A Case for Learned Cloud Emulators

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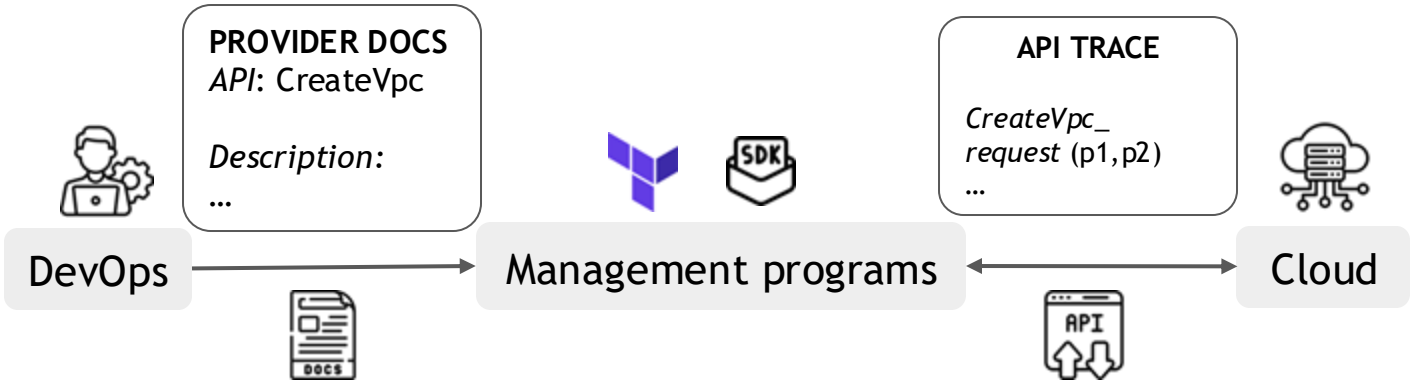
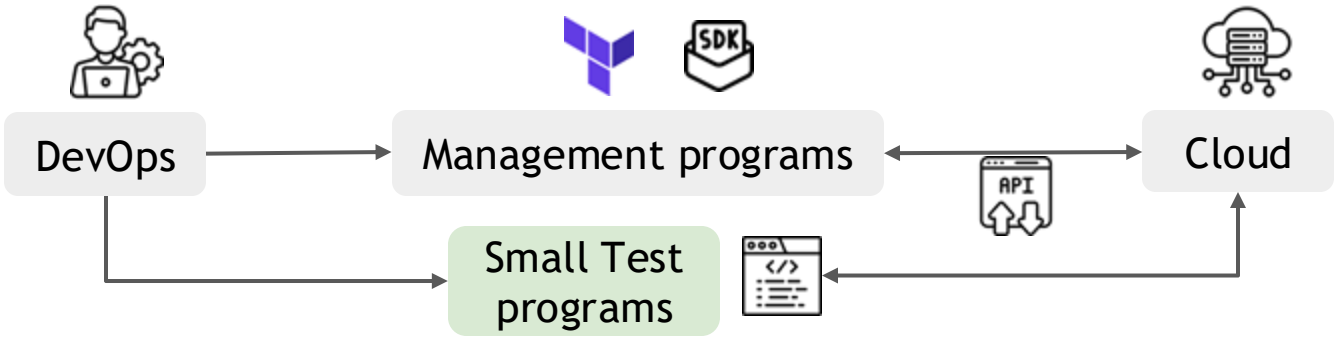
Cloud infra is managed programmatically



DevOps use **management programs** to provision/maintain resources at scale

But, testing Management Programs is hard

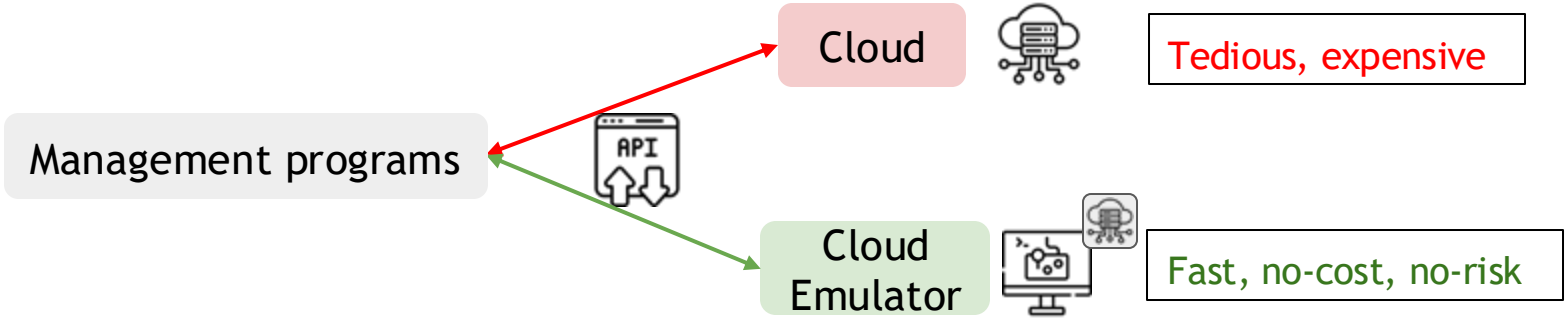


DevOps debug/test mgmt. programs by **running them against the cloud**

Necessary, but tedious (long prov. times) and expensive[1]
Testing directly on cloud impacts development **cost**, **scale** and **velocity**

1. How can I experiment with Cloud without going broke?, *DevOps Stack Exchange*

Cloud emulators are gaining popularity



Emulation: Mock the API request/response behavior
→ Similar to Mininet for setting up virtual networks

SOTA: Emulator for AWS LocalStack ☆ Star 63k

"Emulate cloud services locally. Build fast. Test safely. No surprises."

Problem: Today's emulators are built manually

Labor-intensive

➔ Low API coverage

Not future proof

➔ New services/APIs get added frequently, hard to maintain

Error-prone

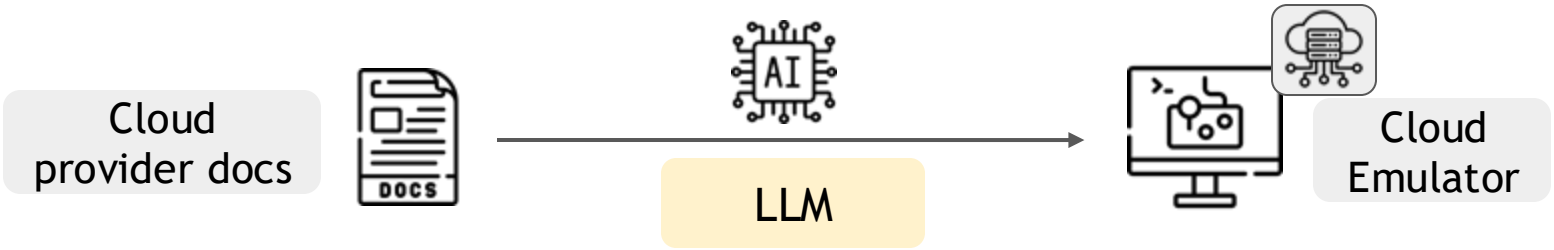
➔ Can have behavior inconsistent with cloud[2]

2. Fidelity of Cloud Emulators: The Imitation Game of Testing Cloud-Based Software, *ICSE'25*

Can LLMs automate emulator generation?

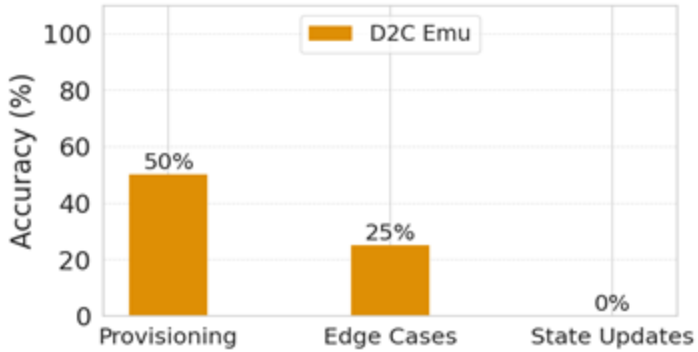
Naive Direct to code(D2C) :

→ use LLM to generate emulation code directly



D2C emulator suffers from inaccuracies

→ missing resources, checks, etc.



Path to Better Automated Emulation

Goal is building a tool that :

→ is automated, can correctly emulate the cloud APIs (with high coverage)

→ keeps updating/refining itself based on the present cloud behavior

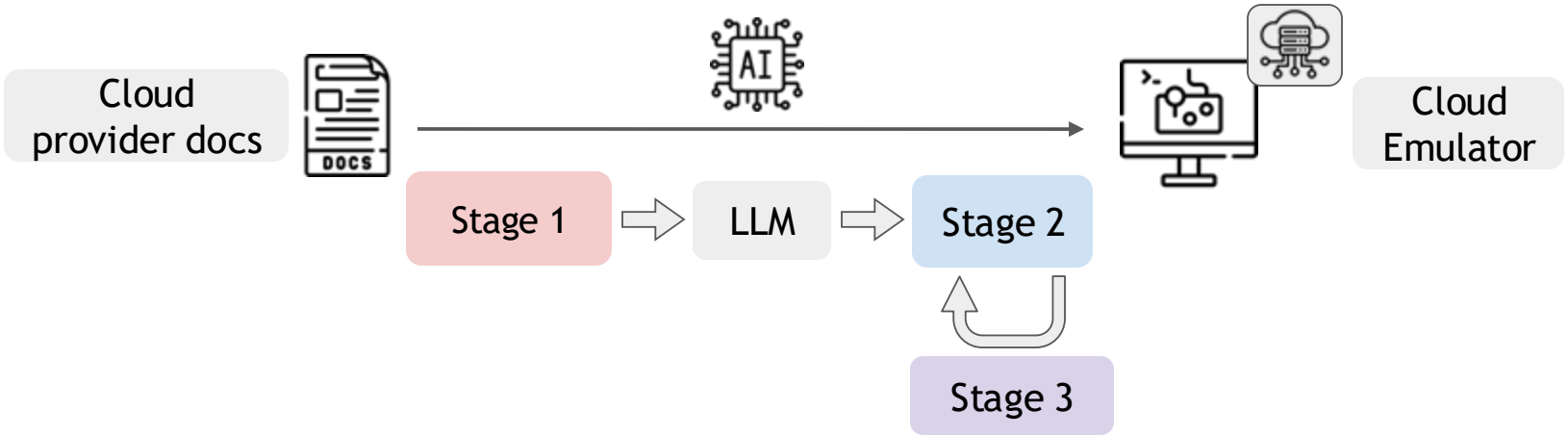
Challenges -

1) Learning the right information given large documents

2) Converting the information into high-fidelity emulation code

3) Adapting with changing cloud services and generation errors

Building the Emulator Generation Workflow



1) Learning the right information given large documents

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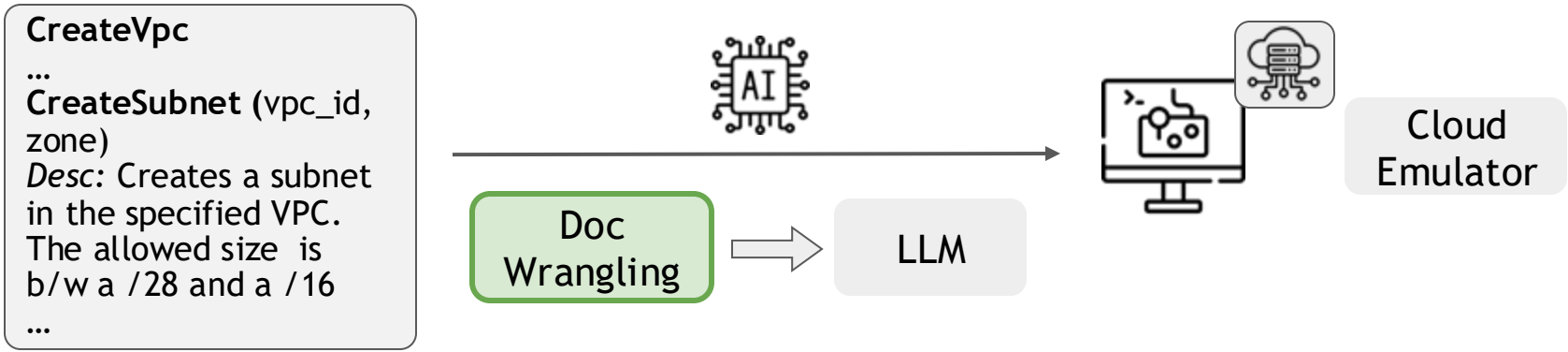
Stage 1: Doc Wrangling for extracting info

Challenge: Large amount of cloud info and limited context window for LLMs



Cloud provider API docs are structured by resources

Docs list API descriptions, params — detailed as users rely on them

Limit Context with Resource-Aware Pruning

CreateVpc
…….

CreateSubnet (vpc_id, zone)
Desc: Creates a subnet in the specified VPC.
…
DeleteSubnet (subnet_id)
…

Per-Resource Info

Dependency Graph based pruning

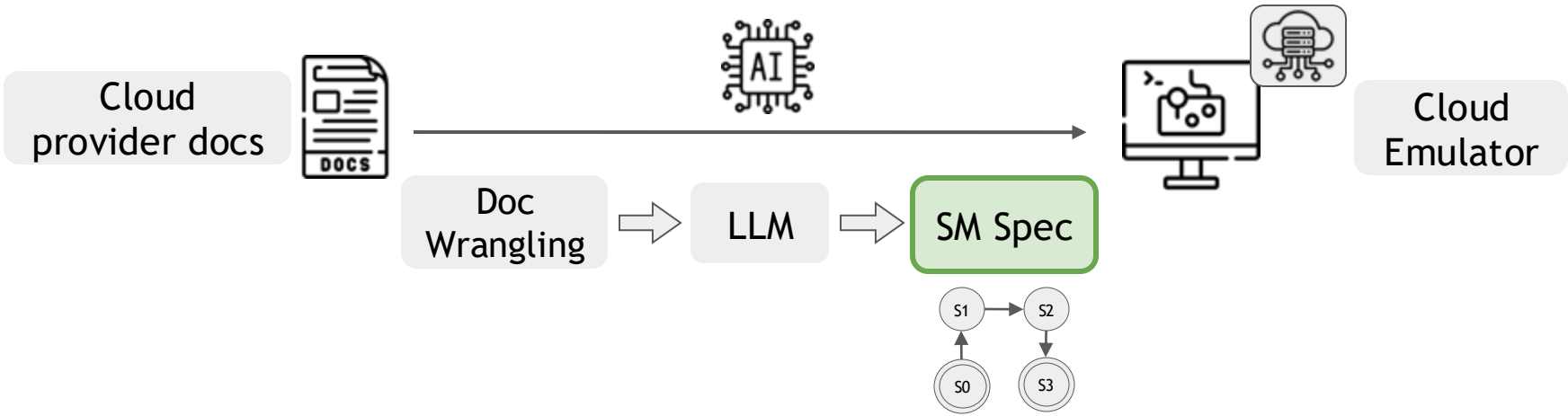
Key insights

Symbolic parsing
—semi-structured docs

Context pruning
—resource-centric info, identify correlation

Stage 2: State Machine Specification

Challenge: Generating high fidelity structured code



Cloud — hierarchical state-machine, API call = transition

State Machine (SM) abstraction helps structured generation

SM Spec Constraints Generated Emulator Code

Subnet.txt:

CreateSubnet (vpc_id, zone)
Desc: Creates a subnet in the specified VPC.

The allowed size is b/w a /28 and a /16 netmask

…

Dependency Graph

Grammar

LLM

```
SM Vpc { States: cidr: str
 … }

SM Subnet {
  States: vpc_id: str, cidr: str
  Transitions:
     CreateSubnet(vpc_id, cidr) {
        assert(16 <= mask(cidr) <= 28);
     }
…
```

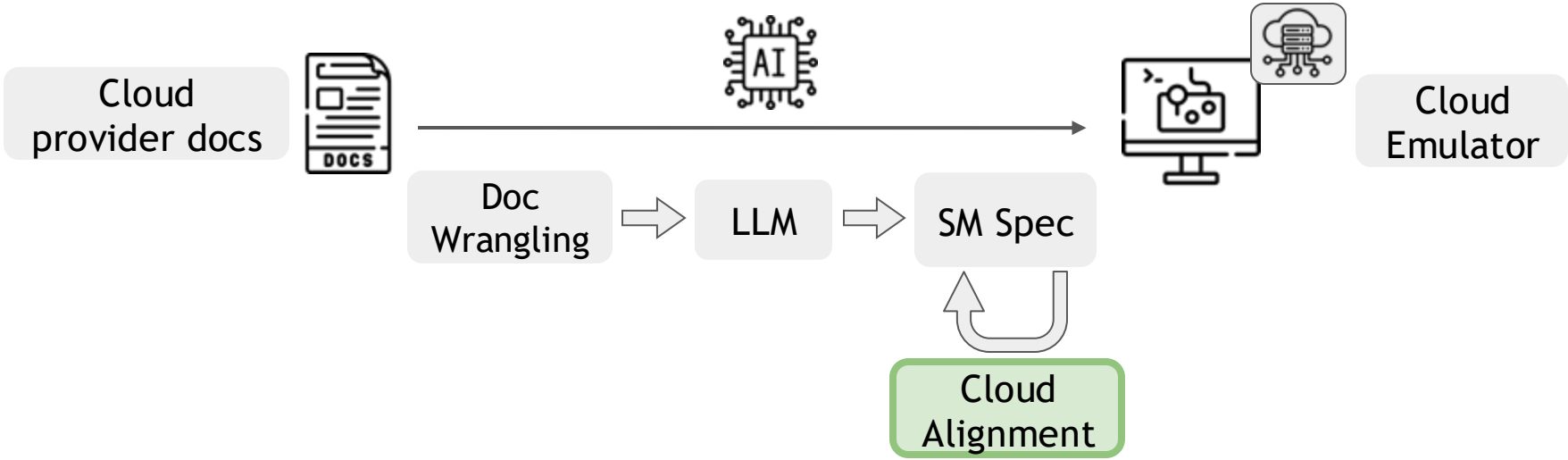
Key insights

Representation to constraint:
— Grammar spec, map intent to action

Incremental Generation
— iterate, generate, leave stubs

Stage 3: Automated Alignment

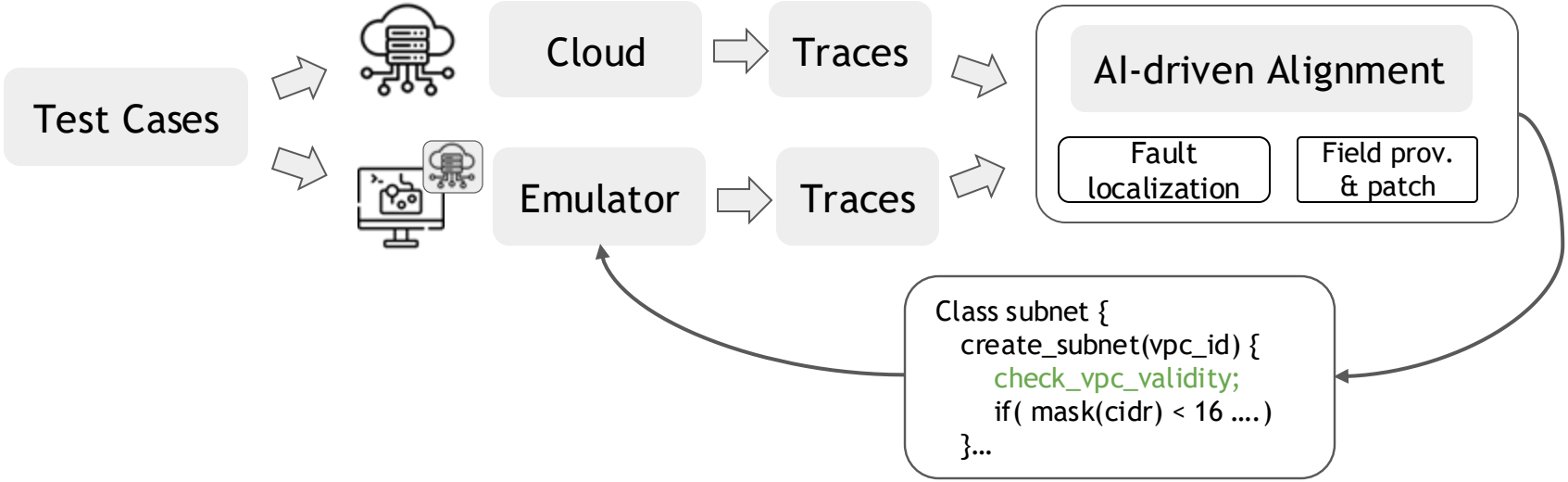
Challenge: Gaps b/w generated emulator and cloud, precise fault isolation



Cloud API traces are verbose to enable **alignment engine**

Can fix test errors, isolating issues and patching logic for **emulator**

Find and Patch Inconsistencies Automatically



Key insights

Fault Localization
— Trace API logs → graph similarity to identify differing log

State provenance for patching
— writers APIs for state, maintain logs

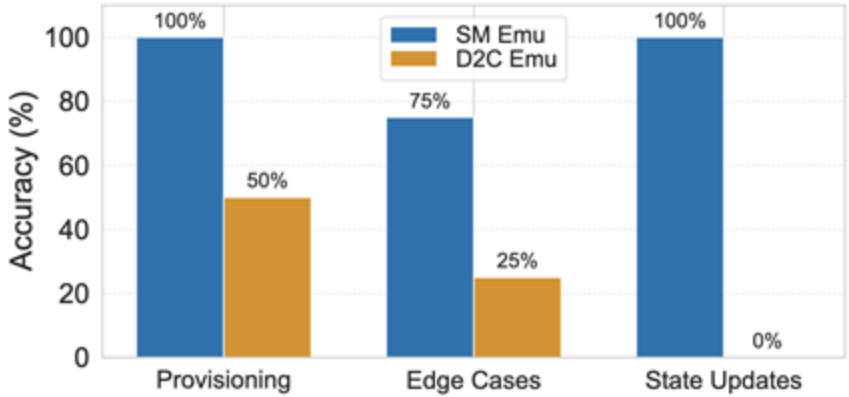
Preliminary Evaluations

Compared CloudEmu (w/o alignment) against 2 baselines–

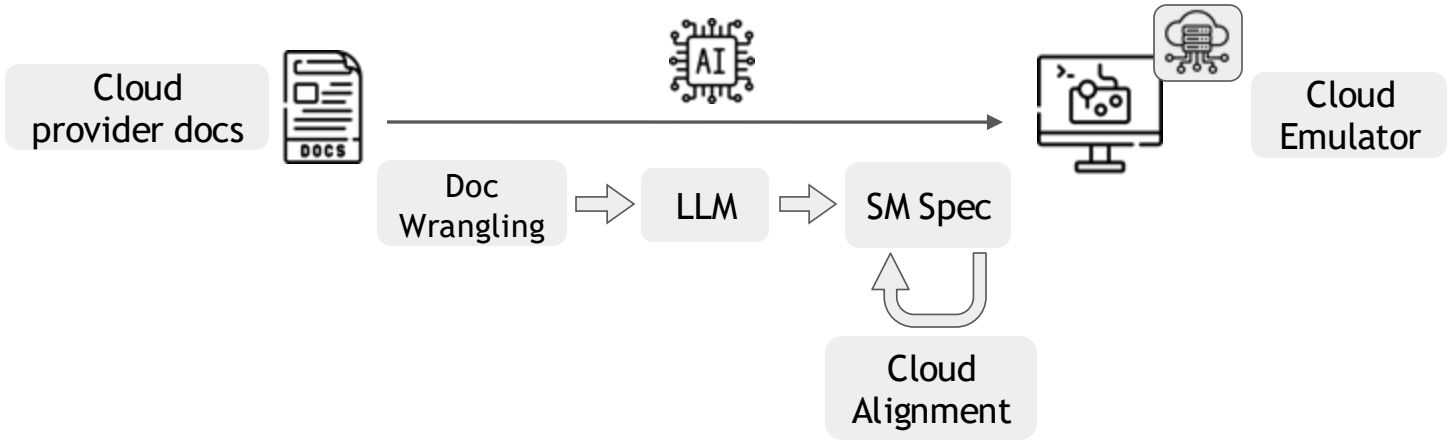
Manual engineering *(Localstack)*:
— CloudEmu outperforms on coverage

Service	CloudEmu API Coverage	LocalStack API Coverage
Network Firewall	100%	11%

D2C emulator:
Issues with state (missing attributes) and transitions (missing/invalid checks)



Summary and Takeaways



Development of modern cloud infrastructure needs emulation for better testing

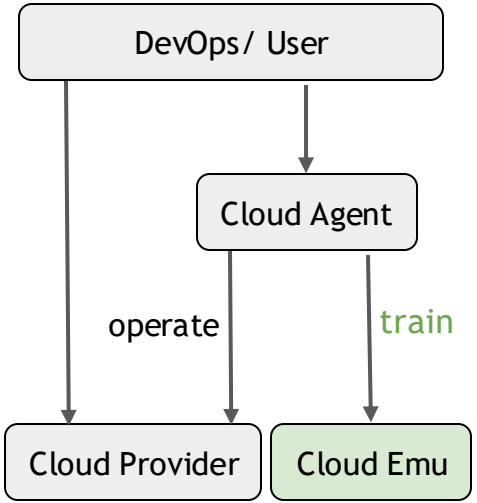
Case for using LLMs to enable emulator code generation

Modeling cloud resources as state machines ⇒ principled code generation

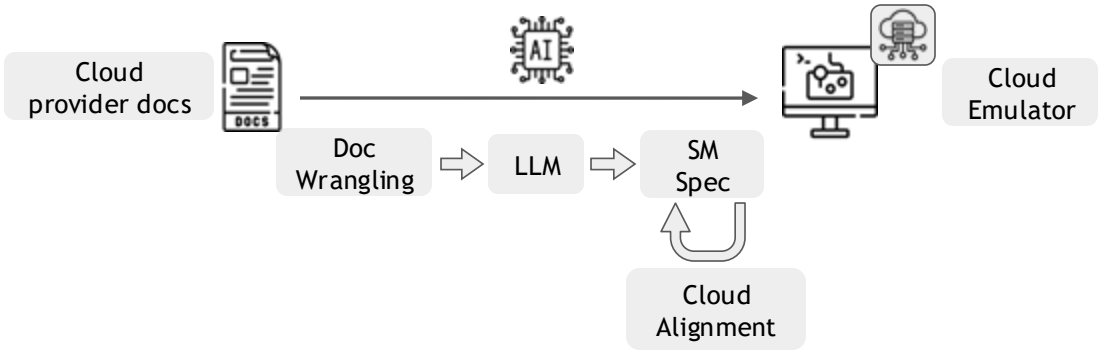
Future Work

Scaling up, Multi-cloud

Cloud Gym: No-cost and no-risk gym environments for cloud agents, AI-assisted CloudOps



Questions?



Check out the paper!

Looking for internships for Summer 2026!

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