Tailoring small language models for enterprise use cases

Julien Simon, Chief Evangelist
julien@arcee.ai
linkedin.com/in/juliensimon
youtube.com/juliensimonfr

Hard truths, part 1

If GenAI looks deceivingly simple, then I’m afraid you are deceived

- How deep is the model's knowledge on your business domain?
- Not just your industry, but also your company, your department, your customers, etc.
- How fresh is that knowledge?
- How compliant are the answers? Structure, length, tone of voice, safety
- Does the model make it easy to trust its answers? Step by step "reasoning", quotes

- Prompt tuning is mostly a bad joke 🤷
- RAG is mandatory for fresh data, but doesn't deliver domain adaptation
- And what about privacy, security, compliance, cost, scaling, etc.

Hard truths, part 2

The « best » closed LLM is not all you need

- Closed LLMs have been built to be a mile wide and an inch deep
- They're convenient for vanilla tasks but quickly show their limits
- They don't know what they don't know and they can't be efficiently fine-tuned
  « *How well do commercial fine-tuning APIs infuse knowledge into LLMs?* » https://arxiv.org/abs/2409.05059 (11/2024)
- Users try to fix this with huge-context RAG, which doesn't work well, if at all
  « *Lost in the Middle: How Language Models Use Long Contexts* » https://arxiv.org/abs/2307.03172 (06/2023)
- You have very few options to tweak cost/business performance/technical performance
- Many business processes require not only a model, but possibly several models, and often external IT tools (documents, APIs, SQL, etc.)

Hard truths, part 3

The « best » open-source SLM is not all you need

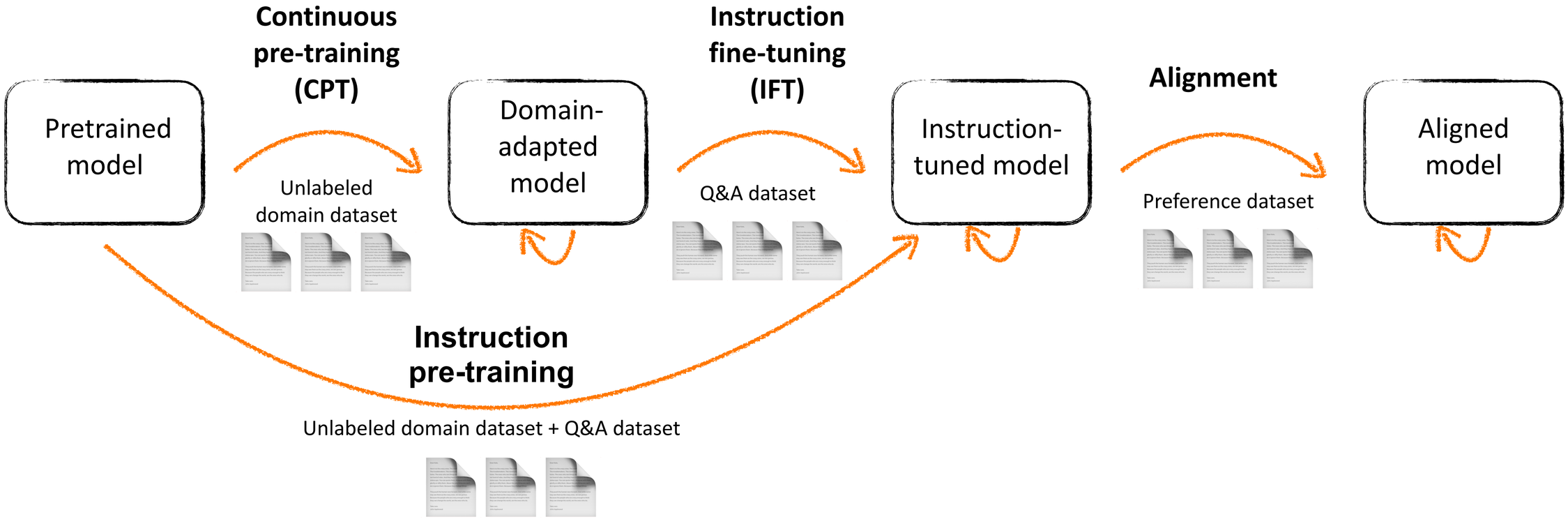
- Yes, open-source SLMs solve most, maybe all, the closed LLM problems.
- There are still challenges to overcome (we'll talk about them in a minute)
- Last night, while you were sleeping, somebody released a new « best » SLM 😳
- Many business processes require not only a model, but possibly several models, and often external IT tools (documents, APIs, SQL, etc.)

Our mission at Arcee AI

- Build SLMs that consistently outperform not only other SLMs, but also LLMs
- Build them quickly and cost-efficiently based on the « best » current architectures
- If need be, make it possible for you to tailor our SLMs
- Make it easy for you to consume models (ours and others)
  - Directly with simple APIs a la OpenAPI - Arcee Model Engine
  - In our agentic workflow platform - Arcee Orchestra
  - In our next-gen router-based inference platform - Arcee Conductor
- Give you several deployment options: SaaS, Cloud (VPC), on-prem
- Deliver industry-leading GenAI solutions, both on quality and ROI

How do we do it?

A typical SLM adaptation workflow



« Language Models are Few-Shot Learners » https://arxiv.org/abs/2005.14165 (05/2020)
« Finetuned Language Models Are Zero-Shot Learners » https://arxiv.org/abs/2109.01652 (09/2021)
« Efficient Continual Pre-training for Building Domain Specific Large Language Models » https://arxiv.org/abs/2311.08545 (11/2023)
« Instruction Pre-Training: Language Models are Supervised Multitask Learners » https://arxiv.org/abs/2406.14491v1 (06/2024)
« How Do Large Language Models Acquire Factual Knowledge During Pretraining? » https://arxiv.org/abs/2406.11813v1 (06/2024)

Challenges of SLM adaptation

- Building datasets is hard work
  - Continuous Pre-Training requires a large corpus (at least 1 billion of tokens)
  - Instruction Fine-Tuning and Alignment requires high-quality, diverse Q&A pairs

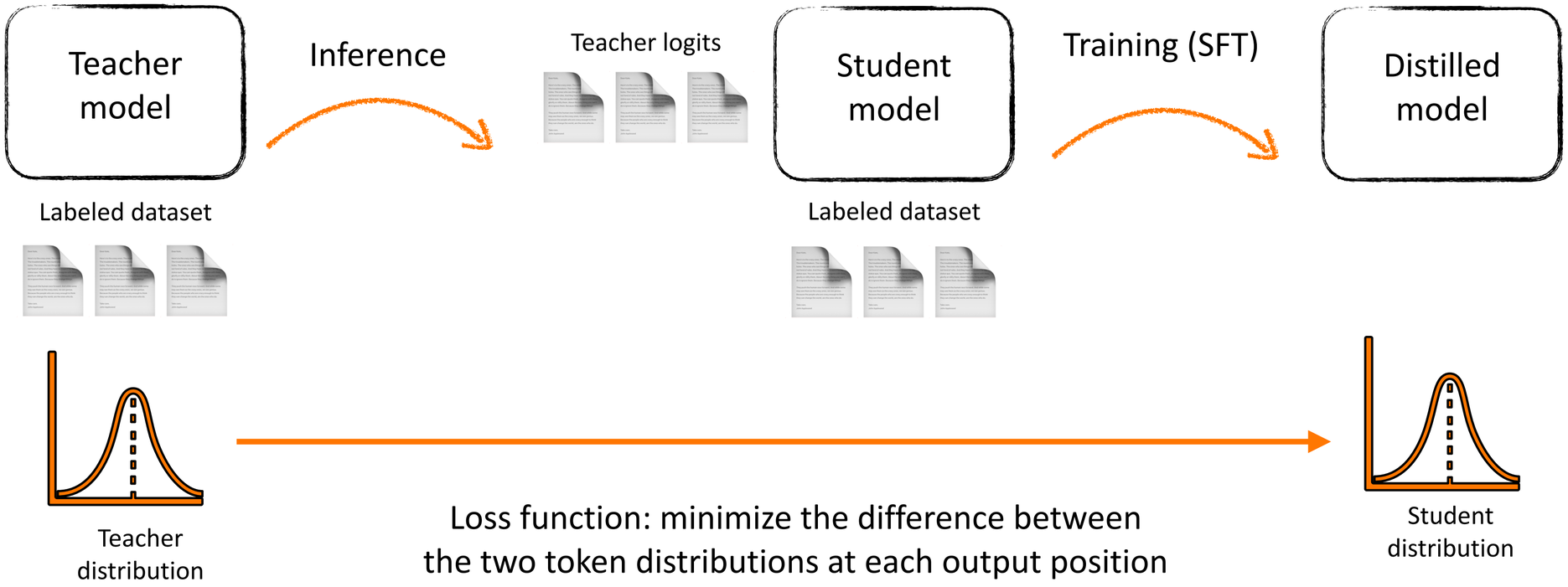
- Training / fine-tuning models: accuracy or cost, pick one
  - Working with the full model in original precision (say, BF16)
    - Compute-heavy and expensive… assuming you can even get the amount of compute you need
  - Parameter Efficient Fine Tuning (PEFT), e.g. LoRA or QLoRA
    - Much more memory-efficient, enabling smaller GPUs and shorter training times
    - Effective for Instruction Fine-Tuning and Alignment
    - Significant accuracy degradation for CPT
      - https://blog.arcee.ai/why-methods-like-qlora-fall-short-in-domain-knowledge-injection-2/
      - « *LoRA vs. Full Fine-Tuning: An Illusion of Equivalence* » https://arxiv.org/abs/2410.21228 (10/2024)

- Can we get FFT-like quality at a fraction of the cost? Yes

Model distillation: DistillKit

https://blog.arcee.ai/distillkit-v0-1-by-arcee-ai/ (08/2024) + https://github.com/arcee-ai/DistillKit

Intuition: if we have excellent large open-source models available,
can we teach smaller models to mimic their output?



Parameter-efficient training: Spectrum

https://arxiv.org/abs/2406.06623 (06/2024)+ https://github.com/cognitivecomputations/spectrum

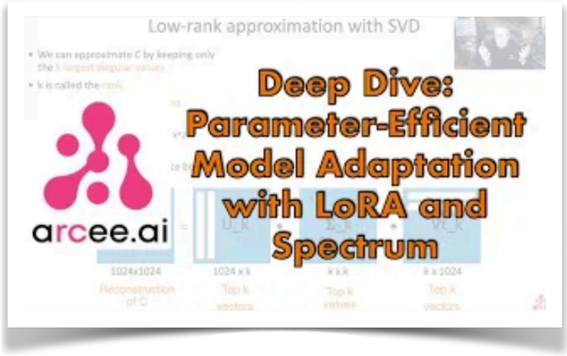
- Intuition: not all layers contribute equally to the output.
- Some layers have a higher signal-to-noise ratio (SNR) than others.
- Spectrum identifies the high SNR layers.
- Run full fine-tuning on high SNR layers, and leaves the other layers untouched.

$$SNR = \frac{\sum_{k|\sigma_k > \varepsilon} \sigma_k}{\sum_{n|\sigma_n < \varepsilon} \sigma_n}$$

```
python spectrum.py --model-name <insert local or HF repo here>
                   --top-percent <top % of SNR ratios to target>
```


```
    "model.layers.10.self_attn.o_proj": {
        "snr": 0.25031203031539917,
        "type": "self_attn.o_proj"
    },
    "model.layers.11.self_attn.o_proj": {
        "snr": 0.2547757625579834,
        "type": "self_attn.o_proj"
    },
    "model.layers.12.self_attn.o_proj": {
        "snr": 0.2616233825683594,
        "type": "self_attn.o_proj"
    },
    "model.layers.13.self_attn.o_proj": {
        "snr": 0.2736438810825348,
        "type": "self_attn.o_proj"
    },
    . . .
```

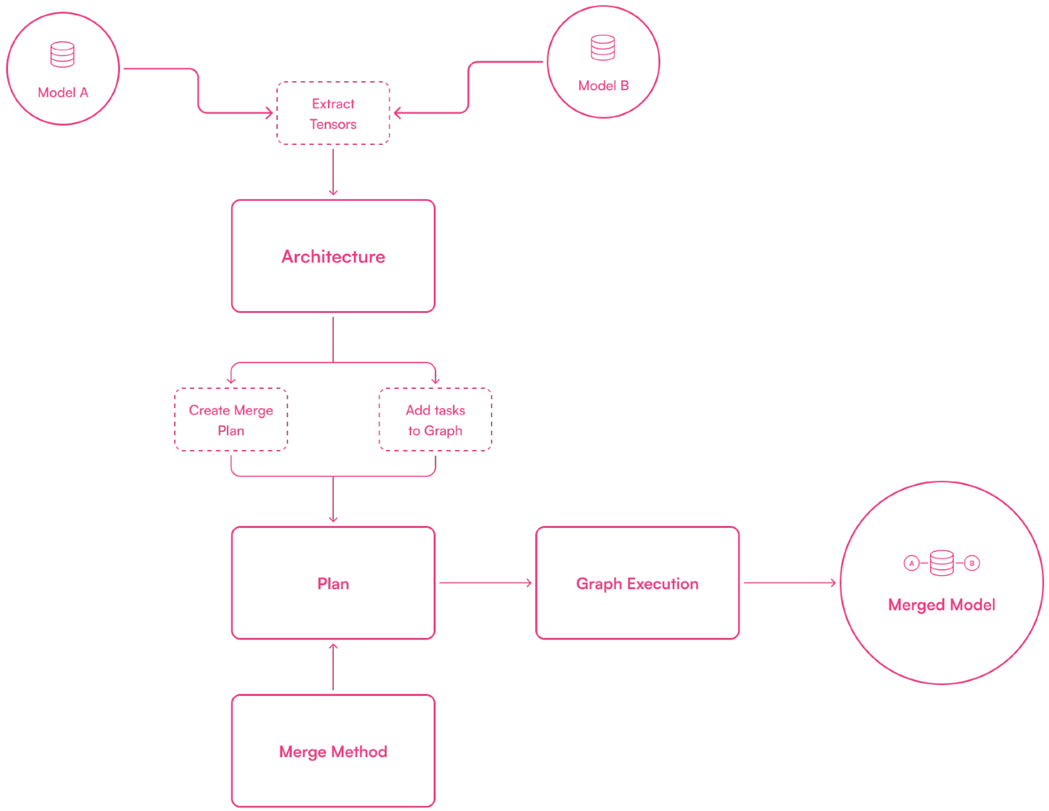

```
unfrozen_parameters:
- ^lm_head.weight$
- ^model.embed_tokens.weight$
# input_layernorm layers
- model.layers.0.input_layernorm
- model.layers.1.input_layernorm
- model.layers.2.input_layernorm
- model.layers.3.input_layernorm
- model.layers.4.input_layernorm
- model.layers.5.input_layernorm
# lm_head layers
# mlp.down_proj layers
- model.layers.21.mlp.down_proj
- model.layers.20.mlp.down_proj
- model.layers.22.mlp.down_proj
- model.layers.19.mlp.down_proj
- model.layers.23.mlp.down_proj
- model.layers.24.mlp.down_proj
. . .
```



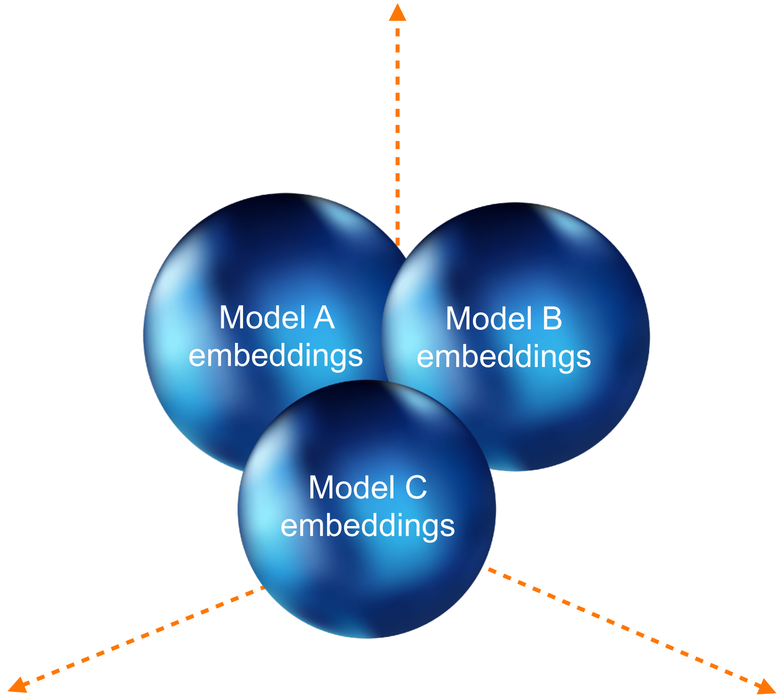
Model merging: MergeKit

https://arxiv.org/abs/2403.13257 (03/2024) + https://github.com/arcee-ai/mergekit

Intuition: if we have plenty of open-source models, can we build a model by merging several models that already have the properties we need?



- Combine several task-specific models (or different checkpoints) into a single model with zero additional training
- Not an ensembling technique: only one model
- Merging only requires lightweight compute
- Fast process, no extra inference latency



Demo: merging models with `mergekit`

```
$ git clone https://github.com/arcee-ai/mergekit.git
$ cd mergekit
$ pip install -e .
```

```
models:
  - model: defog/llama-3-sqlcoder-8b
    parameters:
      density: 1.0
      weight: 0.2
  - model: MathGenie/MathCoder2-Llama-3-8B
    parameters:
      density: 1.0
      weight: 0.6
  - model: ajibawa-2023/Code-Llama-3-8B
    parameters:
      density: 1.0
      weight: 0.2
merge_method: ties
base_model: meta-llama/Llama-3.1-8B
dtype: float16
```

72.48%

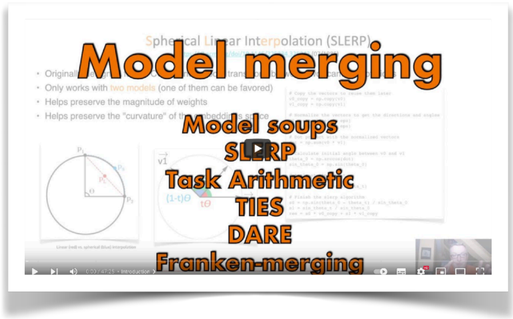
65.35%

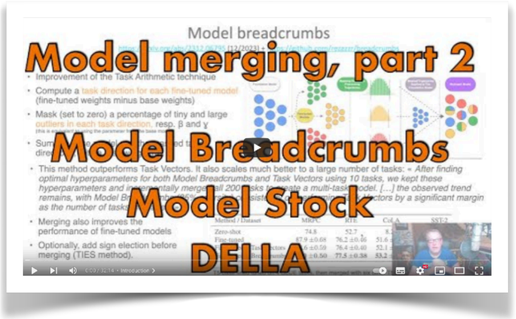
64.37%

```
(env-mergekit) → examples git:(main) ✗ mergekit-yaml ties-demo.yml ties-demo
Fetching 11 files: 100%| | 11/11 [00:00<00:00, 19886.79it/s]
Fetching 11 files: 100%| | 11/11 [00:00<00:00, 14377.48it/s]
Fetching 9 files: 100%| | 9/9 [00:00<00:00, 10960.72it/s]
Fetching 10 files: 100%| | 10/10 [00:00<00:00, 25070.56it/s]
Warmup loader cache: 100%| | 4/4 [00:00<00:00,  5.05it/s]
Executing graph: 100%| | 2039/2039 [01:05<00:00, 30.95it/s]
```

Merging three 8B models with TIES
1 minute on my Mac :)

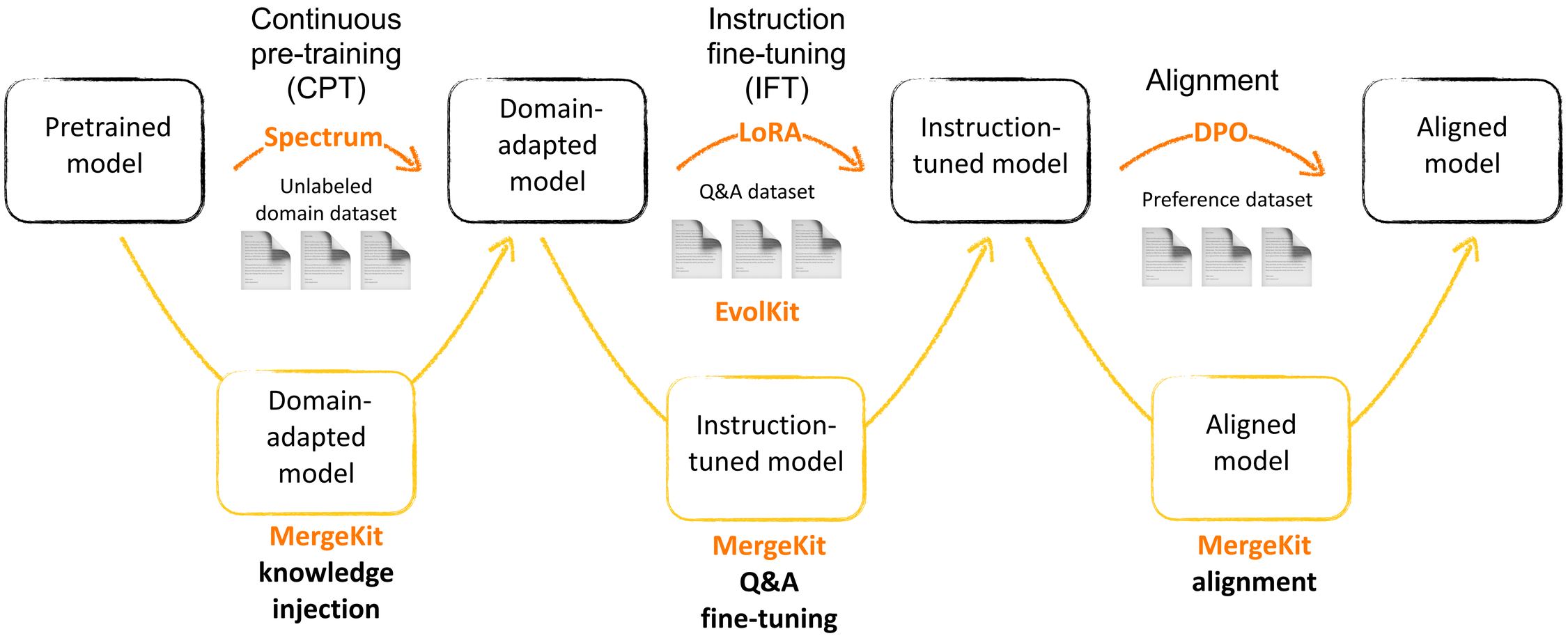
73.62%





GSM8K scores - lm_eval 12/16/2024

A modern SLM adaptation workflow



« Arcee's MergeKit: A Toolkit for Merging Large Language Models » https://arxiv.org/abs/2403.13257 (03/2024)
« Spectrum: Targeted Training on Signal to Noise Ratio » https://arxiv.org/abs/2406.06623 (06/2024)
« Merging in a Bottle: Differentiable Adaptive Merging (DAM) and the Path from Averaging to Automation » https://arxiv.org/abs/2410.08371 (10/2024)

Arcee AI - The Open SLM leader

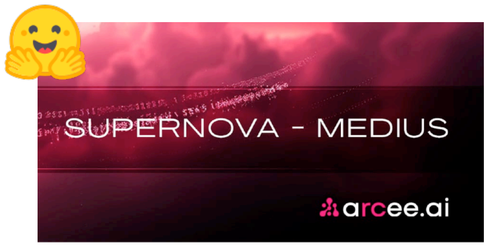
State-of-the-art tech stack based on open-source libraries

Spectrum (continuous pre-training), MergeKit (merging), DistilKit (distillation), EvolKit (dataset improvement)

Best-in-class models based on open-source architectures

Qwen2 1.5B

Llama 3.1 8B



Qwen2.5 14B

Qwen2 72B

Llama 3.1 70B

Best 1.5B model

Best 8B model

Best 14B model

Best Arabic model

Best 70B model

Hugging Face OpenLLM Leaderboard benchmarks

Latest releases: 10B and 32B

https://www.arcee.ai/blog/virtuoso-lite-virtuoso-medium-v2-distilling-deepseek-v3-into-10b-32b-small-language-models-slms

OS SLMs

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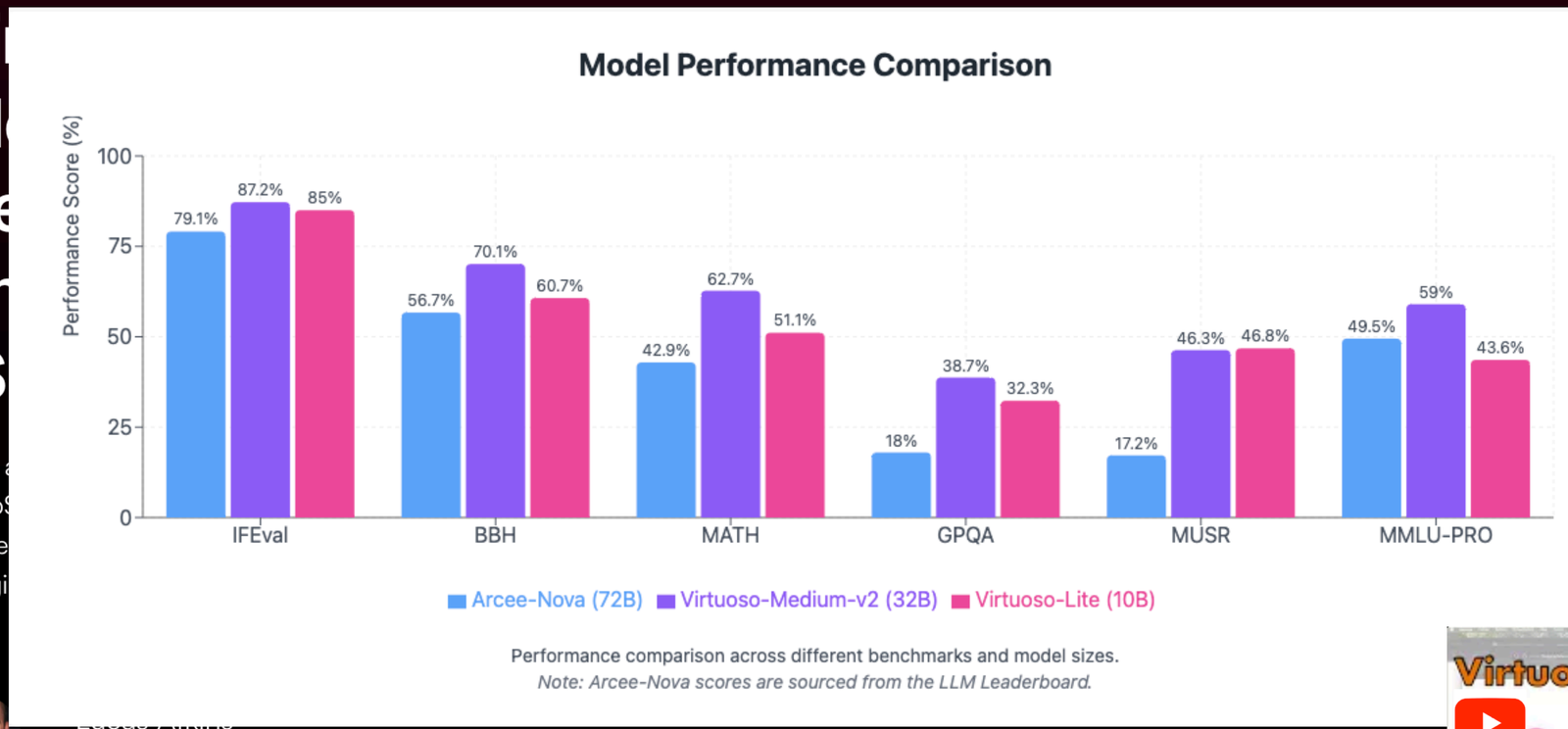

edium

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Arcee SuperNova training pipeline

https://blog.arcee.ai/arcee-supernova-training-pipeline-and-model-composition/

Llama-3.1
405B Instruct

Labeled dataset
500M tokens

Distillation (Distillkit)

32 H100, 5 days

Llama-3.1
70B Instruct
#1

Llama-3.1
70B Base

Synthetic data (EvolKit)
76K samples

Training (Spectrum)
+ checkpoint merging

8 H100

Llama-3.1
70B Instruct
#2

Merging (Mergekit)

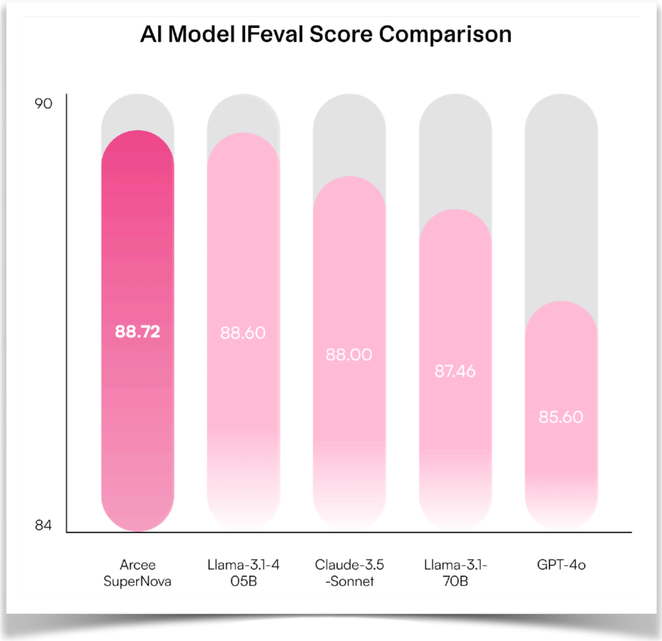
Llama-3.1
70B Base

User preference datasets

Alignment (DPO)

8 H100

Llama-3.1
70B Instruct
#2



Arcee Model Engine - SLM inference platform

https://www.arcee.ai/product/model-engine

arcee.ai

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- API Keys
- Usage
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Virtuoso Large

Our most powerful and versatile general-purpose model

Virtuoso Medium

Versatile model capable of handling complex and varied tasks

Virtuoso Small

Streamlined version of the larger Virtuosos, faster & more cost-efficient

Coder Large

High-performance model tailored for intricate programming tasks

Coder Small

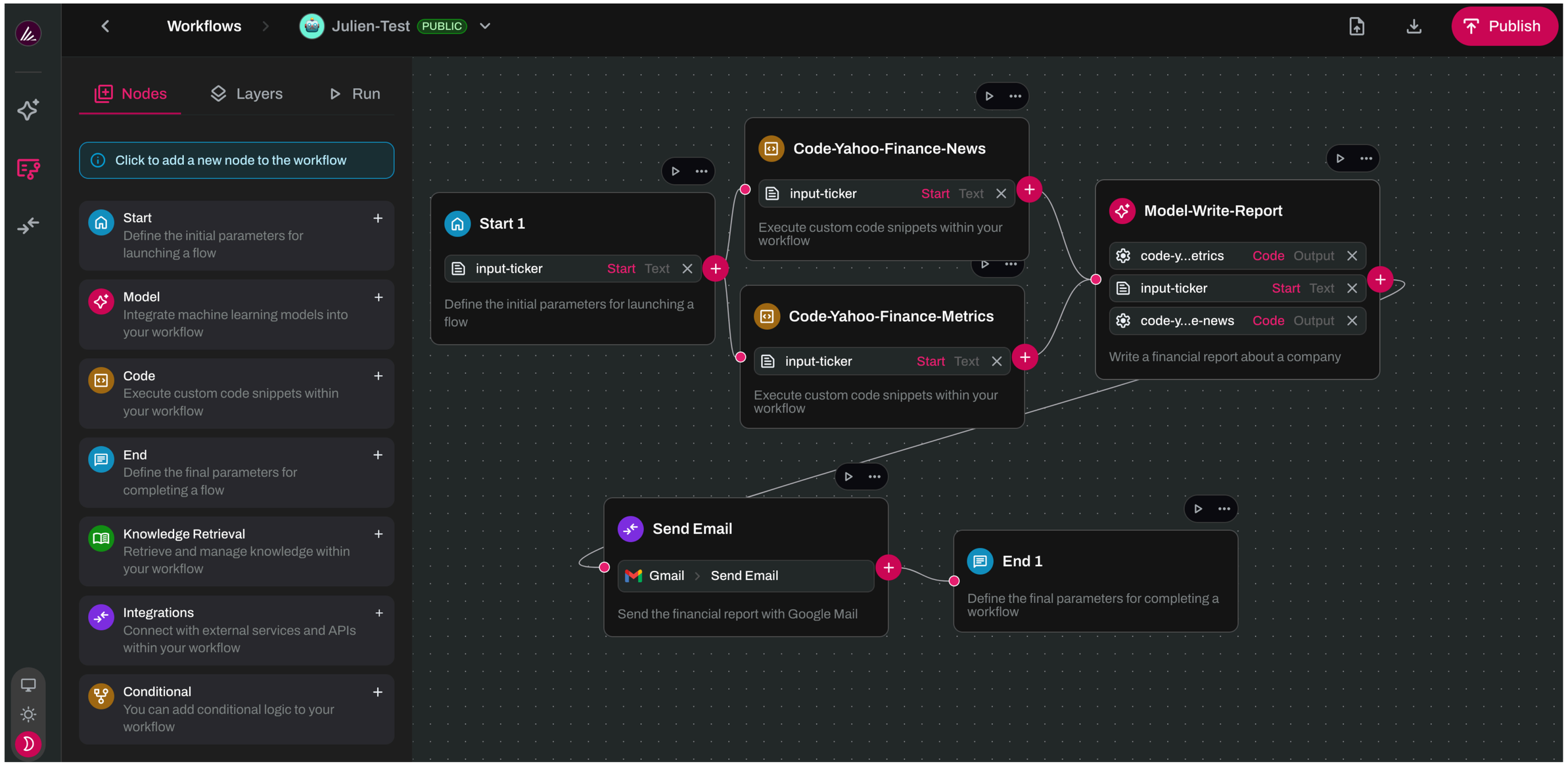
Compact coding model for efficient programming tasks

Caller Large

Optimized for complex tool-based interactions & API function calls

Arcee Orchestra - SLM agentic workflows

https://www.arcee.ai/product/orchestra



Arcee AI

Leader in Small Language Models (SLMs)

End-to-end Training and Agentic Platforms

SaaS and Private Deployments

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