SYSERTSKITE:
Syntactic & Semantic guidance from Refinement Types for Synthesis, via a toKen-based Incremental Type-checking Engine

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https://www.csl.sri.com/users/sgl/sysertskite

Challenge: LLMs alone cannot be trusted to synthesize correct code.

Synthesizing correct code / checking output code correctness may require performing arbitrarily complex computation (e.g., compute a hash) or reasoning (e.g., prove a theorem).

LLMs alone cannot be trusted to do that correctly.

Solution: Involve external trustworthy tools (e.g., code interpreter, formal verification tool)

Possible approaches:

1. Train LLM to select appropriate tools + produce the inputs they will run on.

   Can it be trusted to use external tools correctly?

2. Use trustworthy tools to verify LLM's complete output
   + iterate calls to LLM with new prompts until the output is correct.

   A posteriori checking means search space remains huge at every iteration. Convergence?

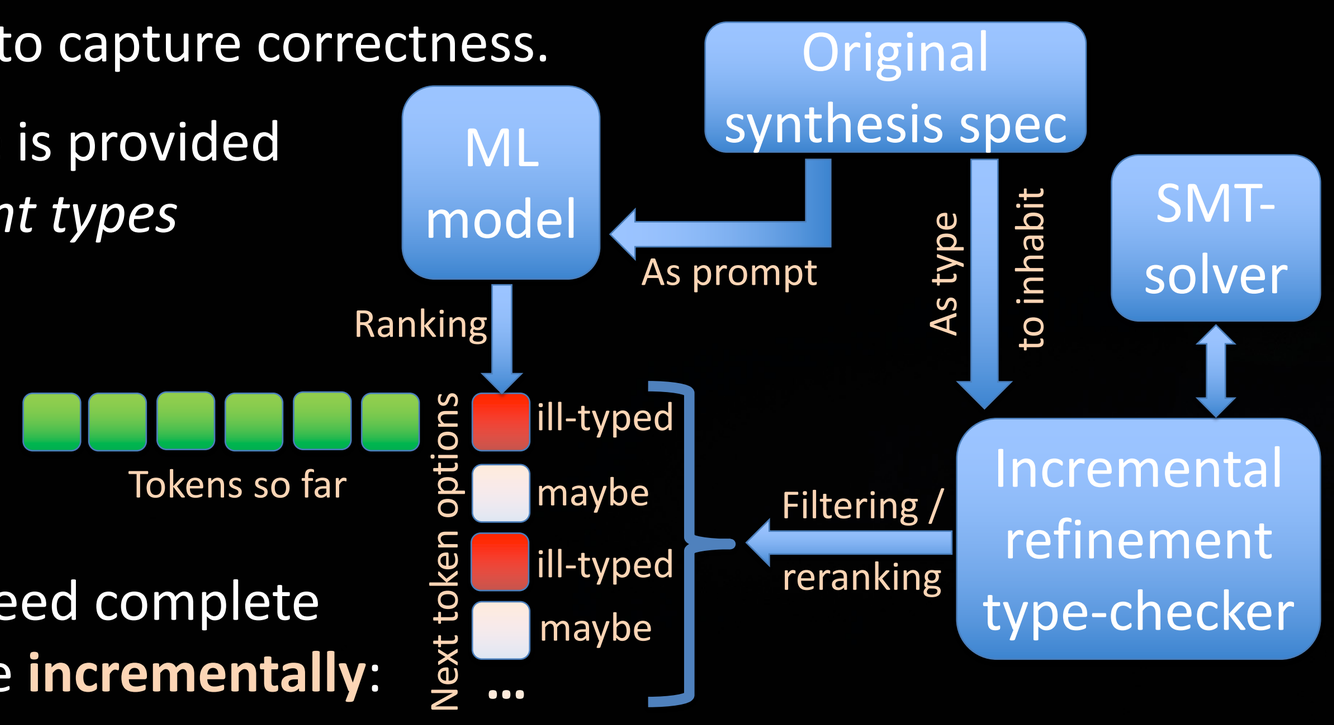
3. Use trustworthy tools to **dynamically guide LLM output**, token-per-token, towards **correct-by-construction output**. Guidance means search space is **reduced** by external tool.

Hope: Single prompt is enough & model size can be a lot smaller.

Classic case in state of the art: force output to adhere to grammar (*Syntax-Guided Synthesis*).

But adhering to grammar is rarely enough to capture correctness.

SYSERTSKITE: Approach 3. where guidance is provided by syntactic + semantic specs via *refinement types* (a.k.a. *predicate subtypes*) + SMT-solving.



- Much **richer than syntactic guidance**; correctness can often be captured with semantics specs;
- **Novel type-checking engine** does not need complete output; it checks output token sequence **incrementally**:
- At each step, it **detects and filters out ill-typed tokens** that would never lead to correct code; tokens can be reranked if type-checking can symbolically infer good tokens ahead;
- Naturally fits *beam search* technique; can be combined with approach 2. when reaching dead-ends; can be used in a *Monte-Carlo Tree Search* instead of LLM sequence production.

Example synthesis task: Synthesize sequence of instructions (i.e., sequence of tokens) to transform state (x = 0, count = 0) to state where count = 1000. Only two kinds of instructions:

`evenHash()` mutates (x, count) to (hash(x), count+1) but crashes if x is odd

`oddHash()` mutates (x, count) to (hash(x), count+1) but crashes if x is even

- Only one single correct solution. Finding the correct sequence of 1000 instructions requires computing hash precisely, otherwise 2^{-1000} probability of getting it right. LLMs alone fail.
- Approach 1 works by "using code interpreter", but fails at minor variant that requires symbolic reasoning. SYSERTSKITE drives the synthesis of correct sequence by eliminating crashing tokens.

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