/QwenLM/Qwen3
T041	MATH-500	评测基准 Benchmark	免费 Free	推理模型评测基准，课题一/二的评测集 Reasoning-model benchmark; the evaluation set for Projects 1 and 2.	https://huggingface.co/datasets/HuggingFaceH…
T042	AIME	评测基准 Benchmark	免费 Free	数学竞赛评测基准，检验推理模型上限 Math-competition benchmark for testing the upper bound of reasoning models.	https://huggingface.co/datasets/AI-MO/aimo-v…
T043	GPQA	评测基准 Benchmark	免费 Free	研究生级问答评测基准 Graduate-level question-answering benchmark.	https://github.com/idavidrein/gpqa
T044	LongBench	评测基准 Benchmark	免费 Free	长文本评测基准：KV Cache 压缩实验 Long-text benchmark for KV Cache compression experiments.	https://github.com/THUDM/LongBench
T045	RULER	评测基准 Benchmark	免费 Free	长上下文评测基准 Long-context benchmark.	https://github.com/NVIDIA/RULER
T046	Needle-in-a-Haystack	评测基准 Benchmark	免费 Free	大海捞针测试，验证长上下文信息保留 Needle-in-a-haystack test verifying that long-context information is retained.	https://github.com/gkamradt/LLMTest_NeedleIn…
T047	SWE-bench	评测基准 Benchmark	免费 Free	软件工程 Agent 评测（SWE-bench Lite） Software-engineering agent evaluation (SWE-bench Lite).	https://github.com/SWE-bench/SWE-bench
T048	OSWorld	评测基准 Benchmark	免费 Free	计算机操作 Agent 评测环境 Computer-use agent evaluation environment.	https://github.com/xlang-ai/OSWorld
T049	WebArena	评测基准 Benchmark	免费 Free	网页智能体评测环境 Web-agent evaluation environment.	https://github.com/web-arena-x/webarena
T018	Unsloth	库 Library	免费 Free	单卡微调加速，显存需求可降 60% Single-GPU fine-tuning acceleration; memory needs can drop by 60%.	https://github.com/unslothai/unsloth
T035	Llama（Llama-3）	模型 Model	免费 Free	开源模型家族，多家族对比实验 Open model family for multi-family comparison experiments.	https://github.com/meta-llama/llama-models
T036	Mistral	模型 Model	免费 Free	开源模型家族，多家族对比实验 Open model family for multi-family comparison experiments.	https://github.com/mistralai/mistral-inference
T037	Gemma	模型 Model	免费 Free	开源模型家族，多家族对比实验 Open model family for multi-family comparison experiments.	https://github.com/google-deepmind/gemma

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
P005	**Teacher-Guided Curriculum for Data-Efficient RLVR** 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	低算力 RLVR 课程学习代表作（ACL Anthology），课题二的对标工作 A representative low-compute RLVR curriculum-learning paper (ACL Anthology); the baseline to compare against for Project 2.	https://aclanthology.org/2026.findings-emnlp…
T033	**ACL Anthology**	网站 Website	免费 Free	NLP 顶会论文库，检索低算力课题的代表作 NLP top-conference paper library for finding representative low-compute work.	https://aclanthology.org/

S6 以研代学 / 30 天计划

> 最小技术栈、代码驱动读论文、PyTorch+Transformer+LoRA 30 天

Learn by doing research: a minimal toolchain, code-driven paper reading, and a 30-day PyTorch + Transformer + LoRA plan.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T006	**PyTorch**	框架 Framework	免费 Free	深度学习主框架：不依赖高层封装手写训练循环 The main deep-learning framework: hand-write training loops without relying on high-level wrappers.	https://pytorch.org/
T007	**Hugging Face**	平台 Platform	免费 Free	模型/数据集/镜像源生态，单卡跑通开源模型的入口 Model, dataset, and mirror ecosystem; the entry point for running open models on a single GPU.	https://huggingface.co/
T012	**vLLM**	框架 Framework	免费 Free	高吞吐推理引擎：评测加速、KV Cache 压缩实验平台 High-throughput inference engine: evaluation acceleration and a platform for KV Cache compression experiments.	https://github.com/vllm-project/vllm
T034	**Qwen（Qwen2.5 / Qwen3）**	模型 Model	免费 Free	开源模型家族：单卡实验与多模型家族验证的首选基座 Open model family: the preferred base for single-GPU experiments and multi-family validation.	https://github.com/QwenLM/Qwen3
T009	**PEFT**	库 Library	免费 Free	参数高效微调：LoRA/QLoRA 显存友好微调 Parameter-efficient fine-tuning: memory-friendly LoRA/QLoRA fine-tuning.	https://github.com/huggingface/peft
T035	**Llama（Llama-3）**	模型 Model	免费 Free	开源模型家族，多家族对比实验 Open model family for multi-family comparison experiments.	https://github.com/meta-llama/llama-models
T008	**Transformers（Hugging Face 库）**	库 Library	免费 Free	AutoModel/AutoTokenizer 三件套，提取中间层激活与注意力矩阵 The AutoModel/AutoTokenizer trio for extracting intermediate activations and attention matrices.	https://github.com/huggingface/transformers
C007	**Let's build GPT: from scratch, in code — Andrej Karpathy**	教程 Tutorial	免费 Free	跟着视频用纯 PyTorch 手敲 Self-Attention/位置编码/自回归采样 Follow the video to hand-code self-attention, positional encoding, and autoregressive sampling in pure PyTorch.	https://www.youtube.com/watch?v=kCc8FmEb1nY
T019	**einops**	库 Library	免费 Free	rearrange 张量维度变换，养成标注 Shape 的习惯 rearrange for tensor-dimension reshaping; build the habit of annotating shapes.	https://github.com/arogozhnikov/einops

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
T038	**nanoGPT**	仓库 Repository	免费 Free	跟随 Karpathy 从零拼装微型 GPT 的参考实现 A reference implementation for assembling a tiny GPT from scratch with Karpathy.	https://github.com/karpathy/nanoGPT
T011	**bitsandbytes**	库 Library	免费 Free	4-bit/8-bit 量化加载，显存控制关键 4-bit/8-bit quantized loading; key to controlling GPU memory.	https://github.com/bitsandbytes-foundation/b…
T039	**Alpaca**	数据集 Dataset	免费 Free	指令微调数据格式范本 A format template for instruction-tuning data.	https://github.com/tatsu-lab/stanford_alpaca
T040	**ShareGPT**	数据集 Dataset	免费 Free	对话式 SFT 数据格式（Alpaca/ShareGPT 两种格式对照） Conversational SFT data format (compare the Alpaca and ShareGPT formats).	https://sharegpt.com/
T010	**trl**	库 Library	免费 Free	SFTTrainer 与后训练工具链，30 天计划的 LoRA 实战 SFTTrainer and the post-training toolchain; LoRA practice for the 30-day plan.	https://github.com/huggingface/trl
T020	**SwanLab**	工具 Tool	免费 Free	实验记录与可视化，从第一天起记录学习率/Loss Experiment tracking and visualization; log learning rate and Loss from day one.	https://github.com/SwanHubX/SwanLab
T021	**TensorBoard**	工具 Tool	免费 Free	经典实验日志与曲线可视化 Classic experiment logs and curve visualization.	https://www.tensorflow.org/tensorboard

S7 证明型选手的理论赛道

> 优化几何/RLHF 理论/注意力理论/可信 AI

For students strong in proofs: four theory directions that need little compute.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
P004	**Grokking: Generalization Beyond Overfitting** 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	顿悟现象（Grokking）与泛化相变，优化几何方向的经典论文 Grokking and generalization phase transitions; a classic paper for the optimization-geometry direction.	https://arxiv.org/abs/2201.02177
P002	**Direct Preference Optimization (DPO)** 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	DPO 原始推导：RLHF/GRPO 理论分析基石，面试手推 KL 正则闭式解 The original DPO derivation: a cornerstone of RLHF/GRPO theory analysis and a whiteboard interview classic on the closed-form KL-regularized solution.	https://arxiv.org/abs/2305.18290
P003	**In-Context Learning as Gradient Descent** 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	证明 Transformer 上下文学习等价于隐式执行梯度下降，理论型顶会经典 Proves that Transformer in-context learning is equivalent to implicit gradient descent; a classic theory-track paper.	https://arxiv.org/abs/2212.07677
T022	**matplotlib**	库 Library	免费 Free	理论验证曲线：双对数坐标斜率验证 O(1/sqrt(T)) 等定理预测 Theory-validation curves: log-log slopes to check theorem predictions such as O(1/sqrt(T)).	https://matplotlib.org/

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B009	Conformal Prediction: A Gentle Introduction — Anastasios N. Angelopoulos & Stephen Bates 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	约 50 页短篇专著：无分布依赖覆盖率保证，3 个月产出一篇不确定性/幻觉控制论文 A roughly 50-page monograph: distribution-free coverage guarantees; supports a paper on uncertainty or hallucination control within 3 months.	https://arxiv.org/abs/2107.07511
C008	Stanford CS229M 讲义：Statistical Learning Theory — Tengyu Ma 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	为写 NeurIPS/ICML 理论论文设计：表达能力/隐式偏置/OOD 泛化 Designed for students writing NeurIPS/ICML theory papers: expressivity, implicit bias, and OOD generalization.	https://web.stanford.edu/class/stats214/

S8 数学诊断题

> 5 道顶会级数学推导诊断题

Locate gaps in your math toolkit with five top-conference-level derivations and a self-assessment scale.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
P004	Grokking: Generalization Beyond Overfitting 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	顿悟现象（Grokking）与泛化相变，优化几何方向的经典论文 Grokking and generalization phase transitions; a classic paper for the optimization-geometry direction.	https://arxiv.org/abs/2201.02177
P003	In-Context Learning as Gradient Descent 留档 1 份 / 1 archived	论文 Paper	开放获取 Open access	证明 Transformer 上下文学习等价于隐式执行梯度下降，理论型顶会经典 Proves that Transformer in-context learning is equivalent to implicit gradient descent; a classic theory-track paper.	https://arxiv.org/abs/2212.07677

S9 AI 理论推荐教材

> 高维概率、矩阵分析、凸优化、信息论、前沿讲义

Read the theory textbooks and lecture notes most used in AI papers: high-dimensional probability, matrix analysis, convex optimization, and information theory.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B001	High-Dimensional Probability: An Introduction with Applications in Data Science — Roman Vershynin 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	AI 理论圣经（开源）：浓度不等式、sub-gaussian、覆盖数、随机矩阵奇异值界，精读 1-4 章 The 'bible' of AI theory (open access): concentration inequalities, sub-gaussian variables, covering numbers, and random-matrix singular-value bounds; read Chapters 1-4 closely.	https://www.math.uci.edu/~rvershyn/papers/HD…
B006	The Matrix Cookbook 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	矩阵求导/迹循环变换速查手册，打印放手边 A quick-reference handbook for matrix derivatives and trace cyclic identities; keep a printed copy at hand.	https://www.math.uwaterloo.ca/~hwolkowi/matr…
B002	High-Dimensional Statistics: A Non-Asymptotic Viewpoint — Martin J. Wainwright	教材 Book	付费 Paid	更严谨的进阶工具书：尾部界与 Rademacher 复杂度/度量熵 A more rigorous advanced reference: tail bounds, Rademacher complexity, and metric entropy.	https://www.cambridge.org/core/books/highdim…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B003	Convex Optimization — Stephen Boyd & Lieven Vandenberghe 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	变分推导与对偶理论标杆（免费）：凸函数/共轭/KKT，DPO 闭式解来源 The benchmark for variational derivations and duality theory (free): convex functions, conjugates, and KKT; the source of DPO closed-form solutions.	https://web.stanford.edu/~boyd/cvxbook/
B004	Convex Optimization: Algorithms and Complexity — Sébastien Bubeck 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	微软研究院短篇专著：梯度下降/镜像下降/SGD 收敛率证明模板 A short Microsoft Research monograph: proof templates for gradient descent, mirror descent, and SGD convergence rates.	https://arxiv.org/abs/1405.4980
B005	Matrix Analysis — Roger A. Horn & Charles R. Johnson	教材 Book	付费 Paid	当字典查：奇异值不等式、Weyl 定理、Davis-Kahan 特征子空间扰动 Use it as a dictionary: singular-value inequalities, Weyl's theorem, and the Davis-Kahan eigenvector-subspace perturbation bound.	https://www.cambridge.org/core/books/matrix-…
B007	Elements of Information Theory — Thomas M. Cover & Joy A. Thomas	教材 Book	付费 Paid	信息论经典：熵/互信息/KL/DPI、Fano 不等式与 Method of Types Information-theory classic: entropy, mutual information, KL, DPI, Fano's inequality, and Method of Types.	https://www.wiley.com/en-us/Elements+of+Info…
B008	Patterns, Predictions, and Actions — Moritz Hardt & Benjamin Recht 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	免费在线新书：用现代视角重写统计学习、优化动力学与因果推断 A free online book: rewrites statistical learning, optimization dynamics, and causal inference from a modern perspective.	https://mlstory.org/
B009	Conformal Prediction: A Gentle Introduction — Anastasios N. Angelopoulos & Stephen Bates 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	约 50 页短篇专著：无分布依赖覆盖率保证，3 个月产出一篇不确定性/幻觉控制论文 A roughly 50-page monograph: distribution-free coverage guarantees; supports a paper on uncertainty or hallucination control within 3 months.	https://arxiv.org/abs/2107.07511
C008	Stanford CS229M 讲义：Statistical Learning Theory — Tengyu Ma 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	为写 NeurIPS/ICML 理论论文设计：表达能力/隐式偏置/OOD 泛化 Designed for students writing NeurIPS/ICML theory papers: expressivity, implicit bias, and OOD generalization.	https://web.stanford.edu/class/stats214/

S10 数学基础教材

> 线代/分析/概率/泛函/数值优化

Strengthen proof skills with core linear algebra, analysis, probability, functional analysis, and numerical optimization texts.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B010	Linear Algebra Done Right — Sheldon Axler 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	摒弃行列式直接建谱定理，官方开放获取 PDF + 作者习题讲解视频 Builds spectral theory directly without determinants; official open-access PDF plus the author's exercise-walkthrough videos.	https://linear.axler.net/
B011	Linear Algebra and Learning from Data — Gilbert Strang	教材 Book	付费 Paid	面向 ML/数据科学：SVD、低秩近似、图拉普拉斯与梯度下降的代数本质 For ML and data science: SVD, low-rank approximation, graph Laplacian, and the algebraic essence of gradient descent.	https://math.mit.edu/~gs/learningfromdata/

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B012	Matrix Computations — Gene H. Golub & Charles F. Van Loan 元数据已补 / metadata recovered	教材 Book	付费 Paid	数值线性代数权威经典：正交分解/条件数/特征值扰动/低秩逼近误差 The authoritative numerical-linear-algebra classic: orthogonal decompositions, condition numbers, eigenvalue perturbation, and low-rank approximation error.	https://www.press.jhu.edu/books/title/10678/…
B013	高等代数 — 丘维声	教材 Book	付费 Paid	中文打底：多项式、线性变换不变子空间、二次型的严格证明训练 Chinese foundation: polynomials, invariant subspaces of linear transformations, and rigorous proof training on quadratic forms.	https://book.douban.com/subject/26739983/
B014	高等代数学 — 张贤科	教材 Book	付费 Paid	中文打底：与丘维声并列的高等代数严格证明训练 Chinese foundation: rigorous advanced-algebra proof training, a peer to Qiu Weisheng's textbook.	https://book.douban.com/subject/1051081/
B015	Principles of Mathematical Analysis（Baby Rudin）— Walter Rudin	教材 Book	付费 Paid	严格 ε-δ 语言、紧致性、一致收敛与函数项级数放缩试金石 The touchstone for rigorous ε-δ language, compactness, uniform convergence, and series-of-functions estimates.	https://archive.org/details/principlesofmath…
B016	Measure, Integration & Real Analysis — Sheldon Axler 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	现代实分析/测度论：Lebesgue 积分、控制收敛、L^p 与 Hilbert 空间（开放获取） Modern real analysis and measure theory: Lebesgue integration, dominated convergence, L^p, and Hilbert spaces (open access).	https://measure.axler.net/
B017	Mathematical Analysis — V. A. Zorich（卓里奇《数学分析》中译本）	教材 Book	付费 Paid	兼具物理几何直觉与严谨性：多元微分、隐函数定理、流形初步 Combines physical and geometric intuition with rigor: multivariable calculus, the implicit function theorem, and an introduction to manifolds.	https://link.springer.com/book/10.1007/978-3…
B018	Probability: Theory and Examples — Rick Durrett 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	测度论概率标准教材：大数定律/CLT/条件期望/鞅收敛（作者官网免费） Standard measure-theoretic probability text: law of large numbers, CLT, conditional expectation, and martingale convergence (free on the author's site).	https://services.math.duke.edu/~rtd/PTE/
B019	Probability and Random Processes — Geoffrey Grimmett & David Stirzaker 元数据已补 / metadata recovered	教材 Book	付费 Paid	从初等概率过渡到马尔可夫链、更新过程与连续时间随机过程 Moves from elementary probability to Markov chains, renewal processes, and continuous-time stochastic processes.	https://academic.oup.com/book/52807
B020	概率论基础 — 李贤平	教材 Book	付费 Paid	中文打底：培养古典与初等概率直觉 Chinese foundation: builds classical and elementary probability intuition.	https://xuanshu.hep.com.cn/front/book/findBo…
B021	概率论基础 — 严士健、王隽骧	教材 Book	付费 Paid	中文打底：测度论公理化体系的概率论 Chinese foundation: probability theory within the measure-theoretic axiomatic framework.	https://book.douban.com/subject/1553785/
B022	Introductory Functional Analysis with Applications — Erwin Kreyszig	教材 Book	付费 Paid	证明极其详尽：Banach/Hilbert 空间、有界与紧算子谱理论，NTK/RKHS 敲门砖 Extremely detailed proofs: Banach/Hilbert spaces and bounded and compact operator spectral theory; the gateway to NTK and RKHS.	https://www.wiley.com/en-us/Introductory+Fun…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B023	Numerical Optimization — Jorge Nocedal & Stephen Wright	教材 Book	付费 Paid	连续优化迭代算法收敛性证明：线搜索/信赖域/共轭梯度/拟牛顿 Convergence proofs for continuous-optimization iterative algorithms: line search, trust region, conjugate gradient, and quasi-Newton.	https://link.springer.com/book/10.1007/978-0…

S11 开放获取教材

> 作者官网免费 PDF 的教材与讲义

Access free, legally downloadable versions of the foundational math textbooks from author and university sites.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B001	High-Dimensional Probability: An Introduction with Applications in Data Science — Roman Vershynin 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	AI 理论圣经（开源）：浓度不等式、sub-gaussian、覆盖数、随机矩阵奇异值界，精读 1-4 章 The 'bible' of AI theory (open access): concentration inequalities, sub-gaussian variables, covering numbers, and random-matrix singular-value bounds; read Chapters 1-4 closely.	https://www.math.uci.edu/~rvershyn/papers/HD…
B003	Convex Optimization — Stephen Boyd & Lieven Vandenberghe 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	变分推导与对偶理论标杆（免费）：凸函数/共轭/KKT，DPO 闭式解来源 The benchmark for variational derivations and duality theory (free): convex functions, conjugates, and KKT; the source of DPO closed-form solutions.	https://web.stanford.edu/~boyd/cvxbook/
B010	Linear Algebra Done Right — Sheldon Axler 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	摒弃行列式直接建谱定理，官方开放获取 PDF + 作者习题讲解视频 Builds spectral theory directly without determinants; official open-access PDF plus the author's exercise-walkthrough videos.	https://linear.axler.net/
B016	Measure, Integration & Real Analysis — Sheldon Axler 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	现代实分析/测度论：Lebesgue 积分、控制收敛、L^p 与 Hilbert 空间（开放获取） Modern real analysis and measure theory: Lebesgue integration, dominated convergence, L^p, and Hilbert spaces (open access).	https://measure.axler.net/
B018	Probability: Theory and Examples — Rick Durrett 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	测度论概率标准教材：大数定律/CLT/条件期望/鞅收敛（作者官网免费） Standard measure-theoretic probability text: law of large numbers, CLT, conditional expectation, and martingale convergence (free on the author's site).	https://services.math.duke.edu/~rtd/PTE/
B024	Linear Algebra — Jim Hefferon 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	GFDL 开源教材 + 逐题完整解答手册（证明步骤无跳跃），官方习题全解 GFDL open-source textbook plus a complete per-problem solution manual (proof steps without gaps); official solutions to all exercises.	https://hefferon.net/linearalgebra/
B025	Introduction to Applied Linear Algebra — Stephen Boyd & Lieven Vandenberghe 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	向量几何/正交投影/最小二乘/矩阵分解的直观推导，配套 Python/Julia 代码 Intuitive derivations of vector geometry, orthogonal projection, least squares, and matrix factorization, with Python/Julia code.	https://vmls-book.stanford.edu/

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B026	**Basic Analysis I & II: Introduction to Real Analysis — Jiří Lebl** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	CC BY-NC-SA 开源实分析教材，逻辑严谨度对标 Rudin 但语言更现代 CC BY-NC-SA open real-analysis textbook; rigor comparable to Rudin but with more modern language and examples.	https://jirka.org/ra/
B027	**Introduction to Probability — Charles M. Grinstead & J. Laurie Snell** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	AMS/达特茅斯免费开源：组合与初等概率过渡到马尔可夫链与随机游走 AMS/Dartmouth free and open: from combinatorics and elementary probability to Markov chains and random walks.	https://math.dartmouth.edu/~prob/prob/
B028	**Functional Analysis — Gerald Teschl** 留档 1 份 / 1 archived（补档）	教材 Book	开放获取 Open access	维也纳大学研究生教材：Banach 代数、紧算子谱理论、无界算子（作者主页免费） Vienna graduate textbook: Banach algebras, compact-operator spectral theory, and unbounded operators (free on the author's site).	https://www.mat.univie.ac.at/~gerald/ftp/boo…
B029	**Foundations of Data Science — Avrim Blum, John Hopcroft & Ravindran Kannan** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	面向计算机理论研究者：高维几何、SVD、随机游走与泛化界 For computer-science theory researchers: high-dimensional geometry, SVD, random walks, and generalization bounds.	https://www.cs.cornell.edu/jeh/book.pdf
B030	**Mathematics for Machine Learning — Marc Peter Deisenroth et al.** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	线代/矩阵微积分/概率/优化直接映射到 PCA、高斯过程、SVM（剑桥出版社授权免费） Maps linear algebra, matrix calculus, probability, and optimization directly onto PCA, Gaussian processes, and SVM (free with Cambridge University Press permission).	https://mml-book.github.io/

S12 配套习题集

> 带官方解答的证明/放缩习题集

Practice proof and inequality techniques with problem sets that include official solutions.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B010	**Linear Algebra Done Right — Sheldon Axler** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	摒弃行列式直接建谱定理，官方开放获取 PDF + 作者习题讲解视频 Builds spectral theory directly without determinants; official open-access PDF plus the author's exercise-walkthrough videos.	https://linear.axler.net/
B024	**Linear Algebra — Jim Hefferon** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	GFDL 开源教材 + 逐题完整解答手册（证明步骤无跳跃），官方习题全解 GFDL open-source textbook plus a complete per-problem solution manual (proof steps without gaps); official solutions to all exercises.	https://hefferon.net/linearalgebra/
B031	**Convex Optimization 官方补充习题与全解（Additional Exercises）— Stephen Boyd** 留档 1 份 / 1 archived（补档）	仓库 Repository	开放获取 Open access	EE364a 历年作业/考试证明题与官方推导：对偶构造、KKT、Fenchel 共轭 EE364a homework and exam proof problems with official derivations: duality construction, KKT, and Fenchel conjugates.	https://github.com/cvxgrp/cvxbook_additional…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B032	**Linear Algebra 官方全解手册 — Jim Hefferon（官方习题解答）** 留档 1 份 / 1 archived	习题集 Problem set	开放获取 Open access	与教材同步的逐题证明全解，规范线性空间/正交投影/特征值分解书写 Complete per-problem proof solutions synchronized with the textbook; standardizes writing for linear spaces, orthogonal projections, and eigendecompositions.	https://hefferon.net/linearalgebra/
B033	**The Cauchy-Schwarz Master Class — J. Michael Steele**	教材 Book	付费 Paid	不等式放缩艺术神作：Cauchy-Schwarz/Hölder/Minkowski/Jensen/重排，书后完整解答 The masterwork of inequality technique: Cauchy-Schwarz, Hölder, Minkowski, Jensen, and rearrangement, with full solutions at the back.	https://www.cambridge.org/core/books/cauchys…
B034	**Problems in Mathematical Analysis（全三卷）— W. J. Kaczor & M. T. Nowak** 元数据已补 / metadata recovered	习题集 Problem set	付费 Paid	全是证明题且逐题完整解答：实数与序列/连续与微分/积分 All proof problems with complete per-problem solutions: real numbers and sequences, continuity and differentiation, and integration.	https://www.ams.org/stml/004
B035	**数学分析中的典型问题与方法 — 裴礼文**	习题集 Problem set	付费 Paid	中文互补：一致收敛、积分不等式与泰勒余项放缩 Chinese complement: uniform convergence, integral inequalities, and Taylor-remainder estimates.	https://book.douban.com/subject/35339701/
B036	**数学分析习题课讲义 — 谢惠民**	习题集 Problem set	付费 Paid	中文互补：一致收敛、积分不等式与泰勒余项放缩 Chinese complement: uniform convergence, integral inequalities, and Taylor-remainder estimates.	https://book.douban.com/subject/30389024/
B037	**Problems and Theorems in Linear Algebra — V. V. Prasolov** 元数据已补 / metadata recovered	习题集 Problem set	付费 Paid	AMS 矩阵证明宝库：秩不等式、迹不等式、特征值交错定理，均附解答 An AMS treasure trove of matrix proofs: rank inequalities, trace inequalities, and eigenvalue interlacing, all with solutions.	https://bookstore.ams.org/MMONO/134
B038	**高等代数中的典型问题与方法 — 李志慧、李永明（指南原标樊恽、刘合国）** 元数据已补 / metadata recovered	习题集 Problem set	付费 Paid	中文互补：不变子空间、若尔当标准形与二次型正定性证明 Chinese complement: invariant subspaces, Jordan normal form, and positive-definiteness proofs for quadratic forms.	https://www.ecsponline.com/goods.php?id=29259
B039	**One Thousand Exercises in Probability — Geoffrey Grimmett & David Stirzaker** 元数据已补 / metadata recovered	习题集 Problem set	付费 Paid	1000 道概率/随机过程证明题完整推导：条件期望、马氏链收敛、鞅与停时 1,000 probability and stochastic-process proof problems with complete derivations: conditional expectation, Markov-chain convergence, martingales, and stopping times.	https://academic.oup.com/book/52798
B040	**Exercises in Functional Analysis — Constantin Costara & Dumitru Popa**	习题集 Problem set	付费 Paid	Banach/Hilbert 空间、算子范数与紧算子谱理论证明习题集 A problem set on Banach/Hilbert spaces, operator norms, and compact-operator spectral theory.	https://link.springer.com/book/10.1007/978-9…

S13 纯数学教材

> 实分析/抽象代数/测度概率/微分几何与最优传输

> Train pure mathematics across real and functional analysis, algebra and representation theory, measure-theoretic probability, and differential geometry and optimal transport.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B010	**Linear Algebra Done Right — Sheldon Axler** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	摒弃行列式直接建谱定理，官方开放获取 PDF + 作者习题讲解视频 Builds spectral theory directly without determinants; official open-access PDF plus the author's exercise-walkthrough videos.	https://linear.axler.net/
B016	**Measure, Integration & Real Analysis — Sheldon Axler** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	现代实分析/测度论：Lebesgue 积分、控制收敛、L^p 与 Hilbert 空间（开放获取） Modern real analysis and measure theory: Lebesgue integration, dominated convergence, L^p, and Hilbert spaces (open access).	https://measure.axler.net/
B018	**Probability: Theory and Examples — Rick Durrett** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	测度论概率标准教材：大数定律/CLT/条件期望/鞅收敛（作者官网免费） Standard measure-theoretic probability text: law of large numbers, CLT, conditional expectation, and martingale convergence (free on the author's site).	https://services.math.duke.edu/~rtd/PTE/
B028	**Functional Analysis — Gerald Teschl** 留档 1 份 / 1 archived（补档）	教材 Book	开放获取 Open access	维也纳大学研究生教材：Banach 代数、紧算子谱理论、无界算子（作者主页免费） Vienna graduate textbook: Banach algebras, compact-operator spectral theory, and unbounded operators (free on the author's site).	https://www.mat.univie.ac.at/~gerald/ftp/boo…
B041	**Real Analysis: Modern Techniques and Their Applications — Gerald B. Folland**	教材 Book	付费 Paid	测度论与实分析标杆：Radon 测度、Riesz 表示、L^p 插值、分布理论 The standard for measure theory and real analysis: Radon measures, Riesz representation, L^p interpolation, and distribution theory.	https://www.wiley.com/en-us/Real+Analysis%3A…
B042	**Princeton Lectures in Analysis（第 3 卷 Real Analysis & 第 4 卷 Functional Analysis）— Elias M. Stein & Rami Shakarchi** 元数据已补 / metadata recovered	教材 Book	付费 Paid	从 Lebesgue 微分定理、Hausdorff 维数到 Banach 三大定理、紧算子谱分解与无界自伴算子 From the Lebesgue differentiation theorem and Hausdorff dimension to the three Banach theorems, compact-operator spectral decomposition, and unbounded self-adjoint operators.	https://www.degruyterbrill.com/document/doi/…
B043	**Functional Analysis, Sobolev Spaces and Partial Differential Equations — Haïm Brezis**	教材 Book	付费 Paid	布尔巴基风格：弱拓扑、自反空间与变分不等式极通透 Bourbaki style: unusually clear treatment of weak topologies, reflexive spaces, and variational inequalities.	https://link.springer.com/book/10.1007/978-0…
B044	**Problems and Theorems in Analysis（全两卷）— George Pólya & Gábor Szegő**	习题集 Problem set	付费 Paid	纯数学分析训练圣经：按逻辑链编排的纯证明题（附完整解答） The bible of pure-analysis training: pure proof problems arranged in logical chains (with complete solutions).	https://link.springer.com/book/10.1007/978-3…
B045	**A Hilbert Space Problem Book — Paul R. Halmos**	习题集 Problem set	付费 Paid	250 个纯概念证明命题 + 提示 + 完整证明：有界/紧/正规算子与不变子空间 250 pure-concept proof propositions plus hints and complete proofs: bounded, compact, and normal operators and invariant subspaces.	https://link.springer.com/book/10.1007/978-1…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B046	**Linear Algebra — Kenneth Hoffman & Ray Kunze**	教材 Book	付费 Paid	纯数系线代试金石：商空间、对偶空间、若尔当/有理标准形、多线性代数与张量积 The touchstone for pure-mathematics linear algebra: quotient spaces, dual spaces, Jordan and rational canonical forms, multilinear algebra, and tensor products.	https://archive.org/details/linearalgebra00h…
B047	**Advanced Linear Algebra — Steven Roman**	教材 Book	付费 Paid	研究生级抽象线代：自由模、半单算子、Hilbert 空间算子谱分解与仿射几何 Graduate-level abstract linear algebra: free modules, semisimple operators, Hilbert-space operator spectral decomposition, and affine geometry.	https://link.springer.com/book/10.1007/978-0…
B048	**Linear Representations of Finite Groups — Jean-Pierre Serre**	教材 Book	付费 Paid	Serre 薄册经典：特征标理论与不可约表示分解，等变网络权重约束的理论来源 Serre's classic short book: character theory and irreducible-representation decomposition; the theoretical source for weight constraints in equivariant networks.	https://link.springer.com/book/10.1007/978-1…
B049	**Exercises in Algebra（《代数学题集》，莫斯科大学教材配套）— A. I. Kostrikin 等**	习题集 Problem set	付费 Paid	俄罗斯纯数学学派：群/环/域/模/表示论/多重线性，多为结构证明题 Russian pure-mathematics school: groups, rings, fields, modules, representation theory, and multilinear algebra; mostly structural proof problems.	https://book.douban.com/subject/30323073/
B050	**代数学引论 — A. I. Kostrikin（中译本）**	教材 Book	付费 Paid	Kostrikin 教材中译本，可与《代数学题集》配套使用 Chinese translation of Kostrikin's textbook, to be used together with the Exercise Book.	https://book.douban.com/subject/2036531/
B051	**Linear Algebra Problem Book — Paul R. Halmos**	习题集 Problem set	付费 Paid	纯代数结构证明题库：向量空间公理推演与线性变换本质 A pure algebraic-structure problem bank: vector-space axiom derivations and the essence of linear transformations.	https://www.cambridge.org/core/books/linear-…
B052	**Probability with Martingales — David Williams**	教材 Book	付费 Paid	剑桥纯数学学派：σ-代数、单调类定理、鞅收敛、一致可积、Radon-Nikodym Cambridge pure-mathematics school: σ-algebras, the monotone class theorem, martingale convergence, uniform integrability, and Radon-Nikodym.	https://www.cambridge.org/highereducation/bo…
B053	**Probability and Measure — Patrick Billingsley**	教材 Book	付费 Paid	测度论与概率论完全融为一体的典范：弱收敛与遍历理论证明无可替代 A model of measure theory fully fused with probability: its proofs of weak convergence and ergodic theory are irreplaceable.	https://www.wiley.com/en-us/Probability+and+…
B054	**Brownian Motion, Martingales, and Stochastic Calculus — Jean-François Le Gall**	教材 Book	付费 Paid	沃夫奖得主：连续时间鞅、布朗运动构造、Itô 积分、Girsanov、SDE A Wolf Prize winner's text: continuous-time martingales, Brownian-motion construction, Itô integrals, Girsanov, and SDEs.	https://link.springer.com/book/10.1007/978-3…
B055	**Counterexamples in Probability — Jordan M. Stoyanov** 元数据已补 / metadata recovered	教材 Book	付费 Paid	用反例厘清几乎必然收敛/依概率收敛/L^p 收敛/独立与不相关的严格边界 Uses counterexamples to clarify the strict boundaries between almost-sure, in-probability, and L^p convergence, and between independence and uncorrelatedness.	https://store.doverpublications.com/products…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B056	**Problems in Probability — Albert N. Shiryaev**	习题集 Problem set	付费 Paid	柯尔莫哥洛夫学派权威习题集：测度论概率、特征函数、鞅与马尔可夫过程（附解答） Kolmogorov-school authoritative problem set: measure-theoretic probability, characteristic functions, martingales, and Markov processes (with solutions).	https://link.springer.com/book/10.1007/978-1…
B057	**Introduction to Smooth Manifolds — John M. Lee**	教材 Book	付费 Paid	光滑流形公理化黄金标准：切向量/余切丛/微分形式/Stokes/李群，自带证明习题 The gold standard for axiomatic smooth manifolds: tangent vectors, cotangent bundles, differential forms, Stokes' theorem, and Lie groups, with proof exercises.	https://link.springer.com/book/10.1007/978-1…
B058	**Riemannian Geometry — Manfredo P. do Carmo** 元数据已补 / metadata recovered	教材 Book	付费 Paid	黎曼度量、Levi-Civita 联络、测地线变分公式与截面曲率经典教材 A classic text on Riemannian metrics, the Levi-Civita connection, geodesic variation formulas, and sectional curvature.	https://web.archive.org/web/20180330191141/h…
B059	**Topics in Optimal Transportation — Cédric Villani** 元数据已补 / metadata recovered	教材 Book	付费 Paid	Kantorovich 对偶、Brenier 定理与 Wasserstein 空间梯度流理论 Kantorovich duality, Brenier's theorem, and gradient-flow theory on Wasserstein space.	https://bookstore.ams.org/gsm-58
B060	**Functional Analysis — Theo Bühler & Dietmar A. Salamon** 留档 1 份 / 1 archived（补档） 元数据已补 / metadata recovered	教材 Book	开放获取 Open access	ETH 研究生泛函分析：Hahn-Banach、一致有界、开映射/闭图像、弱拓扑、Fredholm 算子（作者主页免费） ETH graduate functional analysis: Hahn-Banach, uniform boundedness, open mapping and closed graph, weak topology, and Fredholm operators (free on the author's site).	https://people.math.ethz.ch/~salamon/PREPRIN…
B061	**Abstract Algebra: Theory and Applications — Thomas W. Judson** 留档 1 份 / 1 archived（补档）	教材 Book	开放获取 Open access	GNU FDL 开源抽象代数：群同态/Sylow/环与理想/PID/Galois，每章大量结构证明题 GNU FDL open abstract algebra: group homomorphisms, Sylow theorems, rings and ideals, PIDs, and Galois theory, with many structural proof exercises per chapter.	https://judsonbooks.org/
C015	**Terence Tao UCLA Math 245A/245B/245C 讲义** 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	陶哲轩实分析/泛函/调和分析讲义，正文内嵌数百道 Exercise Terence Tao's real-analysis/functional-analysis/harmonic-analysis notes with hundreds of embedded exercises.	https://terrytao.wordpress.com/category/teac…
B062	**Group Theory & Fields and Galois Theory — J. S. Milne** 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	作者主页免费研究生代数讲义：证明言简意赅 Free graduate algebra notes on the author's site: proofs are concise and to the point.	https://www.jmilne.org/math/CourseNotes/
B063	**Introduction to Representation Theory — Pavel Etingof 等（MIT 研究生讲义）** 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	arXiv 免费讲义：Schur 引理/Maschke 定理/特征标/箭图与李代数表示，自带证明习题 Free arXiv lecture notes: Schur's lemma, Maschke's theorem, characters, quiver and Lie-algebra representations, with proof exercises.	https://arxiv.org/abs/0901.0827
B064	**Stochastic Calculus（Princeton ORF 526 研究生讲义）— Ramon van Handel** 留档 1 份 / 1 archived（补档）	讲义 Lecture notes	开放获取 Open access	从滤子/局部鞅/二次变差严格构建 Itô 积分、Girsanov 与 SDE 强弱解理论 Rigorously builds Itô integrals, Girsanov, and strong/weak SDE solutions from filtrations, local martingales, and quadratic variation.	https://web.math.princeton.edu/~rvan/

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
B065	**Amir Dembo 斯坦福测度论概率讲义（Math 230A / Stat 310）** 留档 1 份 / 1 archived（补档）	讲义 Lecture notes	开放获取 Open access	弱收敛（Portmanteau/Prokhorov）、大偏差原理与布朗运动构造，证明细节完整 Weak convergence (Portmanteau and Prokhorov), large-deviation theory, and Brownian-motion construction with complete proof details.	https://adembo.su.domains/
B066	**Lectures on the Geometry of Manifolds — Liviu I. Nicolaescu** 留档 1 份 / 1 archived	教材 Book	开放获取 Open access	从光滑流形/微分形式/Stokes 到联络、曲率、Riemann 几何与 Hodge 理论（作者主页免费） From smooth manifolds, differential forms, and Stokes' theorem to connections, curvature, Riemannian geometry, and Hodge theory (free on the author's site).	https://www3.nd.edu/~lnicolae/Lectures.pdf
B067	**Optimal Transport: Old and New — Cédric Villani**	教材 Book	部分免费 Partially free	最优传输百科全书：Kantorovich 对偶、Brenier 极分解、Wasserstein 完备性与 Otto 微积分 The encyclopedia of optimal transport: Kantorovich duality, Brenier polar decomposition, Wasserstein completeness, and Otto calculus.	https://link.springer.com/book/10.1007/978-3…

S14 开源纯数学与题库

> 开放获取纯数学教材 + MIT OCW/剑桥 Tripos/arXiv 题库

Use open pure-math textbooks and problem banks (MIT OCW, Cambridge Tripos, arXiv lecture notes) for self-study.

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
C015	**Terence Tao UCLA Math 245A/245B/245C 讲义** 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	陶哲轩实分析/泛函/调和分析讲义，正文内嵌数百道 Exercise Terence Tao's real-analysis/functional-analysis/harmonic-analysis notes with hundreds of embedded exercises.	https://terrytao.wordpress.com/category/teac…
B063	**Introduction to Representation Theory — Pavel Etingof 等（MIT 研究生讲义）** 留档 1 份 / 1 archived	讲义 Lecture notes	开放获取 Open access	arXiv 免费讲义：Schur 引理/Maschke 定理/特征标/箭图与李代数表示，自带证明习题 Free arXiv lecture notes: Schur's lemma, Maschke's theorem, characters, quiver and Lie-algebra representations, with proof exercises.	https://arxiv.org/abs/0901.0827
B068	**18.100B / 18.102 / 18.701 / 18.702 / 18.965 题库（MIT OCW）**	习题集 Problem set	开放获取 Open access	MIT OCW 纯数学核心课程题库：作业（Problem Sets）与考试/复习材料；OCW 现行版本未公开官方解答，解答需自行推导或另寻 MIT OCW pure-mathematics core problem bank: Problem Sets and exam/review materials; the current OCW version does not publish official solutions, so derive them yourself or find them elsewhere.	https://ocw.mit.edu/
C009	**MIT OCW 18.100B（Real Analysis）** 留档 36 份 / 36 archived（OCW）	课程 Course	开放获取 Open access	MIT 公开课：《数学分析原理》水准的度量空间/紧性/一致收敛证明题（OCW 现行版本只公开题单，未公开官方解答） MIT OCW course: measure-space, compactness, and uniform-convergence proof exercises at Baby Rudin level (current OCW version publishes problem sets only, not official solutions).	https://ocw.mit.edu/courses/18-100b-real-ana…

编号 ID	资料 Resource	类型 Type	获取方式 Access	说明 Description	链接 Link
C010	MIT OCW 18.102（Introduction to Functional Analysis） 留档 37 份 / 37 archived（OCW）	课程 Course	开放获取 Open access	Banach/Hilbert 空间、有界/紧算子证明题（OCW 现行版本只公开题单与考试材料） Banach/Hilbert space and bounded/compact operator proof exercises (current OCW version publishes problem sets and exam materials only).	https://ocw.mit.edu/courses/18-102-introduct…
C011	MIT OCW 18.701（Algebra I） 留档 16 份 / 16 archived（OCW）	课程 Course	开放获取 Open access	群作用与线性代数纯证明题（OCW 只公开题单） Group-actions and linear-algebra proof exercises (OCW publishes problem sets only).	https://ocw.mit.edu/courses/18-701-algebra-i…
C012	MIT OCW 18.702（Algebra II） 留档 10 份 / 10 archived（OCW）	课程 Course	开放获取 Open access	表示论、模与域扩张纯证明题（OCW 只公开题单） Representation-theory, module, and field-extension proof exercises (OCW publishes problem sets only).	https://ocw.mit.edu/courses/18-702-algebra-i…
C013	MIT OCW 18.965（Geometry of Manifolds） 留档 32 份 / 32 archived（OCW）	课程 Course	开放获取 Open access	流形、张量场与微分形式证明题（OCW 只公开题单） Manifold, tensor-field, and differential-form proof exercises (OCW publishes problem sets only).	https://ocw.mit.edu/courses/18-965-geometry-…
C014	剑桥大学数学系 Tripos Part II / Part III Example Sheets 留档 72 份 / 72 archived（补档）	习题集 Problem set	开放获取 Open access	世界顶尖纯数研究生难度专题证明题单 Top-tier pure-mathematics graduate-level topic-specific problem sheets.	https://www.maths.cam.ac.uk/undergrad/exampl…

三、指南摘要 / 3. Guide Digest

五个低算力顶会课题 / Five Compute-Light Thesis Topics

课题 Topic	核心痛点 Core pain point	研究切入点 Research entry point	实验与算力配置 Experiment and compute setup	目标顶会 Target venues
一、推理模型"思维预算"动态控制与过度思考抑制 1. Dynamic control of the reasoning-model "thinking budget" and suppression of overthinking	Long-CoT 推理模型面对简单问题易陷入"过度思考（Overthinking）"，生成大量冗余验证 Token 致延迟飙升；高难问题又可能过早停止探索（p5） Long-CoT reasoning models easily fall into "overthinking" on simple problems, generating many redundant verification tokens and sharply increasing latency; on hard problems they may stop exploring too early (p5)	设计轻量甚至训练-free 的推理期早停（Early-Exiting）或动态路由：监测隐藏层状态、注意力熵值变化或思维链中自我否定词频，在模型锁定正确答案的瞬间动态截断思维链，或自适应分配推理计算预算（Test-time Scaling）（p5） Design a lightweight or even training-free inference-time early-exit or dynamic-routing strategy: monitor hidden states, attention-entropy changes, or the frequency of self-negation words in the chain of thought, cut the chain the moment the model has locked in the correct answer, or adaptively allocate inference compute (Test-time Scaling) (p5)	仅需 1 张 24GB/48GB 显卡；直接基于开源 7B/8B/14B 蒸馏推理模型，在 MATH-500、AIME、GPQA 等基准上跑推理评估，对比 Token 消耗量（降低 30%-50%）与准确率保持率（p5） Only 1 GPU with 24GB/48GB is needed; start from open 7B/8B/14B distilled reasoning models and run inference evaluations on MATH-500, AIME, GPQA, comparing token consumption (reduced by 30%-50%) against accuracy retention (p5)	NeurIPS、ICLR、ACL、EMNLP NeurIPS, ICLR, ACL, EMNLP
二、RLVR 高价值样本筛选与课程学习策略 2. High-value sample selection and curriculum-learning strategies for RLVR	用 GRPO 等算法做推理强化学习时，海量样本中存在大量"全对（模型早就会了，梯度为零）"和"全错（太难，采样不到正奖励）"的无效数据，严重浪费训练算力（p6） When using GRPO and similar algorithms for reasoning RL, the massive sample pool contains many invalid samples that are "all correct (the model already knows them, so gradients are zero)" or "all wrong (too hard, no positive reward can be sampled)", severely wasting training compute (p6)	探索数据高效（Data-Efficient）后训练配方：基于模型当前能力边界（Pass@k 分布方差、输出分布困惑度或思维链结构复杂度）做在线动态数据筛选（Online Data Selection）或课程学习，证明仅用 10%-20% 核心训练数据即可达到全量数据训练的 RL 效果，甚至缓解语言退化（p6） Explore data-efficient post-training recipes: use the model's current capability boundary (Pass@k distribution variance, output-distribution perplexity, or chain-of-thought structural complexity) to perform online dynamic data selection (Online Data Selection) or curriculum learning, and prove that only 10%-20% of the core training data matches the RL effect of training on the full dataset, possibly even mitigating language degradation (p6)	2-4 张 4090 或单张 A100/H100（配合 LoRA + vLLM/SGLang 加速采样；3B/7B 模型在几千条高质量数学/代码数据上只需数小时至一两天即可跑完一轮完整实验）（p6） 2-4 RTX 4090s or a single A100/H100 (with LoRA + vLLM/SGLang accelerated sampling; a 3B/7B model on a few thousand high-quality math/code samples completes one full experiment round in hours to one or two days) (p6)	ICML、NeurIPS、ICLR ICML, NeurIPS, ICLR

课题 Topic	核心痛点 Core pain point	研究切入点 Research entry point	实验与算力配置 Experiment and compute setup	目标顶会 Target venues
三、无需训练的 KV Cache 极端压缩与长上下文注意力稀疏化 3. Training-free extreme KV Cache compression and long-context attention sparsification	处理长文档、多轮 Agent 历史记录或长视频时，KV Cache 显存占用成为推理吞吐量最大瓶颈；现有静态驱逐策略（如只保留首尾 Token）经常误删关键"大海捞针"信息（p6） For long documents, multi-turn agent histories, or long videos, KV Cache memory becomes the biggest bottleneck on inference throughput; existing static eviction policies (such as keeping only the first and last tokens) often mistakenly delete key "needle-in-a-haystack" information (p6)	结合注意力机制底层几何或频谱特征，提出自适应层级/头级（Layer-wise / Head-wise）KV Cache 压缩与低比特混合量化：区分"局部语法头"与"全局检索头"，按不同注意力头分配差异化缓存保留预算，把 KV Cache 显存压缩至 15%-20% 的同时保证长上下文推理与多跳问答几乎无损（p6） Combine the underlying geometry or spectral features of attention to propose adaptive layer-wise/head-wise (Layer-wise / Head-wise) KV Cache compression with mixed low-bit quantization: distinguish "local syntax heads" from "global retrieval heads", assign differentiated cache-retention budgets per attention head, and compress KV Cache memory to 15%-20% while keeping long-context reasoning and multi-hop QA almost lossless (p6)	1 张 24GB 显卡即可完成全部实验，完全不需要训练模型；编写自定义 Attention Hook 或基于 vLLM/HuggingFace 改造推理代码，在 LongBench、RULER、Needle-in-a-Haystack 上做充分消融与吞吐量测试（p6） 1 GPU with 24GB is enough for all experiments, and no model training is needed; write a custom Attention Hook or adapt the vLLM/HuggingFace inference code, and run full ablations and throughput tests on LongBench, RULER, and Needle-in-a-Haystack (p6)	ICLR、NeurIPS、MLSys ICLR, NeurIPS, MLSys
四、多智能体协作中的上下文退化诊断与自适应记忆压缩 4. Diagnosing context degradation and adaptive memory compression in multi-agent collaboration	复杂软件工程（SWE）或深度研究智能体（Deep Research Agent）执行几十步工具调用后上下文迅速膨胀，出现"注意力迷失"、重复犯错以及工具调用格式崩溃（p6） After dozens of tool-call steps in complex software engineering (SWE) or deep-research agents (Deep Research Agent), the context balloons rapidly, causing "attention loss", repeated mistakes, and broken tool-call formats (p6)	针对长程交互轨迹（Trajectory）设计基于因果归因或状态摘要的结构化记忆机制（Structured Memory / Context Folding）：自动折叠已完成子任务细节、保留关键环境状态与失败教训，并构建轻量重放/反思策略，提升 7B-14B 小模型作 Agent 基座的任务完成率（p6） For long-horizon interaction trajectories (Trajectory), design a structured memory mechanism based on causal attribution or state summarization (Structured Memory / Context Folding): automatically fold the details of completed subtasks, retain critical environment states and failure lessons, and build a lightweight replay/reflection strategy to improve task completion when 7B-14B small open models serve as the agent base (p6)	1-2 张 24GB 显卡（本地部署 7B/8B/14B 开源模型作 Agent 核心，配合局部轻量 LoRA 微调或纯推理策略优化），在 SWE-bench Lite、OSWorld 或 WebArena 子集上验证（p6） 1-2 GPUs with 24GB (deploy 7B/8B/14B open models locally as the agent core, with light local LoRA fine-tuning or pure inference-time policy optimization), validated on SWE-bench Lite, OSWorld, or a WebArena subset (p6)	ACL、ICLR、NeurIPS（Datasets & Benchmarks 或 Main Track） ACL, ICLR, NeurIPS (Datasets & Benchmarks or Main Track)

课题 Topic	核心痛点 Core pain point	研究切入点 Research entry point	实验与算力配置 Experiment and compute setup	目标顶会 Target venues
五、大模型内部表征干预（Activation Steering）与知识边界校准 **5. LLM internal representation intervention (Activation Steering) and knowledge-boundary calibration**	模型面对超出自身知识边界的问题时产生严重幻觉，或多模态场景下过度依赖语言先验而忽略视觉输入（视觉幻觉）；传统微调成本高且容易破坏通用能力（p7） Models hallucinate severely on questions beyond their knowledge boundary, or over-rely on language priors and ignore visual input in multimodal settings (visual hallucination); conventional fine-tuning is costly and easily damages general capabilities (p7)	分析模型残差流（Residual Stream）或特定注意力头的激活方向，寻找控制"事实确定性""拒答倾向"或"视觉注意力权重"的低维线性子空间；设计推理期自适应激活转向（Adaptive Activation Steering）或轻量级探针干预，在不修改权重的前提下显著降低幻觉率并提升不确定性校准（Calibration）指标（p7） Analyze the residual stream (Residual Stream) or the activation directions of specific attention heads to find low-dimensional linear subspaces that control "factual certainty", "refusal tendency", or "visual attention weights"; design inference-time adaptive activation steering (Adaptive Activation Steering) or lightweight probe interventions that significantly reduce hallucination rates and improve calibration metrics without modifying model weights (p7)	单张 24GB 显卡极速出结果；单次前向传播提取特征与验证只需几分钟，非常适合快速迭代想法、绘制精美的表征可视化图（审稿人非常喜欢这类机理剖析工作）（p7） A single 24GB GPU yields results extremely fast; extracting features and validating them takes only minutes per forward pass, ideal for rapid iteration and for drawing polished representation-visualization figures (reviewers particularly like this kind of mechanistic analysis) (p7)	NeurIPS、ICLR、EMNLP NeurIPS, ICLR, EMNLP

五课题饱和度 / Saturation of the Five Topics

课题方向 Topic direction	饱和度 Saturation	已饱和的"红海做法"（审稿人易拒稿） Saturated "red ocean" approaches (easy for reviewers to reject)	未饱和的"蓝海切入点"（高命中率） Unsaturated "blue ocean" entry points (high hit rate)
课题三：KV Cache 极端压缩 Project 3: Extreme KV Cache compression	极高 ★★★★★ Extremely high ★★★★★	针对"长输入、短输出"的常规 Token 驱逐（仅换个注意力打分公式在 LongBench 上刷分，ACL 2026 已有系统综述总结此类方法）（p8） Conventional token eviction for "long input, short output" (just swapping the attention-scoring formula and chasing points on LongBench; ACL 2026 already has a survey summarizing such methods) (p8)	面向推理模型长输出（Long-CoT）的阶段感知异构压缩；结合 Triton 算子融合实现真实吞吐量（Throughput）提升，而非仅在 Transformers 里模拟稀疏率（p8） Stage-aware heterogeneous compression for long reasoning-model outputs (Long-CoT); Triton-kernel fusion to achieve real throughput gains rather than merely simulating sparsity ratios inside Transformers (p8)
课题一：推理模型"思维预算"控制 Project 1: Reasoning-model "thinking budget" control	高 ★★★★☆ High ★★★★☆	简单的基于 Token 熵值、全局置信度阈值早停，或单纯用 Prompt 限制思维链长度（相关综述与基准已密集涌现）（p8） Simple early stopping based on token entropy or global confidence thresholds, or limiting chain-of-thought length with prompts alone (related surveys and benchmarks are already proliferating) (p8)	解决"伪收敛"与"过度思考导致对改错"问题：利用内部特定注意力头（如思维划分头）做细粒度步骤级干预；或转向多模态长思维链（Multimodal CoT）的跨模态冗余抑制（p8） Solve "pseudo-convergence" and the problem of overthinking turning correct answers into wrong ones: use specific internal attention heads (such as thought-divider heads) for fine-grained step-level intervention; or move to suppressing cross-modal redundancy in multimodal long chain-of-thought (Multimodal CoT) (p8)
课题五：内部表征干预（Activation Steering） Project 5: LLM internal representation intervention (Activation Steering)	中高 ★★★☆☆ Medium-high ★★★☆☆	全局静态、固定强度的线性转向向量（审稿人已熟知其会破坏通用能力、对超参敏感，且无法强行注入新事实知识）（p8） Global static linear steering vectors of fixed strength (reviewers already know they damage general capabilities, are sensitive to hyperparameters, and cannot force new factual knowledge in) (p8)	动态闭环与条件门控干预（引入控制论反馈机制或 Token 级动态拒止，仅在越界风险出现时介入）；在 VLM 中抑制语言先验过强导致的视觉幻觉（p8） Dynamic closed-loop and conditional-gated intervention (introduce control-theory feedback or token-level dynamic refusal, intervening only when an out-of-boundary risk appears); suppress visual hallucination caused by an over-strong language prior in VLMs (p8)
课题二：RLVR 样本筛选与课程学习 Project 2: RLVR sample selection and curriculum learning	中 ★★★☆☆ Medium ★★★☆☆	仅过滤掉"全对或全错（零梯度）"样本的静态筛选（已成为主流 RL 训练框架的默认工程技巧）（p8） Static filtering that only removes "all-correct or all-wrong (zero-gradient)" samples (already a default engineering trick in mainstream RL training frameworks) (p8)	突破推理边界（Expanding Reasoning Boundary）：传统 GRPO 往往只提高 Pass@1 却导致大 k 下 Pass@k 探索覆盖率萎缩；研究如何用极少高难样本配合逆向课程解锁模型原本不会的难题（p8） Expand the reasoning boundary (Expanding Reasoning Boundary): conventional GRPO often only raises Pass@1 while shrinking Pass@k exploration coverage at large k; study how to unlock problems the model originally could not solve using very few hard samples plus a reverse curriculum (p8)
课题四：多智能体上下文退化与记忆压缩 Project 4: Multi-agent context degradation and memory compression	中低 ★★☆☆☆ Medium-low ★★☆☆☆	每隔固定轮次调用大模型做粗暴的纯文本摘要（Summarization），导致关键报错信息或约束丢失（p8） Calling an LLM every fixed number of rounds for crude plain-text summarization (Summarization), losing critical error messages or constraints (p8)	可恢复的状态近似（Recoverable State Approximation）与潜在/KV 级跨步记忆复用：压缩 50+ 步长程工具调用轨迹时保留因果回溯指针，系统性诊断并修复智能体失败模式（p8） Recoverable state approximation (Recoverable State Approximation) and latent/KV-level cross-step memory reuse: keep causal backtracking pointers when compressing 50+ step long-horizon tool-call trajectories, and systematically diagnose and repair agent failure modes (p8)

30 天学习计划 / 30-Day Study Plan

周次 Week	周目标 Weekly goal	关键学习与动手内容 Key learning and hands-on content	验收标准 Acceptance criteria	关键工具 Key tools
第 1 周（Day 1-7） Week 1 (Day 1-7)	掌握 PyTorch 核心机制与训练闭环，彻底摆脱对封装训练框架的依赖 Master PyTorch core mechanisms and the training loop, and stop depending on wrapper training frameworks	Day 1-2 张量内存布局、广播机制、view/reshape/permute/transpose；Day 3-4 autograd、detach、nn.Module、AdamW，手写含 LayerNorm 与残差的两层全连接小网络并打印 .grad；Day 5-7 完整训练循环（Dataset/DataLoader、交叉熵、梯度裁剪、torch.amp）（p11） Day 1-2 tensor memory layout, broadcasting, view/reshape/permute/transpose; Day 3-4 autograd, detach, nn.Module, AdamW, hand-write a small two-layer fully connected network with LayerNorm and residual connections and print the .grad of each layer; Day 5-7 a complete training loop (Dataset/DataLoader, cross-entropy, gradient clipping, torch.amp) (p11)	不查文档写出包含 optimizer.zero_grad()、loss.backward()、optimizer.step() 与 model.eval() 的标准 PyTorch 训练模板，并能独立排查 RuntimeError: shape mismatch（p11） Without consulting documentation, write the standard PyTorch training template containing optimizer.zero_grad(), loss.backward(), optimizer.step(), and model.eval(), and independently troubleshoot the common RuntimeError: shape mismatch (p11)	PyTorch、einops、nvidia-smi PyTorch, einops, nvidia-smi
第 2 周（Day 8-14） Week 2 (Day 8-14)	手撕 Transformer 与现代大模型架构，从底层矩阵运算理解 Decoder-only 大模型的每个组件 Hand-code Transformer and modern LLM architectures, understanding every component of a Decoder-only large model from bottom-level matrix operations	Day 8-9 BPE Tokenizer、词嵌入、RoPE 旋转位置编码数学直觉与一维旋转矩阵手写；Day 10-11 用 torch.matmul 与 softmax 手写带因果掩码的 GQA 模块；Day 12-14 RMSNorm、SwiGLU、Pre-Norm 残差结构与 KV Cache 原理，跟 nanoGPT 拼装微型 GPT 完成预训练与逐 Token 自回归生成（p11-12） Day 8-9 BPE Tokenizer, word embeddings, mathematical intuition of RoPE rotary positional encoding and a hand-written 1-D rotation matrix; Day 10-11 hand-write a causal-masked GQA module with torch.matmul and softmax; Day 12-14 RMSNorm, SwiGLU, Pre-Norm residual structure, and KV Cache principles, assemble a tiny GPT with nanoGPT and complete pretraining plus token-by-token autoregressive generation (p11-12)	能在白板或空白 .py 文件独立手写出 GQA 注意力核心前向代码，并用自己的话解释为什么推理时引入 KV Cache 能大幅降低时间复杂度（p12） Independently hand-write the core GQA attention forward code on a whiteboard or in an empty .py file, and explain in your own words why introducing KV Cache at inference greatly reduces time complexity (p12)	PyTorch、Karpathy nanoGPT PyTorch, Karpathy nanoGPT

周次 Week	周目标 Weekly goal	关键学习与动手内容 Key learning and hands-on content	验收标准 Acceptance criteria	关键工具 Key tools
第 3 周（Day 15-21） Week 3 (Day 15-21)	熟练驾驭 HuggingFace 工具链，学会加载开源大模型并提取内部表征（科研必备技能） Become fluent with the HuggingFace toolchain and learn to load open LLMs and extract internal representations (an essential research skill)	Day 15-16 AutoTokenizer / AutoModelForCausalLM / AutoConfig 三件套与 apply_chat_template，加载 Qwen2.5-7B-Instruct（或 3B）；Day 17-18 FP16/BF16、bitsandbytes 4-bit/8-bit 量化、temperature/top_p/do_sample，对比显存与生成速度；Day 19-21 用 output_hidden_states=True 与 register_forward_hook 提取激活张量，并部署 vLLM 跑通离线批量推理（p12） Day 15-16 the AutoTokenizer / AutoModelForCausalLM / AutoConfig trio and apply_chat_template, load Qwen2.5-7B-Instruct (or the 3B version); Day 17-18 FP16/BF16, bitsandbytes 4-bit/8-bit quantization, temperature/top_p/do_sample, compare memory use and generation speed; Day 19-21 extract activation tensors with output_hidden_states=True and register_forward_hook, and deploy vLLM for offline batch inference (p12)	能在单卡上流畅运行开源大模型的批量推理，且掌握用 PyTorch Hook 拦截并打印中间层激活值的能力（复现表征干预、注意力分析类顶会论文的核心基础）（p12） Run batch inference with open LLMs smoothly on a single GPU, and master using PyTorch Hooks to intercept and print intermediate-layer activations (the core foundation for reproducing top-conference papers on representation intervention and attention analysis) (p12)	transformers、bitsandbytes、vLLM、HuggingFace 镜像源 transformers, bitsandbytes, vLLM, HuggingFace mirror
第 4 周（Day 22-30） Week 4 (Day 22-30)	掌握 LoRA / QLoRA 原理，完成从数据清洗、模型微调到效果评测的完整闭环 Master LoRA / QLoRA principles and complete the full loop from data cleaning and model fine-tuning to effect evaluation	Day 22-23 指令微调（SFT）数据格式 Alpaca / ShareGPT、Loss Masking，准备 500-1000 条垂直任务数据；Day 24-25 LoRA/QLoRA 数学原理（低秩旁路矩阵 W + BA）、秩 r / lora_alpha / target_modules 与 peft 库，打印可训练参数量占比（通常仅占总参数量的 0.5%–2%）；Day 26-28 BF16 + gradient_checkpointing + trl 的 SFTTrainer 跑通微调；Day 29-30 merge_and_unload、在独立 100 条验证集上对比原始基座与微调模型，代码与实验记录整理至 GitHub（p12-13） Day 22-23 instruction-tuning (SFT) data formats Alpaca / ShareGPT and Loss Masking, prepare 500-1000 vertical-task samples; Day 24-25 LoRA/QLoRA mathematics (low-rank bypass matrices W + BA), rank r / lora_alpha / target_modules, and the peft library, printing the share of trainable parameters (usually only 0.5%-2% of all parameters); Day 26-28 run fine-tuning with BF16 + gradient_checkpointing + the trl SFTTrainer; Day 29-30 merge_and_unload, compare the original base model with the fine-tuned model on an independent 100-sample validation set, and organize the code and experiment records on GitHub (p12-13)	拥有一个亲手微调、有明确量化对比指标（如格式准确率从 62% 提升至 96%）的 GitHub 仓库，具备正式进组或复现顶会论文基线代码的工程能力（p13） Own a GitHub repository with a model you fine-tuned yourself and clear quantitative comparison metrics (such as format accuracy rising from 62% to 96%), demonstrating the engineering ability to officially join a lab or reproduce top-conference baseline code (p13)	peft、trl（SFTTrainer）、bitsandbytes、SwanLab/TensorBoard peft, trl (SFTTrainer), bitsandbytes, SwanLab/TensorBoard

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五、缺口与已知问题 / 5. Gaps & Caveats

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六、怎么用 / 6. How to Use

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   Use the stage labels (S1-S14) to open the section that matches your current goal, and start with tools and papers before textbooks.
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