AI-based Fault-proneness Metrics for Source Code Changes

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Software Evolution

- The lifecycle of a Software Project does not end with its initial release
- Software systems indeed typically **evolve** over time
  - To **fix bugs**
  - To **adapt** to changing environment and requirements
  - To introduce **new features**
  - To **improve design** and **performance**

Software Evolution and Regressions

- During software evolution, **changes** are made to the **codebase**
- Software evolution presents many **challenges**:
  - Keep **documentation aligned** with the code
  - Track evolving requirements
  - Refactor code to maintain adequate levels of **Software Quality**
  - **Ensure** no **regression fault** is introduced with the changes
- Not all changes are equal in terms of **fault-proneness**

Not all changes are equal

Version *i*

```
public int method(){
  int x, y;
  y = 3;
  x = y - 1;
  for(int i = 0; i < x; i++){
    x += i;
  }
  return x;
}
```

Version *i+1*

```
public int method(){
  int value, threshold;
  threshold = 3;
  value = threshold - 1;
  for(int i = 0; i < value; i++){
    value += i;
  }
  return value;
}
```

Not all changes are equal

Version *i*

```
public int method(){
  int x, y;
  y = 3;
  x = y - 1;
  for(int i = 0; i < x; i++){
    x += i;
  }
  return x;
}
```

Version *i+1*

```
public int method(){
  int x, y, i = 0;
  y = 3;
  x = y - 1;
  while(++i < x){
    x += i;
  }
  return x;
}
```

Assessing the Fault-proneness of changes

Effectively **estimating** the **fault-proneness** of codebase changes can provide several benefits:

- Allow more effective allocation of limited resources
  - **Focus testing** and **inspection** efforts towards the **most critical changes**
- Guide **fault localization** efforts

Related Works

- Many works investigated metrics to predict fault-proneness of a software system [1]
  - Detecting the most fault-prone components (classes, methods, modules)
  - Often use **historical data** to train project-specific models
- Fewer works have focused on the fault-proneness of **codebase changes**, and evaluated fault-proneness with respect to **human assessments**

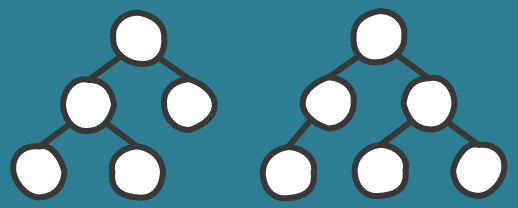
[1] A. Ouellet, M. Badri, Combining object-oriented metrics and centrality measures to predict faults in object-oriented software: An empirical validation, Journal of Software: Evolution and Process (2023)

Goals

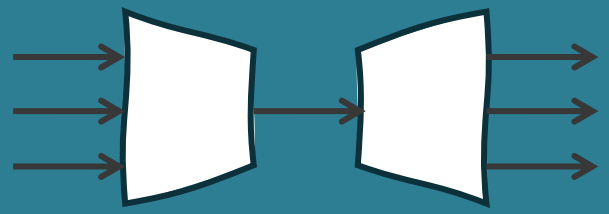
- We present a set of **AI-based metrics** for **estimating fault-proneness** of codebase **changes**, in a **project-agnostic way**
- We **assess** their **effectiveness** by comparing them with fault-proneness scores defined manually by a Software Engineer

Proposed Metrics

The Considered AI-based Metrics



Tree Kernel Functions

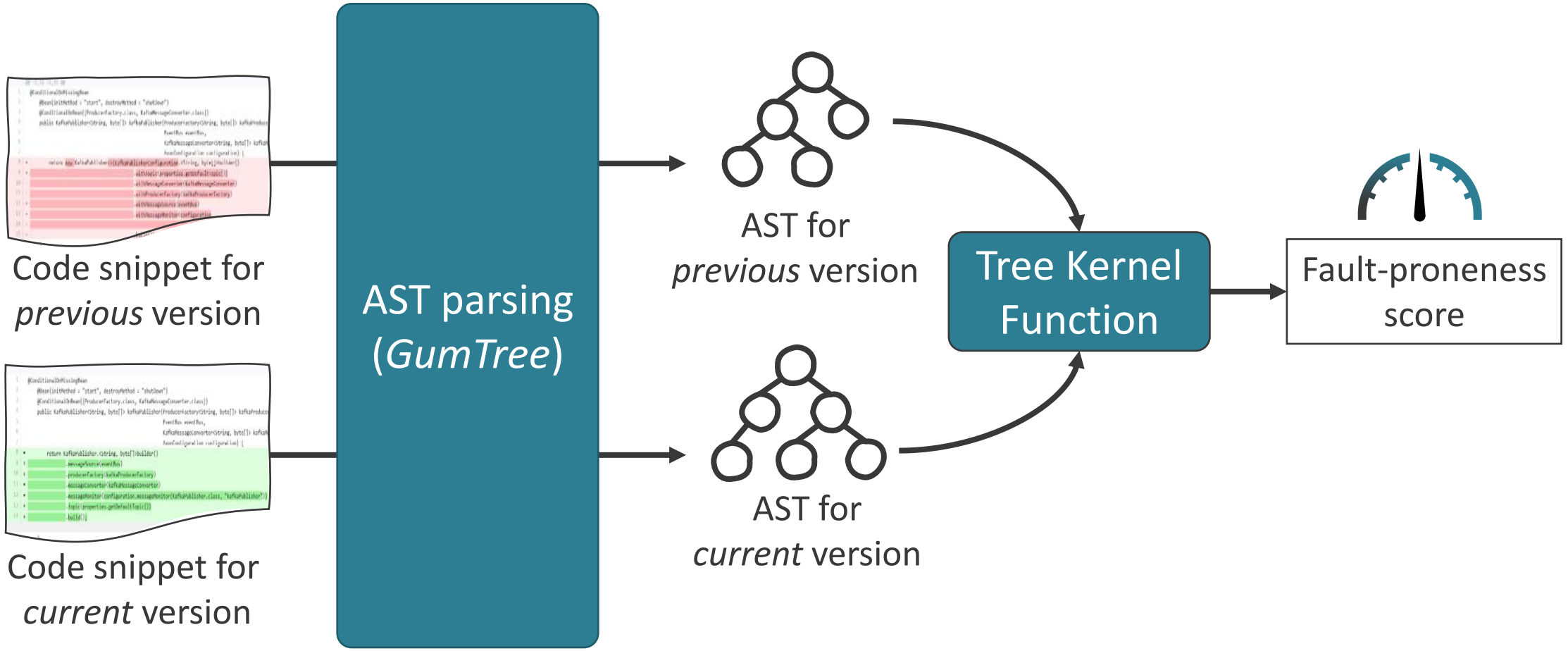


Transformer Models

Tree Kernel (TK) Functions

- Largely and effectively used in **NLP**
- **Idea**: similarity between two trees depends on the number of **fragments** *(subsets of nodes and edges)* they share
- Different definitions of «fragments» lead to different TKs
- We considered 3 TK functions from the literature:
  - Subtree Kernels
  - Subset-Tree Kernels
  - Partial Tree Kernels

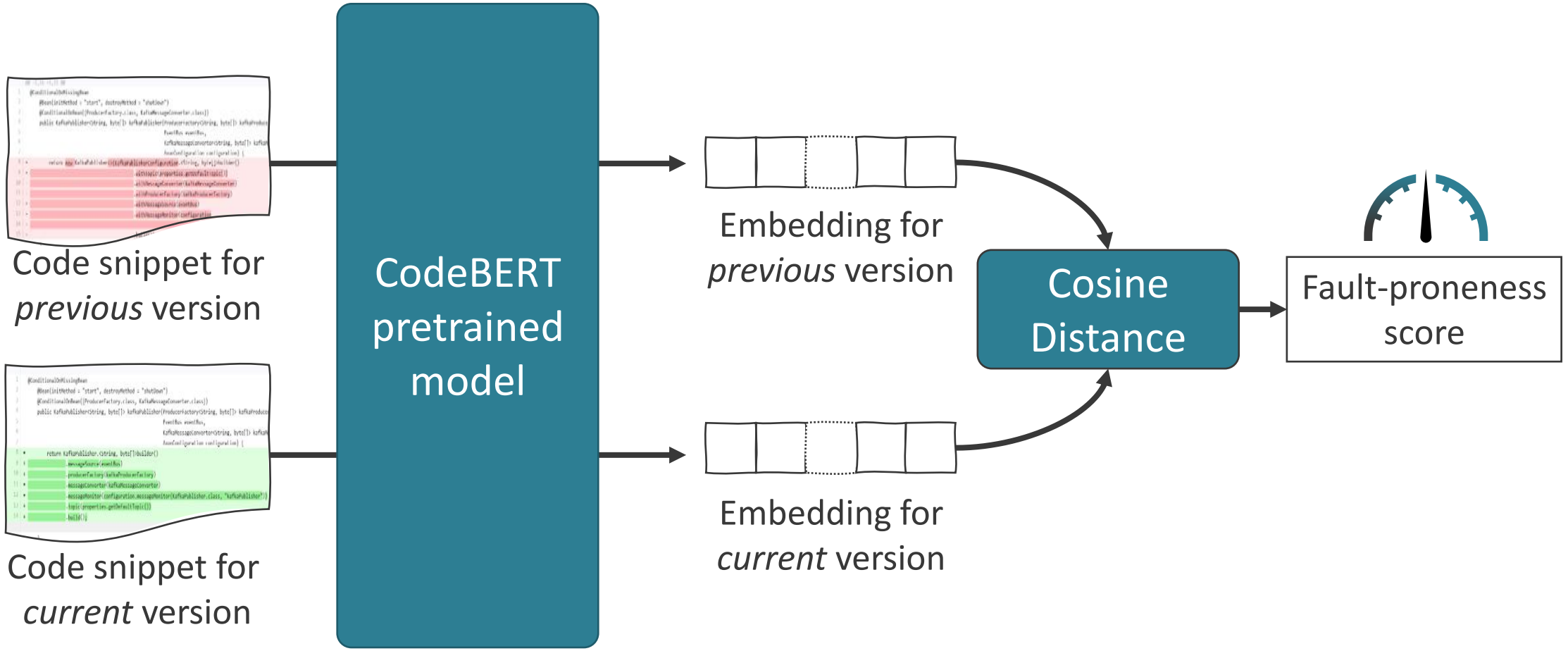
Tree Kernel-based Metrics



Transformer Models

- A class of **deep learning** models
- Trained on large corpora of data using unsupervised learning objectives (masked language modelling or next sentence prediction)
- Such models can be used to learn vector representations capturing the semantic and syntactic structure of the input
- We leverage a pre-trained **CodeBERT** model to map code snippets to vector representations in the latent vector space

Transformer-based Metric: CodeBERT-distance



Empirical Evaluation

Research Questions

- **RQ1**: To what extent do the considered metrics **correlate** with fault-proneness scores defined by a Software Engineer?

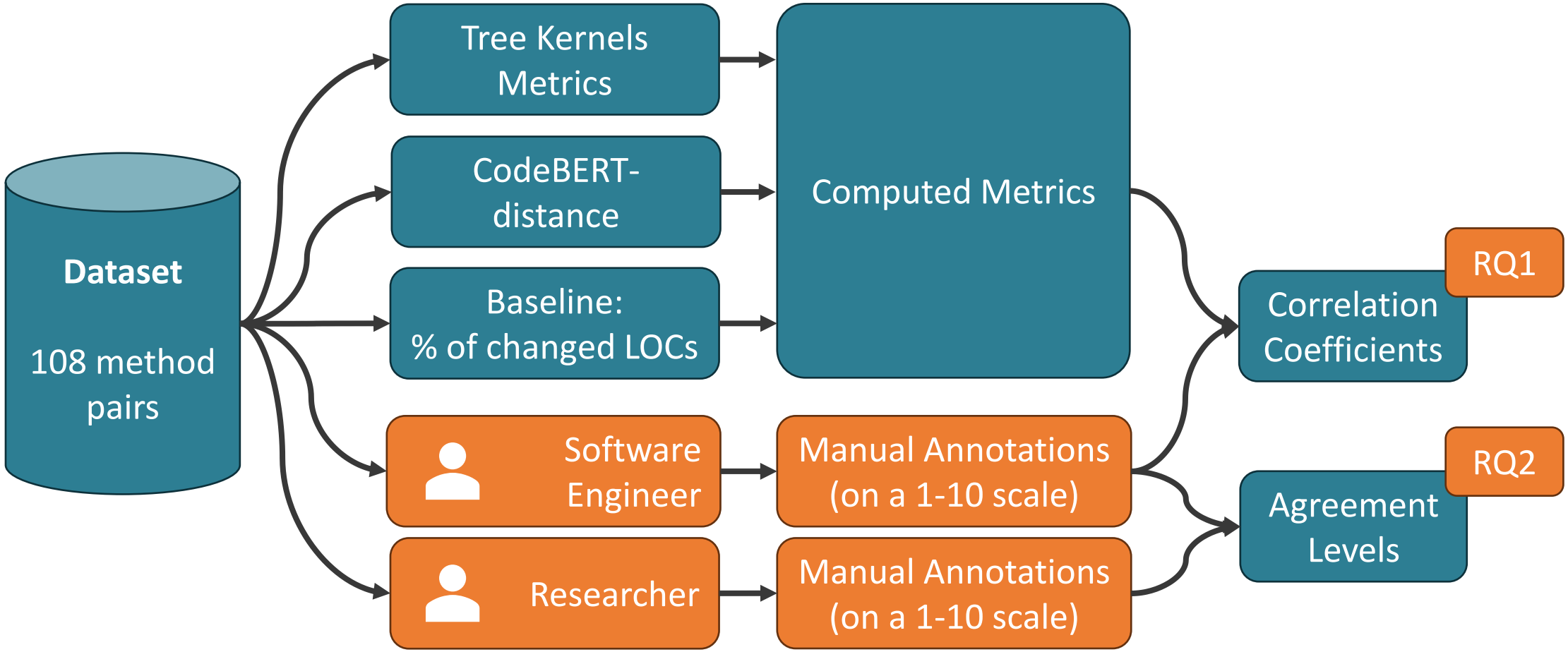
- **RQ2**: How **subjective** are manually-defined fault-proneness scores?

Dataset collection

- Started from a recent dataset for regression testing research [2]
- 104 subsequent version pairs from open source **Java projects**
- More than **1k method-level evolution scenarios**
  - Two subsequent versions of the same method **(m1, m2)**, where m2 has been affected by some changes
- Using **stratified sampling** w.r.t. projects, we sampled **108 method pairs** from **19 different projects**

[2] F. Altiero, A. Corazza, S. Di Martino, A. Peron, L. L. L. Starace, Recover: A curated dataset for regression testing research, in: Proceedings of the 19th International Conference on Mining Software Repositories, 2022.

Experimental Procedure



RQ1: Correlation with human-assigned scores

- All the considered metrics are **positively correlated** with human-defined fault-proneness scores
- SubTree Kernel and CodeBERT-distance exhibit a ***strong*** correlation
- The other metrics perform roughly as good as the baseline

Technique	Spearman's Coeff.	Grading
SubTree Kernel	0,61	Strong
CodeBERT-distance	0,52	Strong
% of changed LOCs (baseline)	0,43	Moderate

RQ2: Subjectivity of fault-proneness perception

The **Software Engineer** and the **Researcher** have a **near-perfect** agreement on fault-proneness scores (**0,84 Weighted Cohen's Kappa**)

Entity of Disagreement	% of Occurrence	Cumul. % of Occurrence
0 (perfect agreement)	22	22
1	56	79
2	16	94
3	2	96
4	4	97
5	3	100

Conclusions and Future Works

- Some of the proposed metrics are **strongly correlated** with time-consuming fault-proneness assessments performed by an expert
- In **future works**, we plan to:
  - **Further improve** the metrics, by defining ad-hoc Tree Kernels and fine-tuning the CodeBERT pre-trained model
  - Investigate correlation with the presence of **actual faults**
  - Apply the metrics in software engineering tasks such as **regression test optimization** or **fault localization**
  - Investigate the **factors** influencing human fault-proneness **perception** (i.e., **seniority**, **education**, **type of changes**, etc…)

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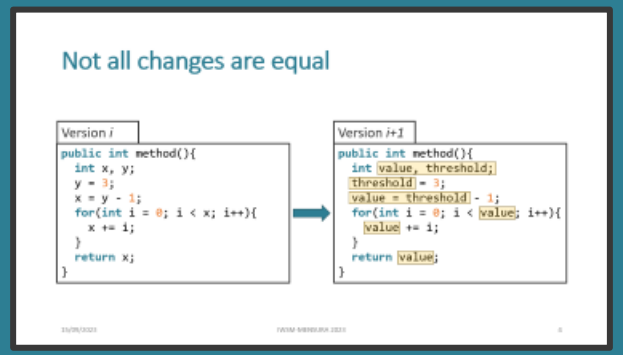

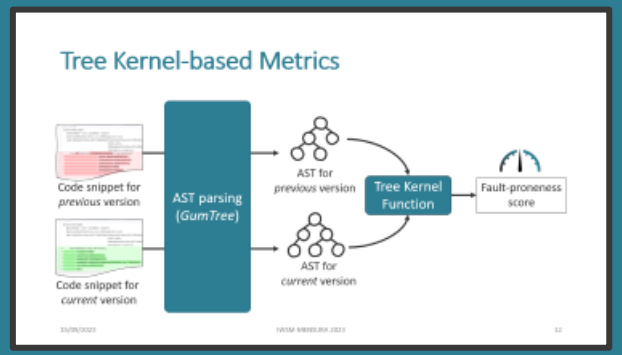

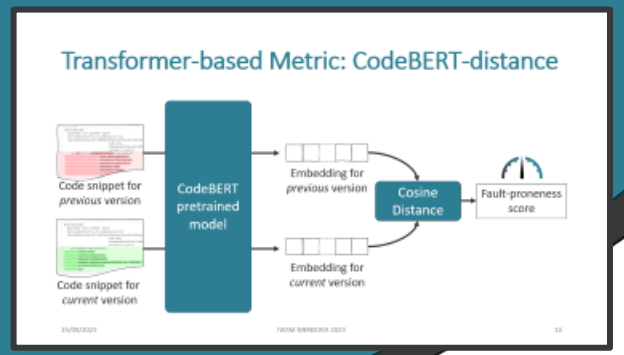

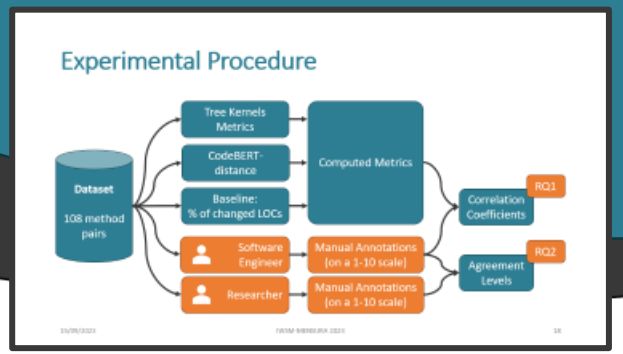

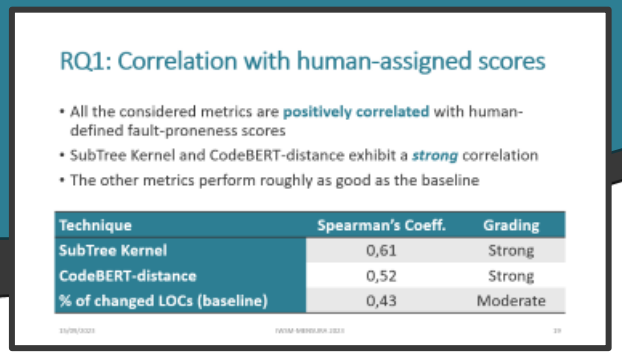

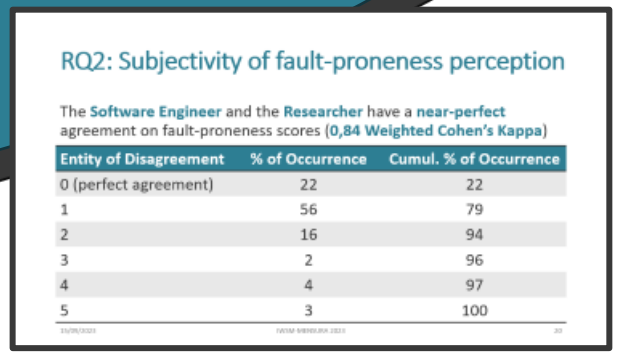

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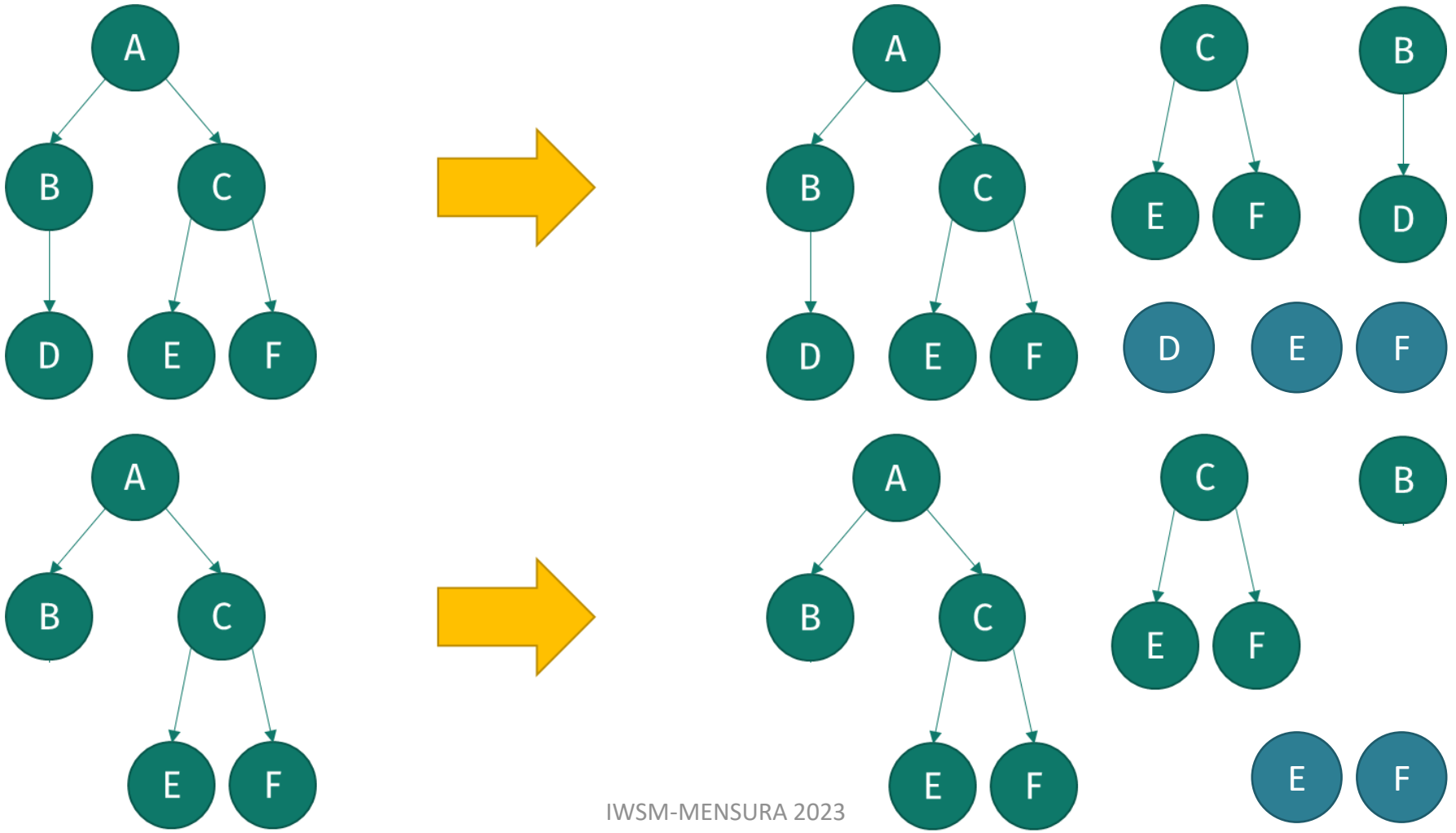
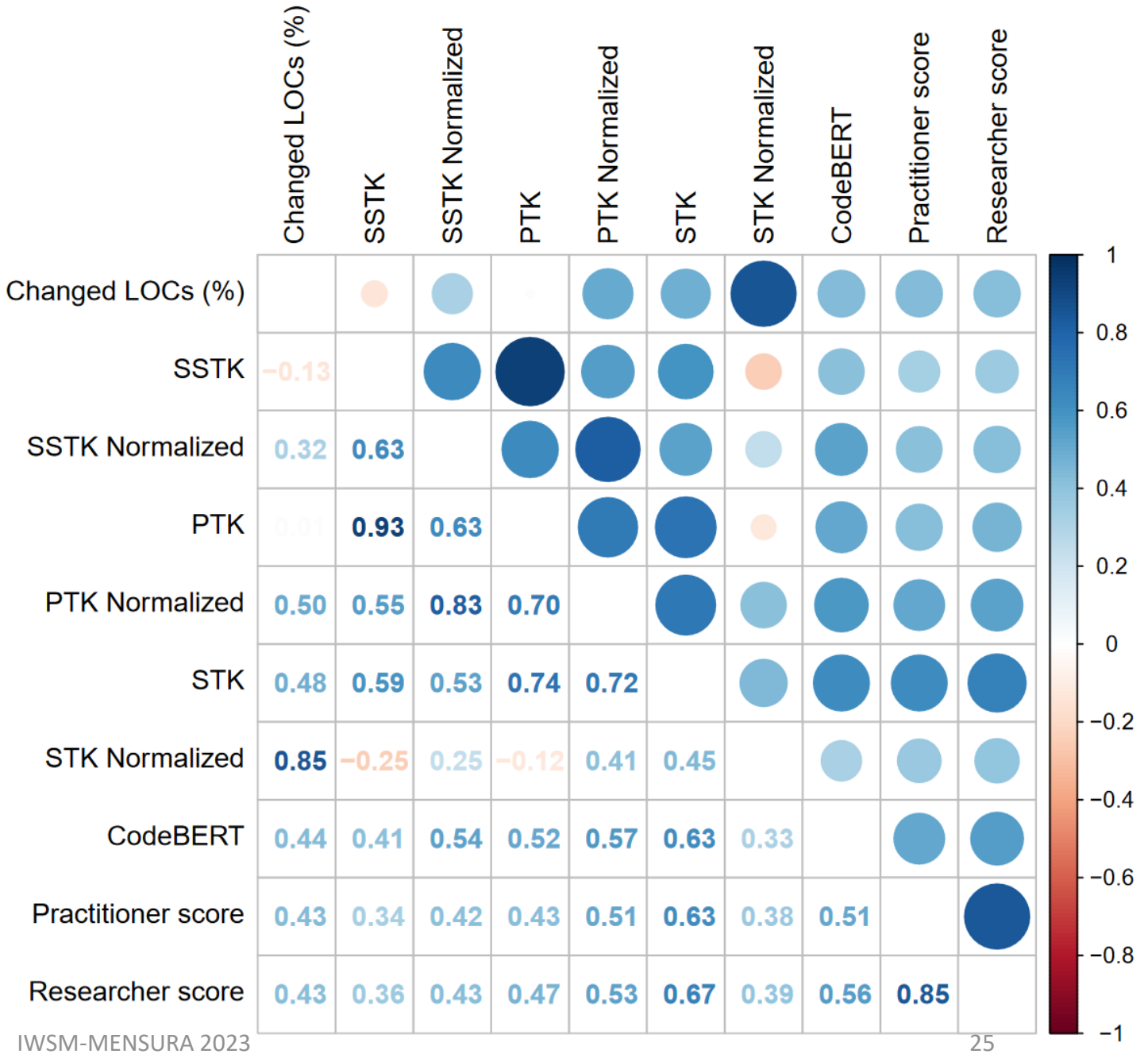
Backup Slides

Tree Kernels: Fragments Example



Correlation Analysis



Code Change View

Diff to HTML by rtfpessoa

Files changed (1) show

C://Users//luigi//Research//code-changes-mensura//dataset//code//3//{old.txt → new.txt} RENAMED

Viewed

```
@@ -1,37 +1,38 @@
 /**
      * Process a batch of events. The messages are processed in a new
      * the event processor creates an interceptor chain containing all
      * interceptors}.
      *
      * @param eventMessages The batch of messages that is to be proces
      * @param unitOfWork    The Unit of Work that has been prepared to
      * @param segment       The segment for which the events should be
      * @throws Exception when an exception occurred during processing
      */
     protected void processInUnitOfWork(List<? extends EventMessage<?>>
                                        UnitOfWork<? extends EventMessa
                                        Segment segment) throws Excepti
-        try {
-            unitOfWork.executeWithResult(() -> {
-                MessageMonitor.MonitorCallback monitorCallback =
-                        messageMonitor.onMessageIngested(unitOfWork.ge
-                return new DefaultInterceptorChain<>(unitOfWork, inter
-                    try {
-                        eventHandlerInvoker.handle(m, segment);
-                        monitorCallback.reportSuccess();
-                        return null;
-                    } catch (Throwable throwable) {
-                        monitorCallback.reportFailure(throwable);
-                        throw throwable;
-                    }
-                }).proceed();
-            }, rollbackConfiguration);
-        } catch (Exception e) {
+        ResultMessage<?> resultMessage = unitOfWork.executeWithResult(
+            MessageMonitor.MonitorCallback monitorCallback =
+                    messageMonitor.onMessageIngested(unitOfWork.getMes
+            return new DefaultInterceptorChain<>(unitOfWork, intercept
+                try {
+                    eventHandlerInvoker.handle(m, segment);
+                    monitorCallback.reportSuccess();
+                    return null;
+                } catch (Throwable throwable) {
+                    monitorCallback.reportFailure(throwable);
+                    throw throwable;
+                }
+            }).proceed();
+        }, rollbackConfiguration);
+
+        if (resultMessage.isExceptional()) {
+            Throwable e = resultMessage.exceptionResult();
             if (unitOfWork.isRolledBack()) {
                 errorHandler.handleError(new ErrorContext(getName(), e
             } else {
                 logger.info("Exception occurred while processing a mes
                             e.getClass().getName());
             }
         }
     }
```