CAP5602
Hybrid Neuro-Symbolic Theorem Prover

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Problem Statement

Why is theorem proving hard?

-Requires creative reasoning: choosing strategies, identifying lemmas

-Requires formal precision: all steps must be logically correct

-Modern LLMs are good at intuition, but hallucinate

-Proof assistants are perfectly accurate, but not creative

Goal: Build a system combining both strengths.

We address the problem of automating mathematical theorem proving using a hybrid AI system that:

-Takes natural-language math statements

-Converts them into Lean/Coq formal statements

-Uses an LLM to propose proof steps and strategies

-Uses a symbolic proof assistant to validate every step

-Adapts its strategy based on failed attempts

Related Work

LLM-guided theorem proving is a rapidly advancing area that DeepMind, OpenAI, Meta, and other groups are currently publishing.

The aim is to address limitations on human and computer math problem solving capabilities.

Prior similar work:

-DeepMind AlphaGeometry and AlphaProof

-OpenAI GPT-f (Metamath)

-Meta’s LeanDojo

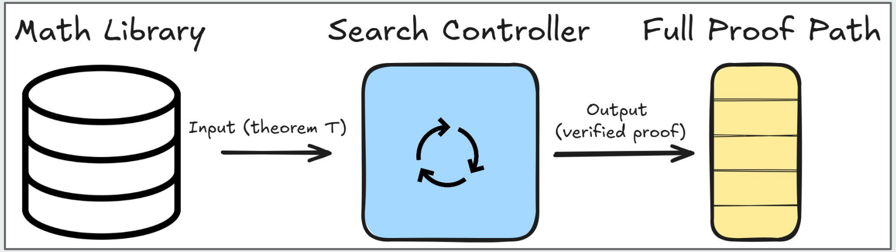
-Stanford TacticZero

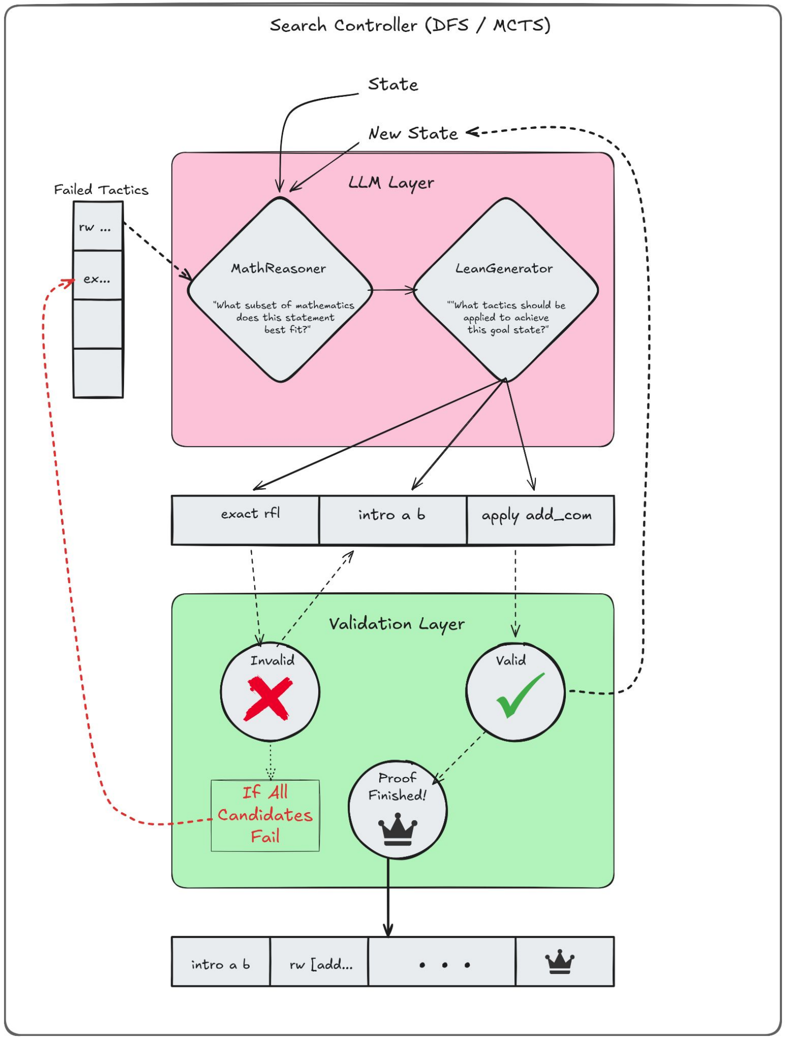
Our Contributions

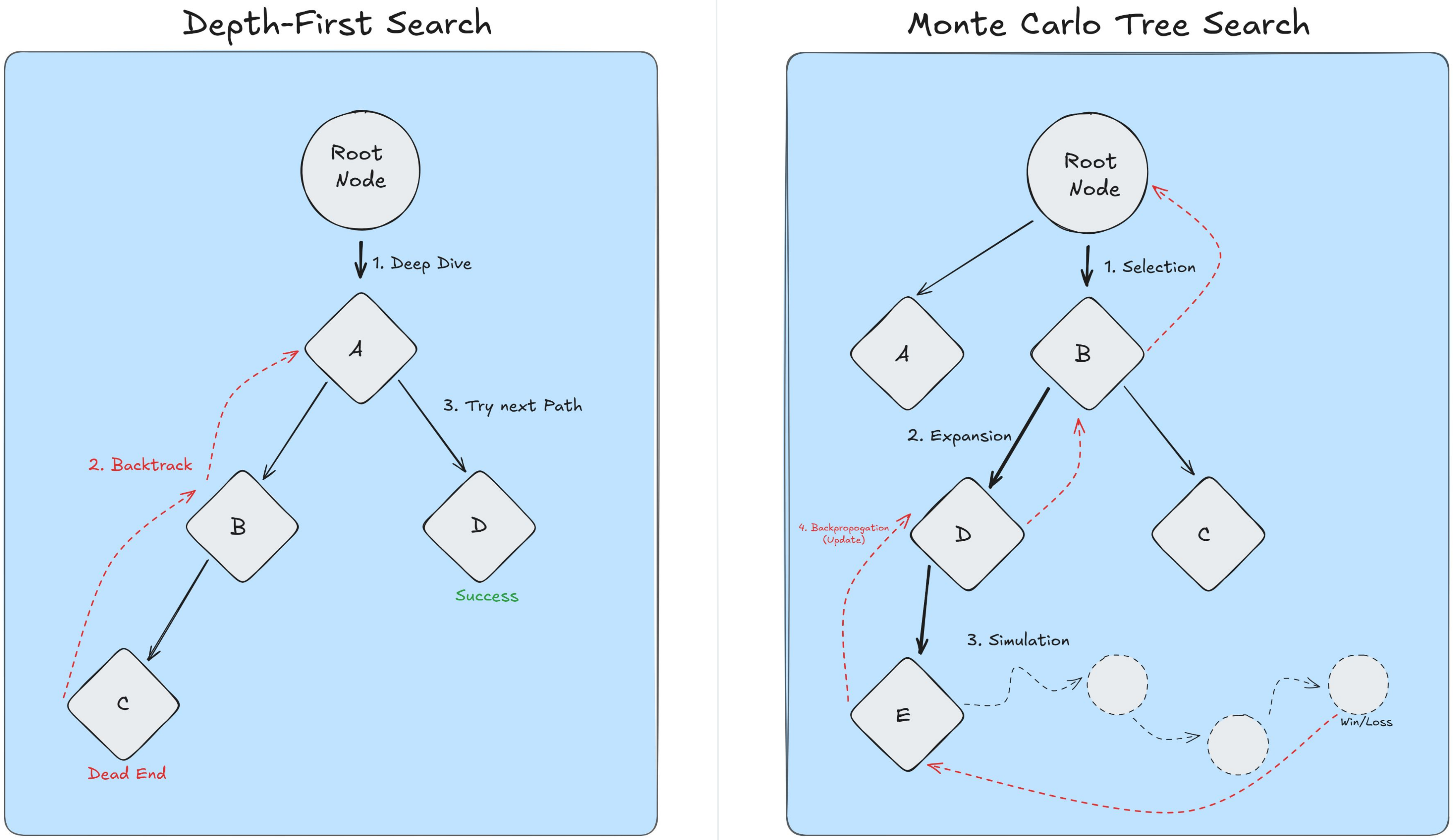
What's new in our project?

- LLM generates strategy, not just raw proof text
- We use adaptive reasoning loops: LLM revises steps based on Lean feedback
- NL to Formal conversion pipeline
- Proof search guided by success/failure signals
- Lightweight prototype for Intro to AI

General Architecture



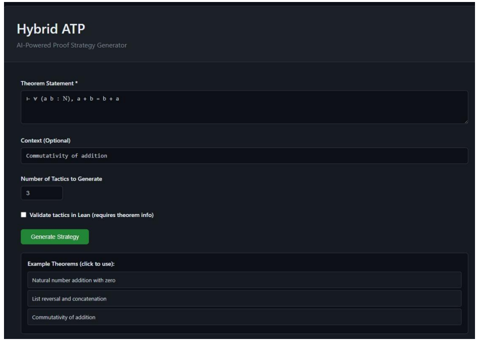



Depth-First Search
Root Node
1. Deep Dive
A
3. Try next Path
2. Backtrack
B
D
Success
C
Dead End
Monte Carlo Tree Search
Root Node
1. Selection
A
B
2. Expansion
4. Backpropogation (Update)
D
C
3. Simulation
E
Win/Loss

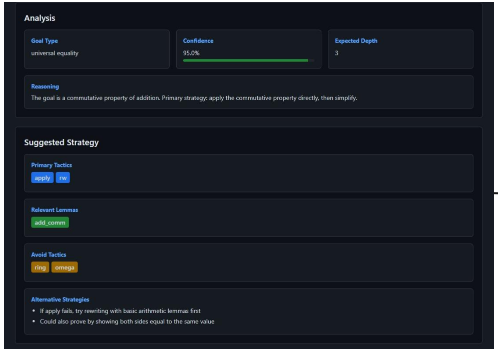
Architectural and System Design cont.

In order to display the architecture, we designed a front end which mirrors what is seen in the terminal. Hosted via Flask.

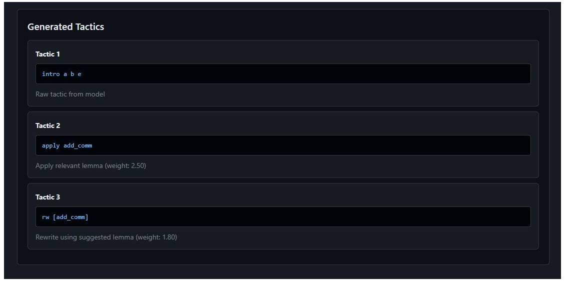
1. Give a Theorem



2. LLM-based strategies and analysis



3. Generated Lean Code (Tactics)



Demo Video

https://www.youtube.com/watch?v=OFIABpHIHfg

- Tested with two theorems (A simple one and a more complex one)

Lessons Learned

- The complexity of compiler integration (particularly the Lean environment)
- Navigating infinitely branching spaces
  - Use pruning and depth bounding
- Resource constraints on local hardware
- Limitations of current math reasoning from LLMs
- Prompt engineering for formal syntax
  - LLMs make symbol predictions, which can violate formal languages like lean
- Importance of feedback loops
  - Proofs require search in addition to generation

Future Work

- Fully implement a MCTS
- Scale to testing from basic arithmetic to more complex domains like Real Analysis
- Implement better LLM models for mathematical reasoning (or fine-tune an open-source model)
- Develop a Fuzzy Cognitive Map (FCM) for causal relationships between mathematical tactics (aiding MathReasoner model)
- Abstract to other proof assistants (Isabelle, Coq, Agda)

Thank You