STARS: Static Analysis-Guided Assertion Synthesis using Large Language Models

Jialun Cao[*], Haoyu Wang[$], Haoran Yan[$], Ming Wen[$], Michael Pradel[#]

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Assertion Synthesis Problem

```
@Test
public void testGetTextElements() {
  Cell cell = new Cell(0, 0, 0, 0);
  TextElement tElement = new TextElement(0, 0, 0, 0,
    new PDType1Font(Standard14Fonts.FontName.HELVETICA_BOLD), 10, "test", 5);
  TextChunk tChunk = new TextChunk(tElement);
  List<TextChunk> tList = new ArrayList<>();
  tList.add(tChunk);
  cell.setTextElements(tList);

}
```

Given: Test prefix
(optionally, also focal method or class)

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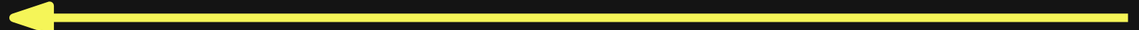
  TextChunk tChunk = new TextChunk(tElement);
  List<TextChunk> tList = new ArrayList<>();
  tList.add(tChunk);
  cell.setTextElements(tList);
  // ???????
}
```



Want: One or more assertions

Assertion Synthesis Problem

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  List<TextChunk> tList = new ArrayList<>();
  tList.add(tChunk);
  cell.setTextElements(tList);
  assertEquals("test", cell.getTextElements().get(0).getText());
}
```

Ground truth (written by developer)

Assertion Synthesis Problem

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How to guess this complex expression?

Ground truth (written by developer)

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  cell.setTextElements(tList);
  assertEquals("test", cell.getTextElements().get(0).getText());
}
```

How to guess this complex expression?

How to even know that this method exists?

Ground truth (written by developer)

Previous Approaches

- **Pre-LLM**
  - Static analysis + heuristics
  - Rule-based inference from documentation
  - Specialized neural models
- **Prompt LLM with**
  - Test prefix
  - Focal method or class
  - Documentation

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Unrealistic or incorrect assertions

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Insufficient context limits success

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Unrealistic or incorrect assertions

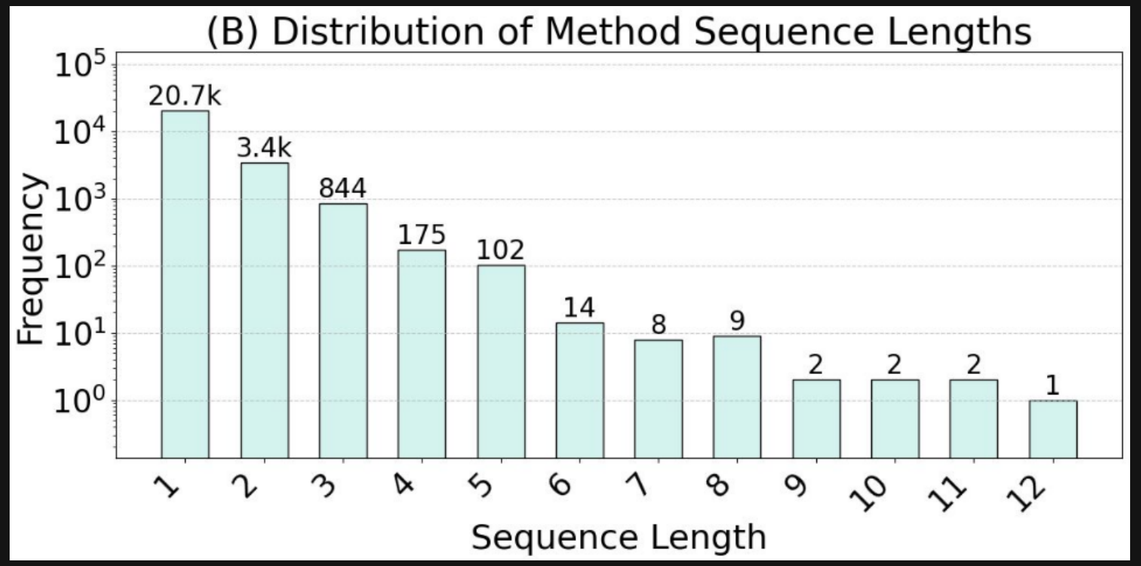
Insufficient context limits success

Huge search space

Characteristics of Real-World Assertions

Preliminary study of 32.7k assertions *

Assertions	Nb.	Ratio
With variables only	3.7k	11.3%
With method calls	25.3k	77.4%
incl. arguments	13.6k	41.5%
to JDK API	14.6k	44.5%



* Based on *Methods2Test* dataset, Tufano et al., 2020

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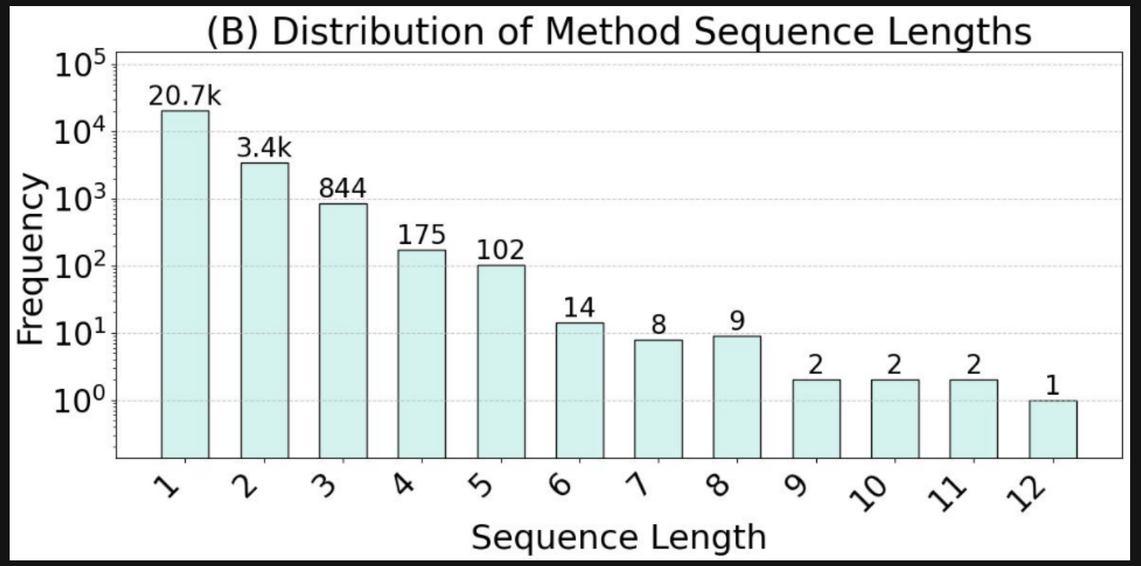
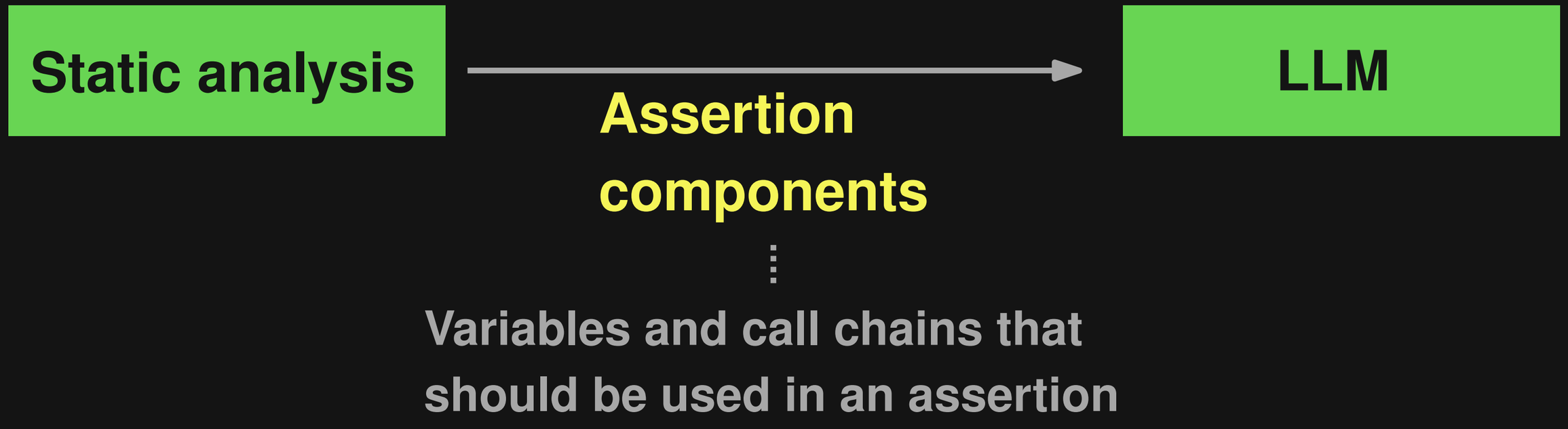


Many assertions: Almost impossible for an LLM to guess

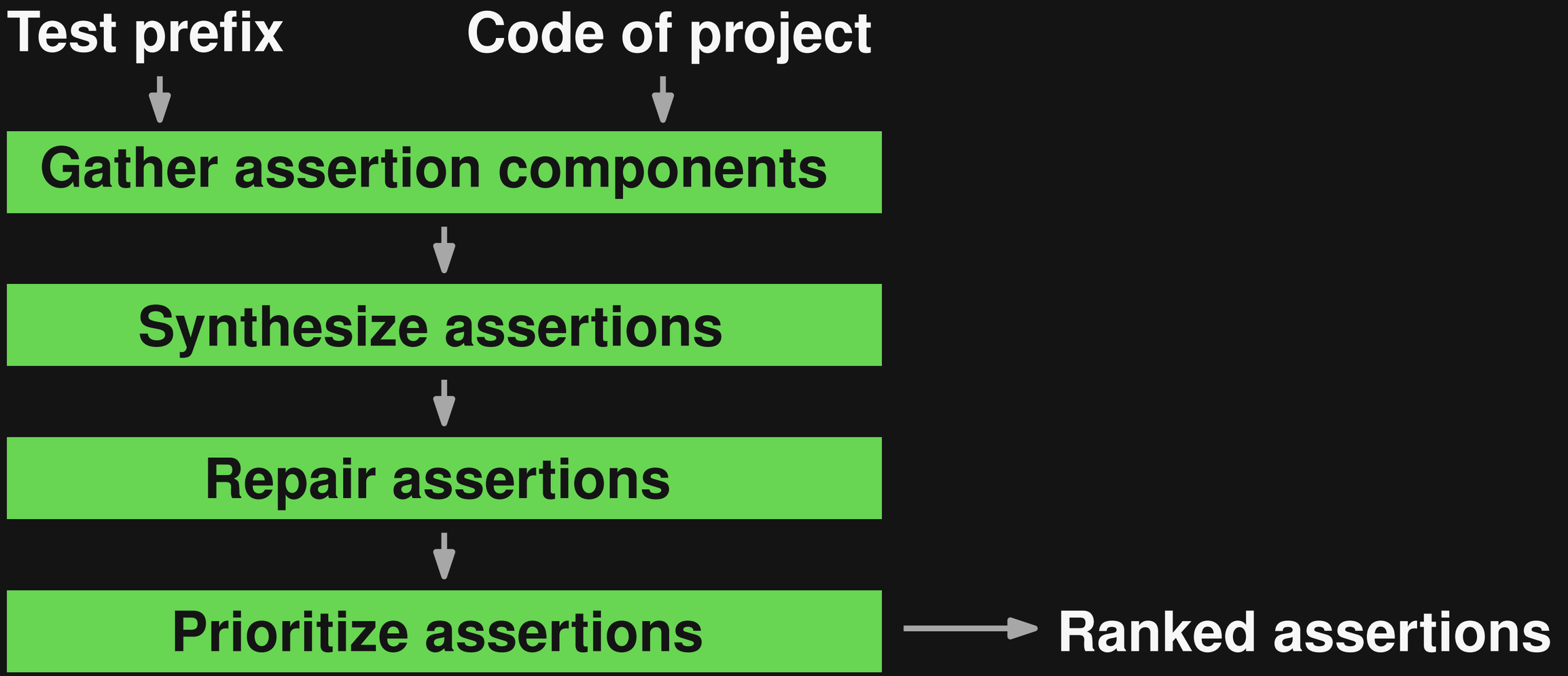
* Based on *Methods2Test* dataset, Tufano et al., 2020

Key Idea: Assertion Components



Reduces search space & provides missing context to LLM

Overview of STARS



Gathering Assertion Components

Three kinds of assertion components:

- **Variables** → `assertNotNull(x)`
- **Pairs of variables** → `assertEquals(expX, actX)`
- **Method call sequences** → `assertEquals("ab", x.getY().getZ())`

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Three kinds of assertion components:

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Challenge: Naive approach yields huge set of components

Assertion Components: Variables

```
public class CellTest {
  private final Cell initialCell = ...;

  @Test
  public void testGetTextElements() {
    Cell cell = new Cell(0, 0, 0, 0);
    TextElement tElement = new TextElement(0, 0, 0, 0,
    new PDType1Font(Standard14Fonts.FontName.HELVETICA_BOLD), 10, "test", 5);
    TextChunk tChunk = new TextChunk(tElement);
    List<TextChunk> tList = new ArrayList<>();
    tList.add(tChunk);
    cell.setTextElements(tList);
    // assertion?
}}
```

Assertion Components: Variables

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Extract variables and their types

Assertion Components: Variables

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```

Extract variables and their types

Pair variables of same type

Assertion Components: Method Seqs.

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Assertion Components: Method Seqs.

Compute type-correct method calls chains

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  List<TextChunk> tList = new ArrayList<>();
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  cell.setTextElements(tList);
  // assertion?
}
```

```
cell.setSpanning(boolean)
cell.hasColor(Color)
cell.getTextElements()
```

Assertion Components: Method Seqs.

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@Test
public void testGetTextElements() {
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Compute type-correct method calls chains

Skip methods with side effects

~~`cell.setSpanning(boolean)`~~

`cell.hasColor(Color)`

`cell.getTextElements()`

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Skip methods with unavailable parameters

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~~`cell.setSpanning(boolean)`~~

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`cell.getTextElements()` → `.spliterator()`

`.get(int)`

`List`

Skip methods with unavailable parameters

Assertion Components: Method Seqs.

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Focus on most frequent JDK methods

Skip methods with unavailable parameters

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Compute type-correct method calls chains

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~~cell.setSpanning(boolean)~~

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cell.getTextElements() → ~~.spliterator()~~

.get(int) → .getText()

List

TextChunk

Focus on most frequent JDK methods

Skip methods with unavailable parameters

Assertion Synthesis

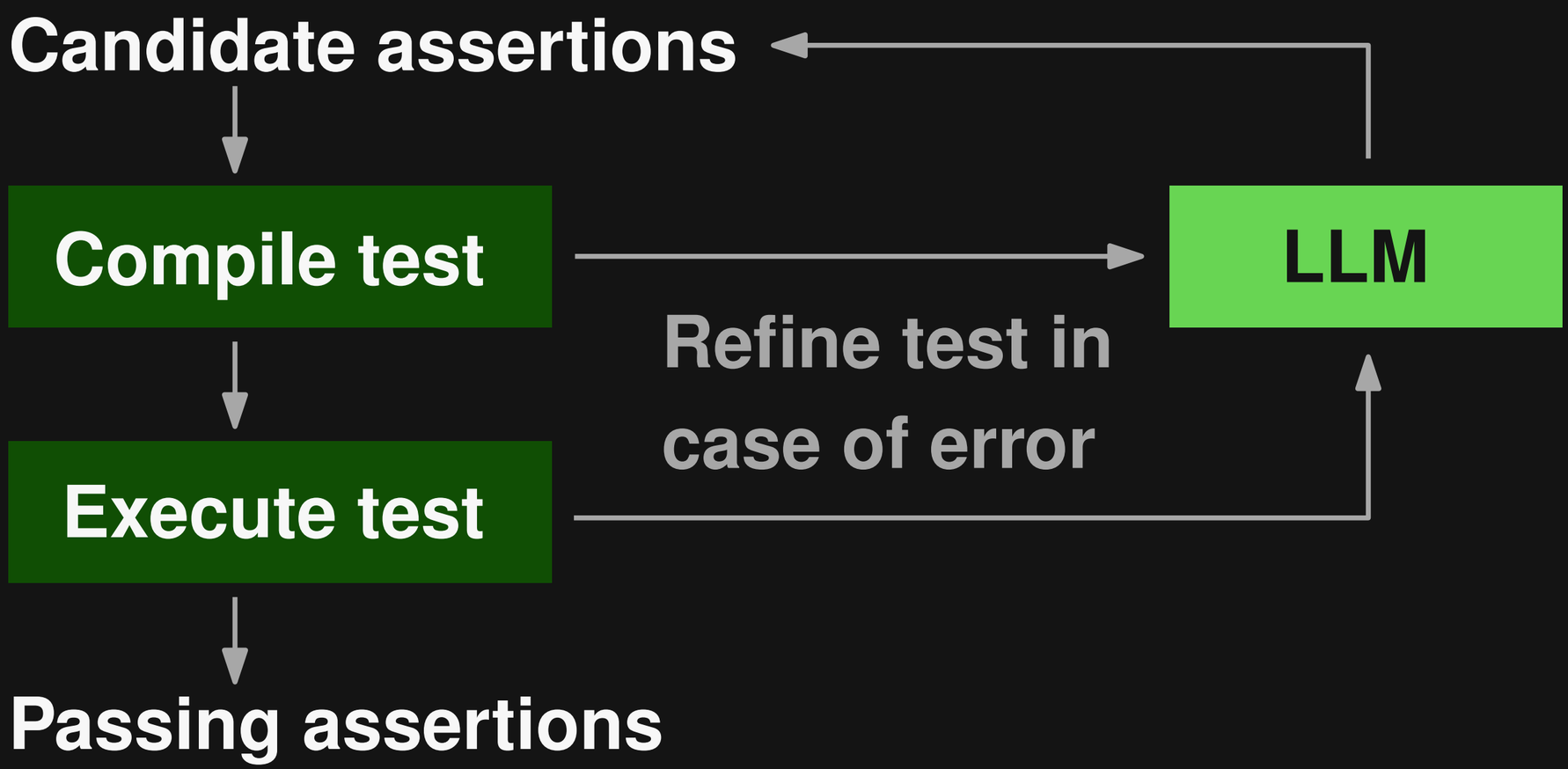
Test prefix

Assertion components:

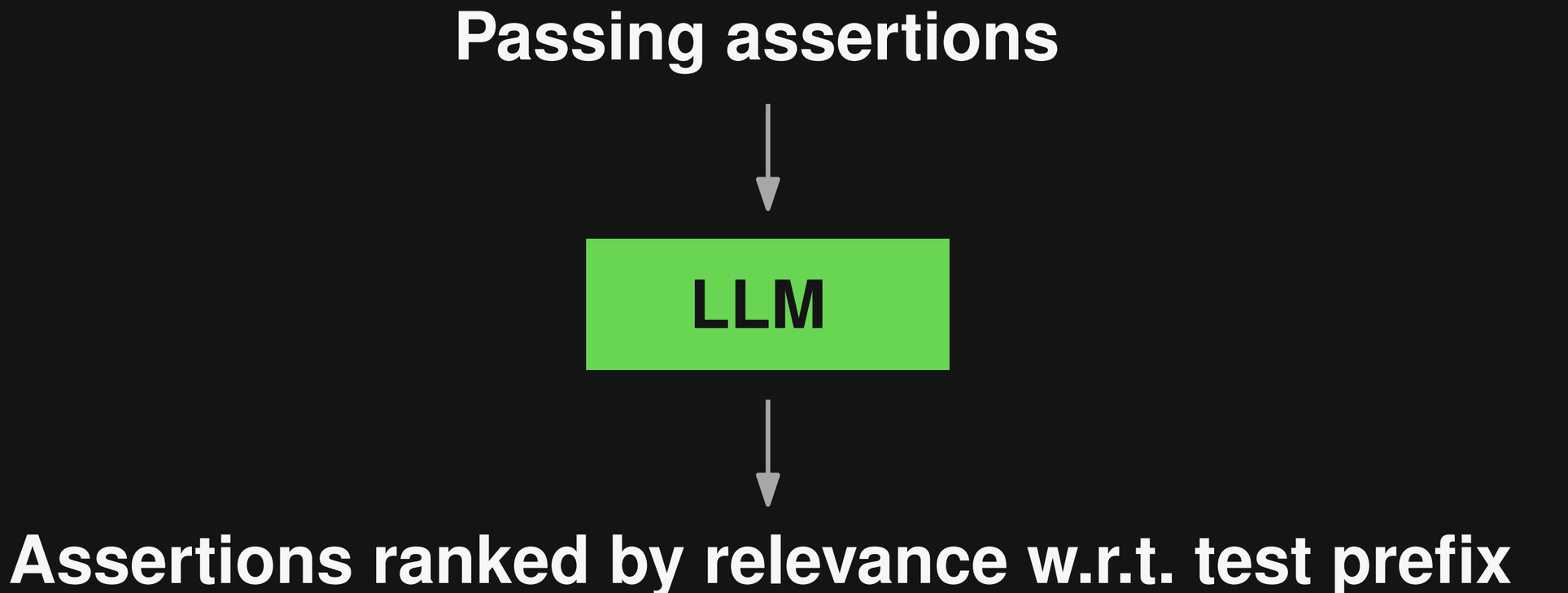
```
initialCell, cell
cell.getSize()
cell.getTextElement().get(_).getText()
tChunk.getText()
```

Most likely assertions built from components

Repairing Assertions



Assertion Prioritization



Evaluation

- **Experimental setup**
  - 500 test prefixes with 1,683 ground truth assertions *
  - LLMs: GPT-3.5-turbo, DeepSeek-V3, GPT-5-mini, GPT-5.4
- **Questions**
  - RQ1: Effectiveness (exact match, test strength, etc.)
  - RQ2: Comparison with ChatAssert baseline
  - RQ3: Ablation study
  - RQ4: Cost analysis

* Augmented version of dataset from *ChatAssert: LLM-Based Test Oracle Generation With External Tools Assistance*, Hayet et al., 2025

Comparison with Frontier LLM

Assertion Per Prefix	Direct Use (GPT-5.4)			STARS (GPT-5.4)		
	W/o Repair	W/ Repair		W/o Repair	W/ Repair	
	Match	Match	Strength	Match	Match	Strength
Top 1	103	103	61.21	183	293	65.8
Top 10	202	208	65.73	285	415	69.53
All	210	216	67.16	306	417	71.43

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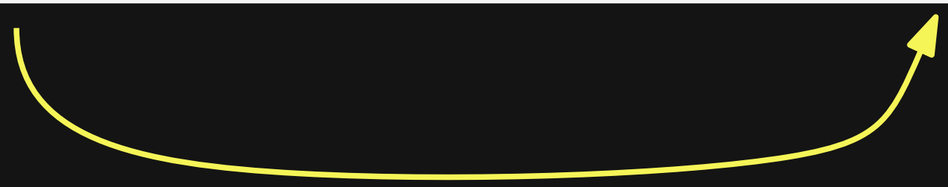

Matches ground truth more often

Comparison with Frontier LLM

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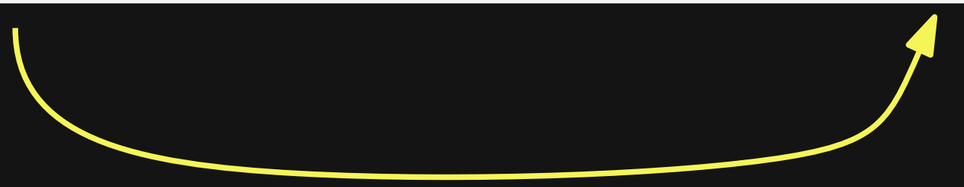

Assertions kill more mutants

Comparison with Baseline Approach

		ChatAssert	STARS
Exact match	Top-1	119	146
Exact match	Top-10	209	260
Test strength	Top-1	36.9%	49.5%
Test strength	Top-10	45.1%	59.1%

Baseline:

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More effective

(with only 75% token consumption)

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Conclusion

- **Assertion synthesis benefits from both ...**
  - Static analysis $\rightarrow$ Reduces search space
  - LLMs $\rightarrow$ Produces natural, likely correct assertions

More general neuro-symbolic pattern

- **Key idea:**
  Gather assertion components before querying the LLM
- **Increases exact-match rate & mutation score, while reducing token costs**