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# Learning to Parallelize Source Code via OpenMP with Transformers


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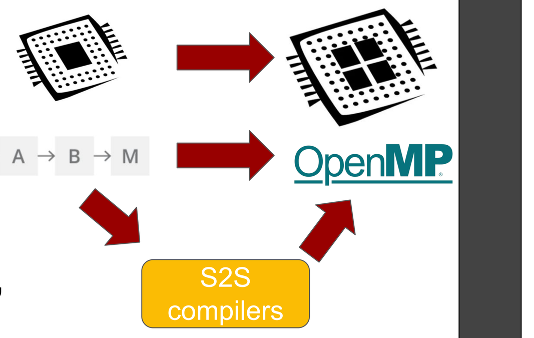
## Introduction

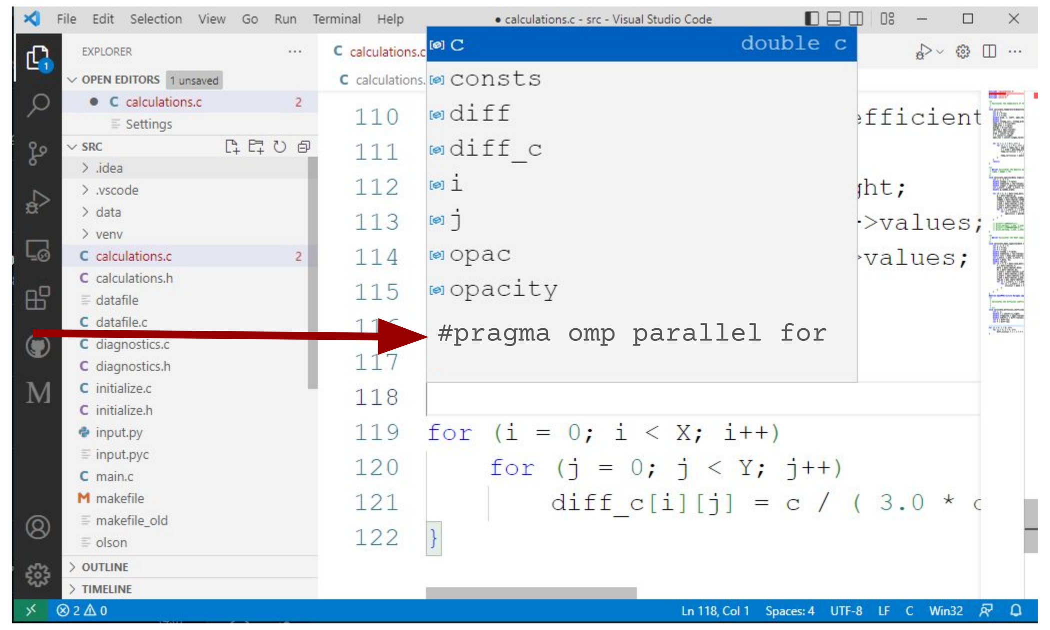
- In order to fully utilize **shared-memory architectures**, developers needed to introduce **OpenMP** to their code.
- Introducing OpenMP schemes is a **hard** and **tedious** task, especially in legacy codes. Thus, many automatic source-to-source compilers (S2S) have been created to cope with this task.
- Nevertheless, S2S compilers have many **pitfalls** due to the **complexity** in parsing the source code; **limited robustness** to the input; and **time consuming** data-dependence algorithms.
- Due to recent innovations in **natural language processing (NLP)**, such as **Transformers**, the possibility of tackling the task of introducing OpenMP directives with **NLP models**, rises.




## Research Objective

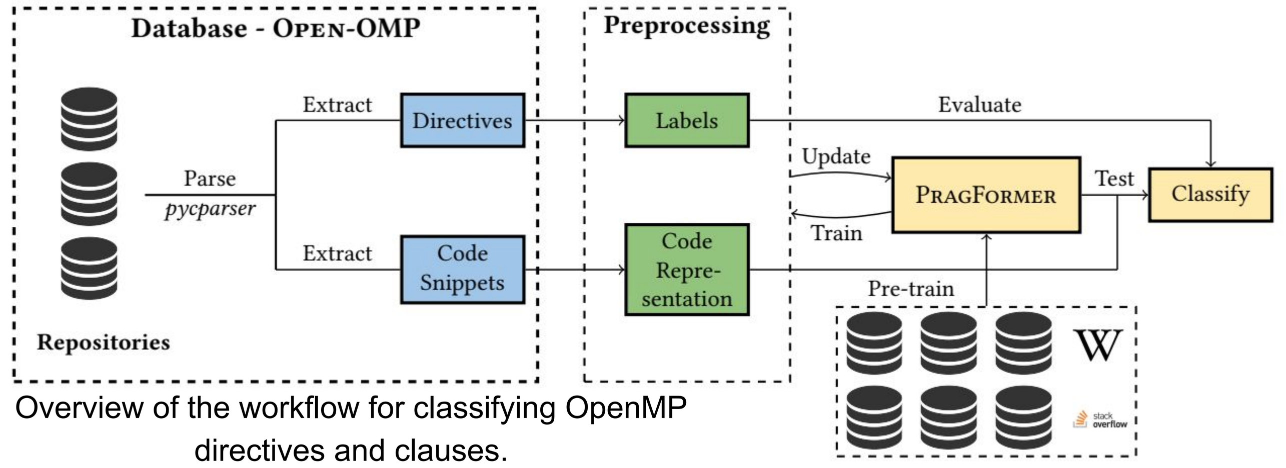
- *We propose an* ***NLP model*** *– based on a novel* ***parallel code database*** *– that will* ***suggest*** *locations in need for an* ***OpenMP directive*** *and even* ***specific clauses*** *such as private and reduction.*
- *Due to negligible inference time, the model can* ***suggest immediate on-the-fly advice*** *for the developer:*

Illustration of said model incorporated with an IDE, suggesting OpenMP directive



## *PragFormer*

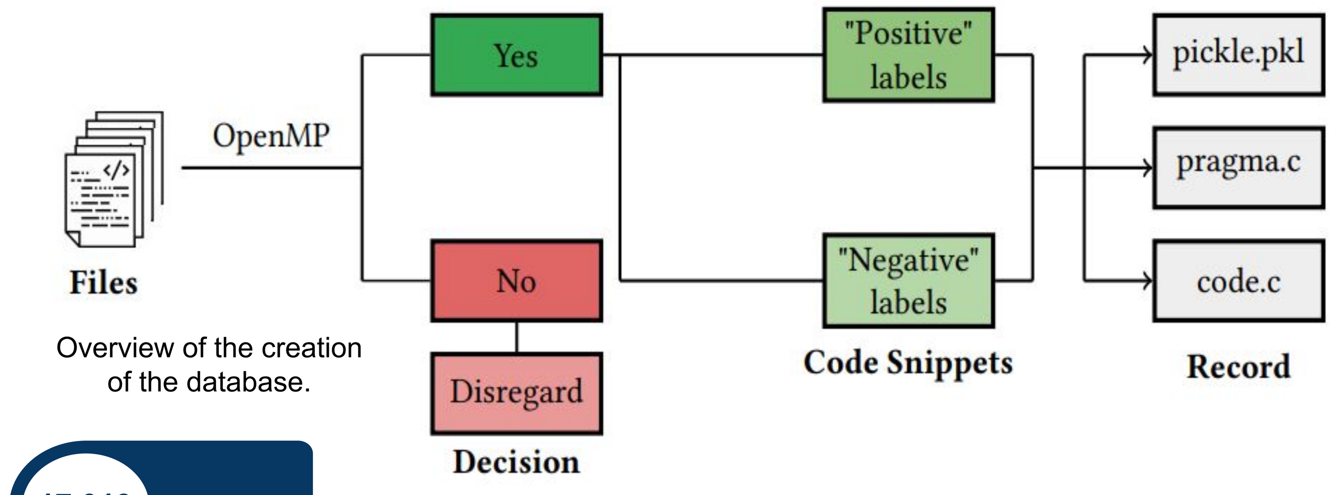
- We propose a **novel model** named ***PragFormer*** for **identifying the need for an** OpenMP directive and specific clauses based on the transformer architecture.




Overview of the workflow for classifying OpenMP directives and clauses.

## Corpus

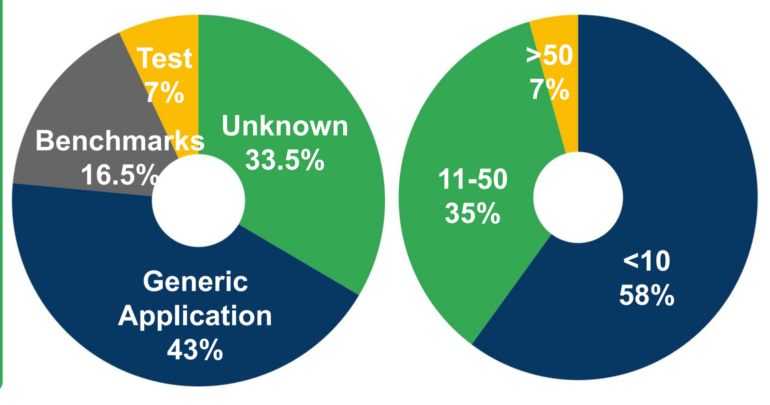
- We created a database named ***Open-OMP*** with 17,000 unique code snippets containing the for-loop, OpenMP directive (if exists), and an AST representation of the two.
- Half of the code snippets are labeled with an OpenMP directive, while the other half with a high probability, not.
- The code snippets were extracted from ***C*** **files exclusively** that were gathered with ***Github*** by searching the phrase "OpenMP".
- The data-validation-test were split in an 80%-10%-10% ratio.




Overview of the creation of the database.

**17,013**
- Query GitHub.com searching "OpenMP"
- Contains snippets with and without OpenMP directives
- Unique
- Extracted from C files exclusively

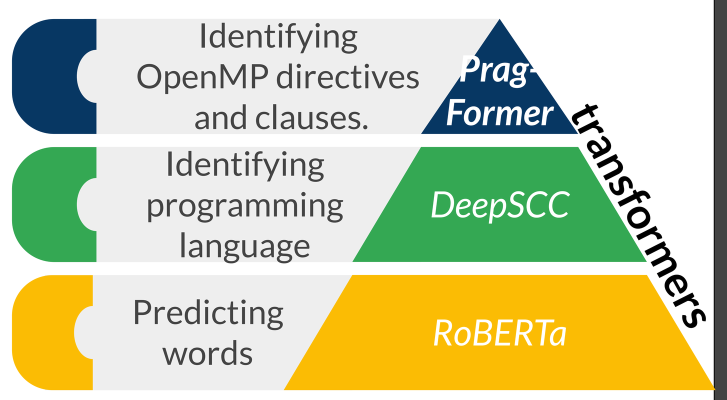
**7,613** OpenMP directives
- 3,403 *private clause*
- 1,455 *reduction clause*
- 374 *schedule dynamic*




The distribution of OpenMP snippets sources. The line length distribution.

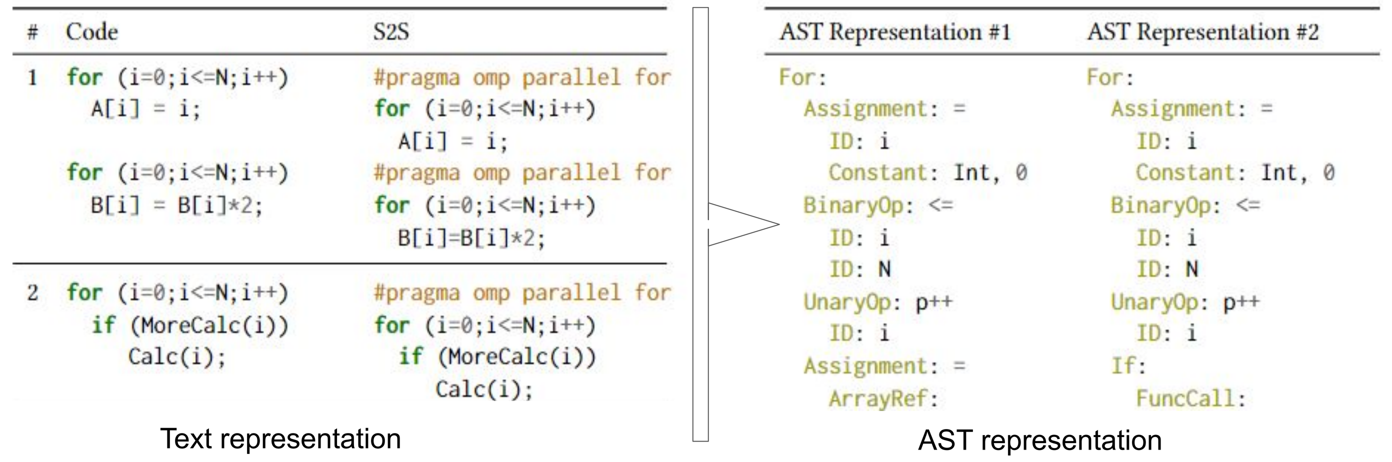
## Model

- The **self-attention mechanism** in the transformer architecture calculates a **score** for each element with respect to any other element. The score determines the **amount** of **consideration** between elements in each consecutive layer.
- Identifying OpenMP directives is mostly hinted from the **dependencies** between variables and statements. Therefore, the **self-attention mechanism is crucial** for the task at hand.
- *PragFormer* is **based** on the **pre-trained model** ***DeepSCC***, a fine-tuned ***RoBERTa*** model for source code.
- To perform the **classification**, the transformer architecture feeds its output to an FC layer that **predicts** a **binary label** through a **softmax layer**.



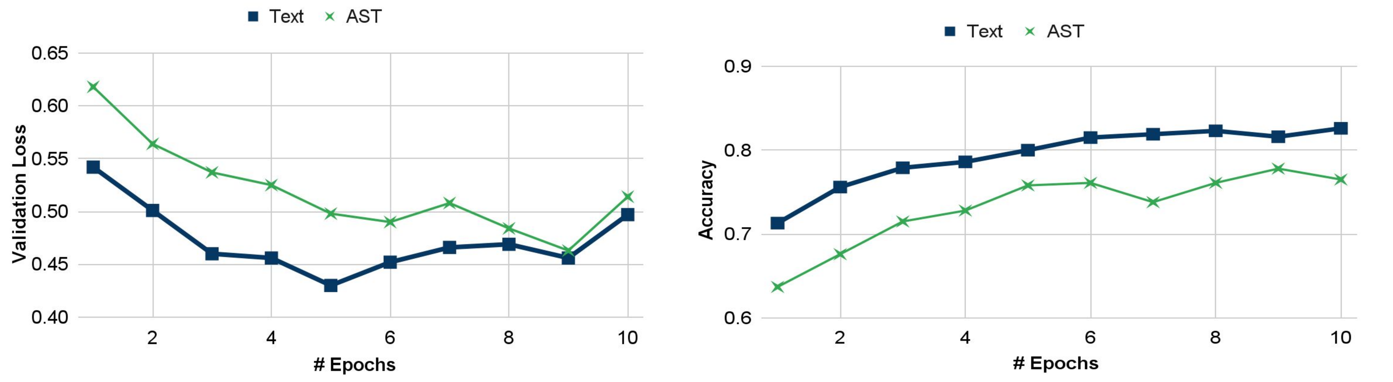

## Code Representation

- The source code is represented as a **sequence of tokens** (from a predefined vocabulary), each token is associated with a numerical vector – the vector in turn is fed to ***PragFormer***.
- We test two source code representations: natural **text** and **AST**.




## Results

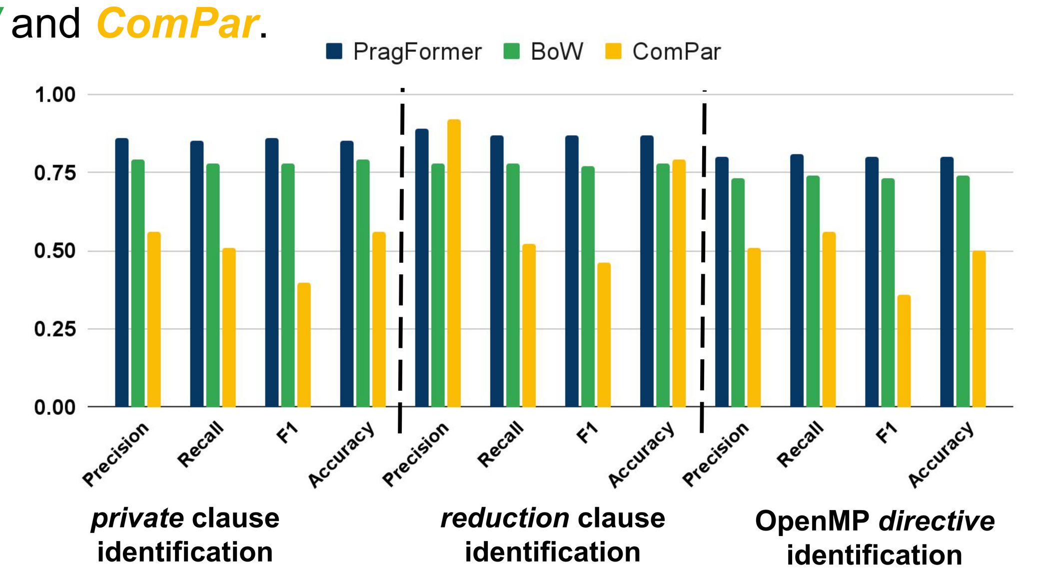
- We present the validation loss and accuracy of the **textual** and **AST representation** over the validation set:




- The **text representation** achieves the **best performance**, likely due to DeepSCC and RoBERTa **familiarity** with this representation.

## OpenMP Directive and Clause Classification

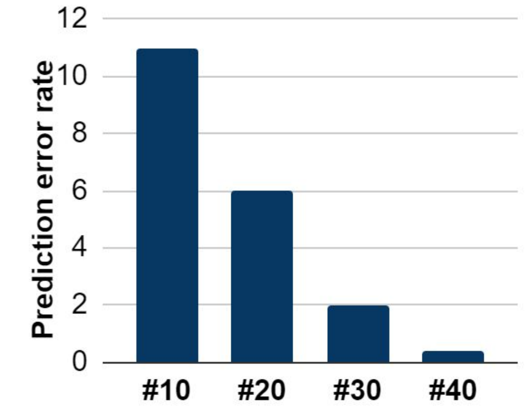
- We compare ***PragFormer*** with the text representation to the S2S compiler ***ComPar*** which incorporates three S2S compilers - *AutoPar*, *Par4All* and *Cetus* and produces their combined best results; and a simple classification model **Bag-of-Words** (**BoW**).
- For the two research questions presented, the **precision**, **recall**, **f1** and **accuracy** scores are calculated over the test for ***PragFormer***, ***BoW*** and ***ComPar***.



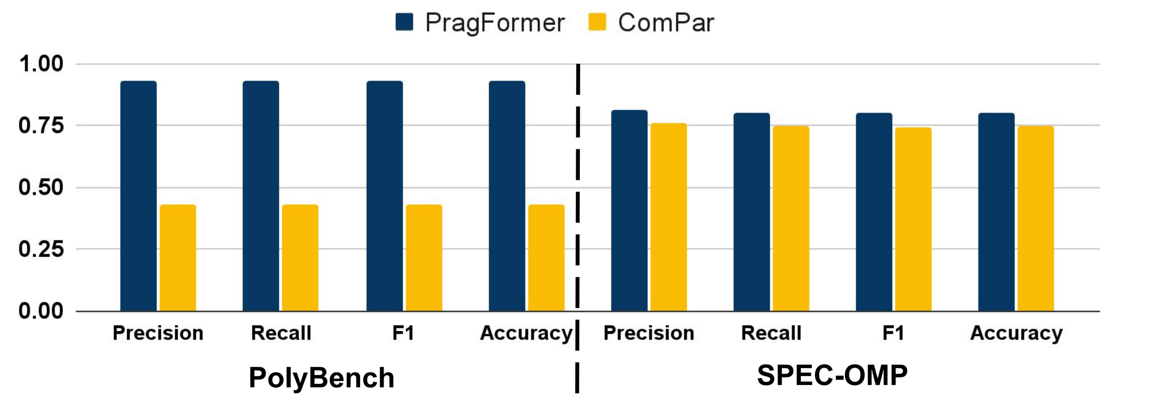

- ***PragFormer*** **achieves the best results on all four metrics on all three test cases.**

## Explainability & Benchmarks

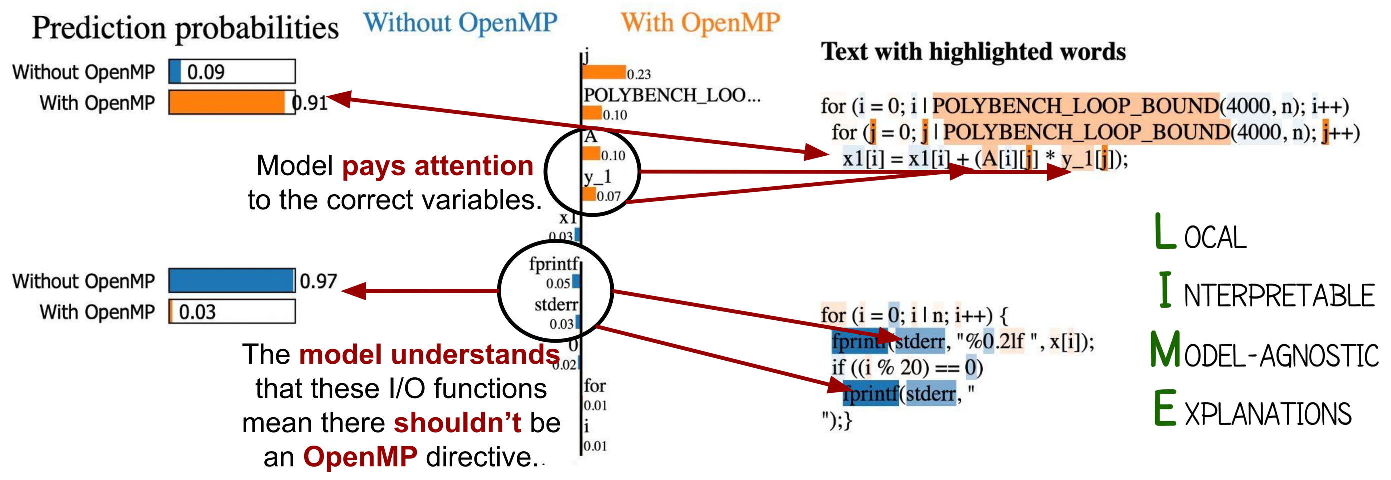
- The prediction error rate as a function of the **code length** is presented.
- Relatively, examples with length >10 and length <10 produced the same error rate of ~18%.
- It might indicate that **length doesn't** effect the **decision** of the model.




- To further test the **generality** of *PragFormer*, two benchmarks are tested: **SPEC-OMP** and **PolyBench**:



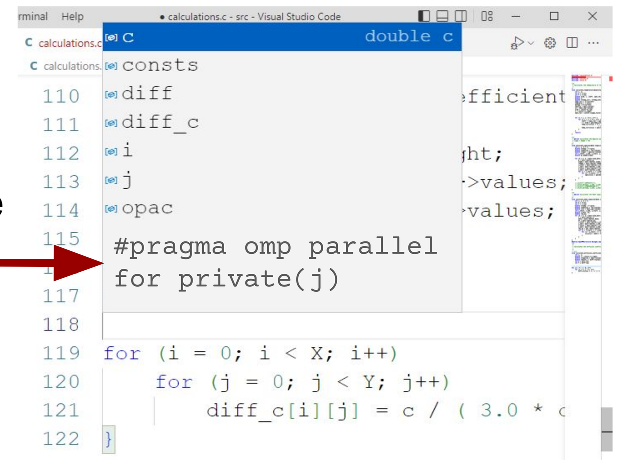

- *PragFormer* produces **excellent results** on OpenMP benchmarks.
- The following figure presents the result of the **explainability** tool **LIME** on two representative examples from the benchmarks:




- Attention to array variables and indices.
- ***fprintf*** is the main reason for predicting without OpenMP.

## Future Work

- Providing the **full context** of the source code rather the for-loop segment.
- Exploring new **source code representations** such as *IR2vec*.
- Enhancing the model to **generate** the OpenMP directive.
- Exploring other parallelization paradigms such as ***MPI*** and **heterogeneous systems**.

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