

XGrammar: Flexible And Efficient Structured Generation Engine for Large Language Models

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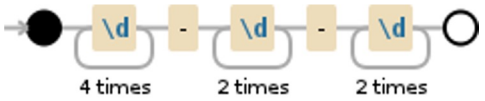
Background: Structured Generation for LLMs

Structured Outputs

- Language Code — GitHub Copilot
- JSON Schema — LangChain
- DSL (e.g. PDDL)

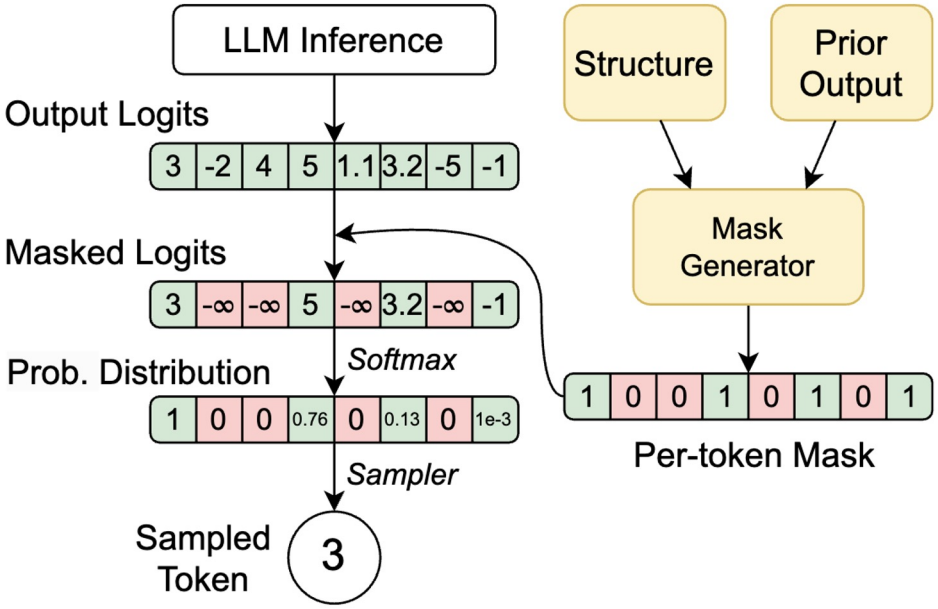
- RegEx



Most of them
can be described as
Context-free Grammar

* Some programming languages like Python can be described as CFG plus maintaining a state

Background: Constrained Decoding



Apply a per-token mask to prevent generating invalid tokens according to the structure

The overhead of the mask generator is crucial!

XGrammar: Flexible and Efficient Structured Generation Engine

XGrammar is a structured generation library that features

Flexibility: Full support for context-free grammar

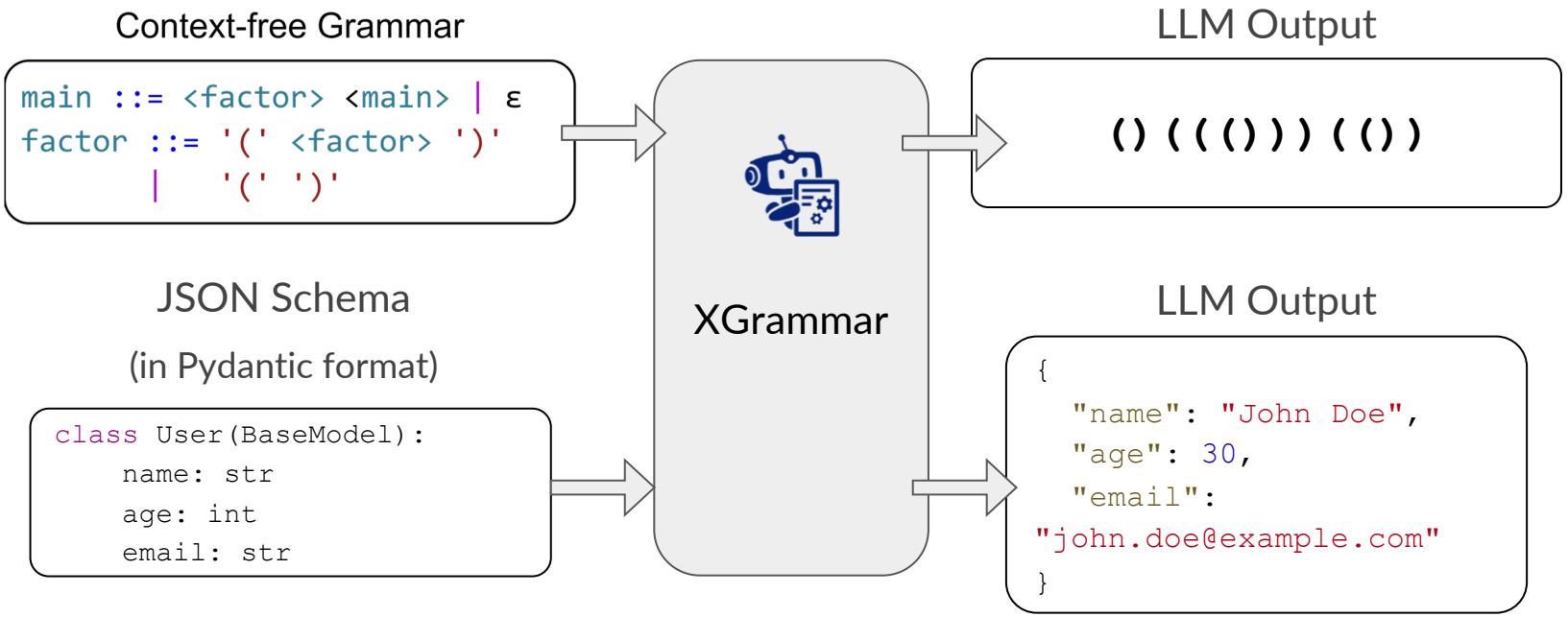
Efficiency: SOTA performance in constraint decoding

Zero-overhead JSON Schema generation

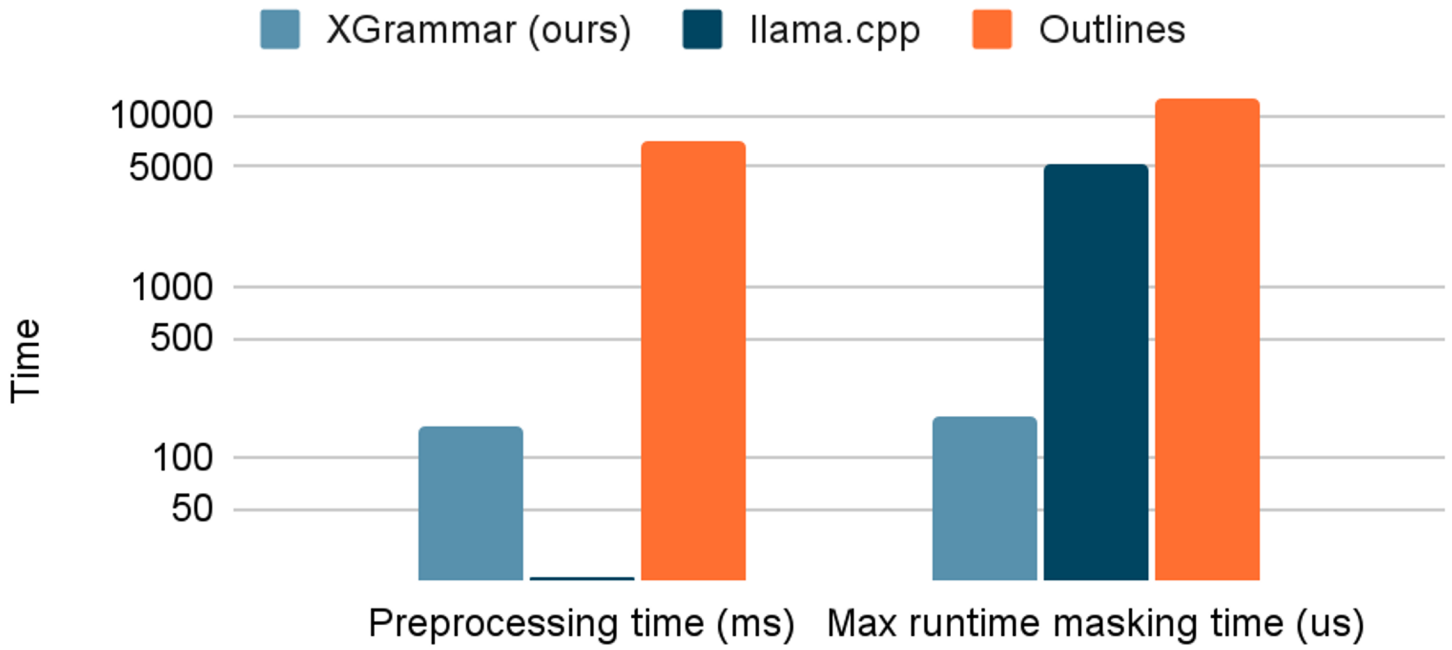
Integration: Easy to integrate with existing LLM serving frameworks

MLC-LLM, SGLang, Web-LLM, etc

Demonstration: CFG or JSON Schema with XGrammar

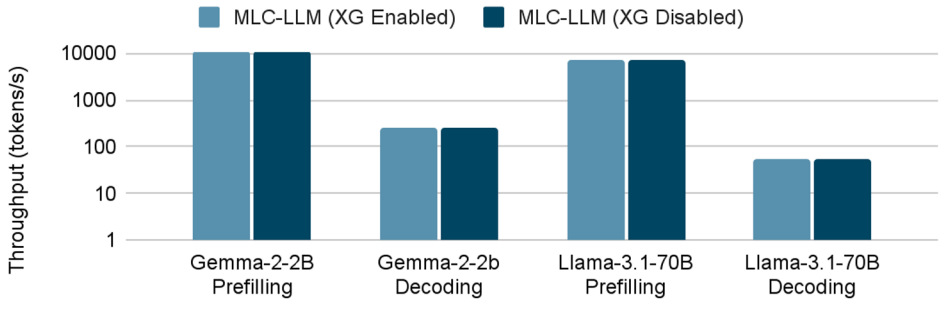


Unit benchmarks



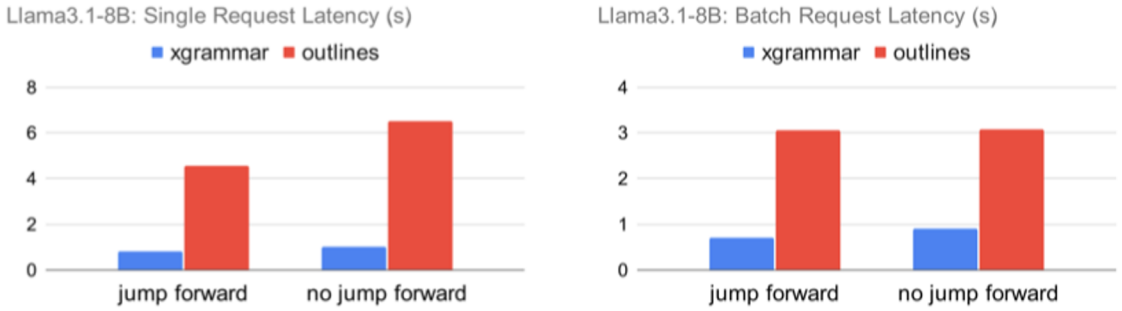
End-to-end benchmarks

MLC-LLM E2E demonstrates zero-overhead constrained decoding



(H100, batch=1)

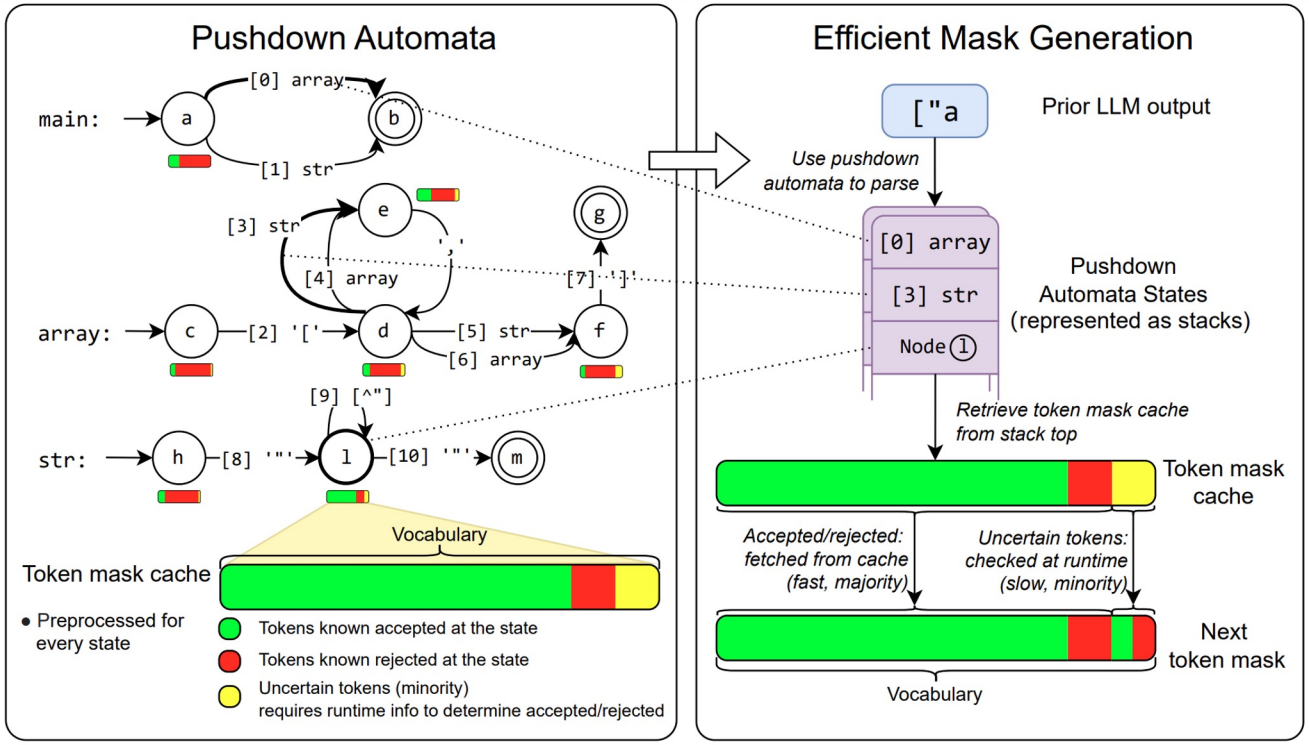
SGLang E2E demonstrates the superiority of XGrammar over other libraries



(A100)

Key optimization: token mask cache

Most part of the mask can be precomputed, although a few remaining ones need to be detected at runtime



Usage: BNFGrammar

```
bnf_grammar = BNFGrammar(
    """main ::= factor main | ""
    factor ::= "(" factor ")" | "()" """,
    main_rule="main",
)
```

Provide the grammar specification in the extended Backus-Naur form (EBNF)

And specify the name of the main rule ("main" by default)

Usage: BuiltinGrammar

```
BuiltinGrammar.json()
BuiltinGrammar.json_schema(schema: str | type[Pydantic.BaseModel])
BuiltinGrammar.str(s: str)
BuiltinGrammar.multiple_choices(choices: List[str])
BuiltinGrammar.concat(grammars: List[BNFGrammar])
BuiltinGrammar.regex(pattern: str)
```

XGrammar provides multiple helper methods to conveniently generate grammar

Usage: GrammarMatcher

```
matcher = GrammarMatcher(bnf_grammar, TokenizerInfo(hf_tokenizer))
while True:
    logits = model.inference(input_tokens)
    bitmask: torch.Tensor = matcher.find_next_token_bitmask()
    GrammarMatcher.apply_bitmask_inplace(logits, bitmask)
    token_id = sampler.sample(logits)
    matcher.accept_token(token_id)
```

At every step, XGrammar provides a token mask to apply to logits, masking invalid tokens.

Each generated token updates the matcher state.

Usage: Caching the preprocessing result

```
init_context = GrammarMatcherInitContext(grammar, tokenizer_info) # 150 ms

matcher = GrammarMatcher(init_context) # 20us
bitmask = matcher.find_next_token_bitmask() # 30us

------------------
init_context_cache = GrammarMatcherInitContextCache(tokenizer_info) # 20us

init_context_1 = init_context_cache.get_init_ctx_for_grammar(grammar) # 150ms
init_context_2 = init_context_cache.get_init_ctx_for_grammar(grammar) # 10us
```

The preprocessing can be slow (100-200 ms)

GrammarMatcherInitContext:

The preprocessing result, can be used to construct GrammarMatcher fast

GrammarMatcherInitContextCache:

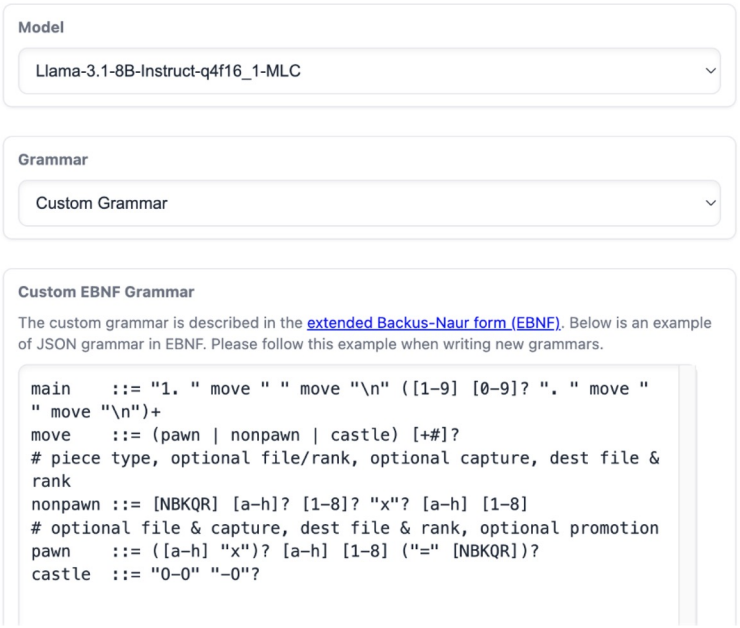
Quickly retrieve the init context of the same grammar multiple times.

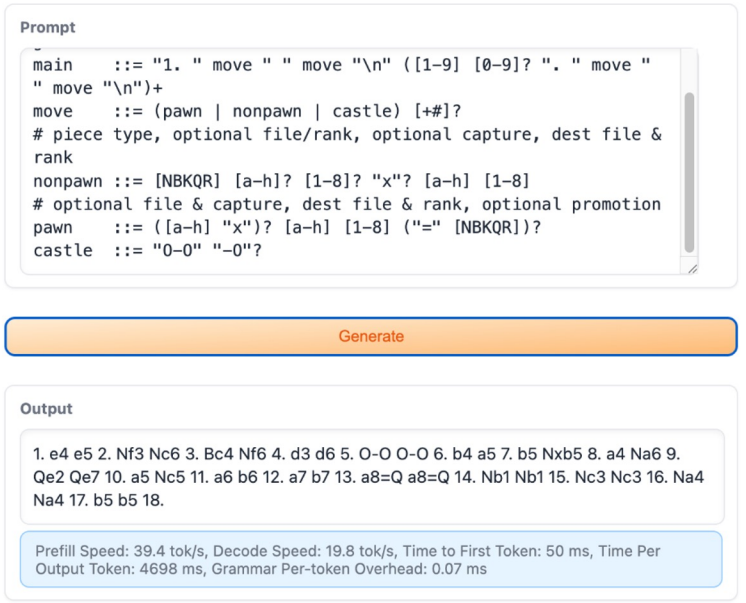
Integration with LLM serving frameworks

- XGrammar is designed for easy integration and cross-platform support (with C++, Python, and TypeScript APIs)
- XGrammar has already been integrated with SGLang, MLC-LLM and WebLLM and is currently being integrated with deepseek
- XGrammar will be open-sourced and released later this month

Try it out on Web-LLM

Run structured generation completely on your web browser with great efficiency!





With help from Charlie Ruan and Nestor Qin from CMU Catalyst Lab



Thanks

Questions are welcome!

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