NICAD: A Next Generation Clone Detection Tool

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1. Introduction

- Intentional copy/paste a common reuse technique in software development
- Previous studies report 7% - 23% cloned code in various kinds of software systems, Baker WCRE'95

In response, many clone detection methods

- Lightweight text-based and lexical
  - High recall and text accuracy
  - But results aren't meaningful syntactic units
- Heavier parser-based techniques
  - Meaningful units and high precision
  - But expensive comparison and low recall
- Neither handles near-miss clones well

Our plan, a hybrid:

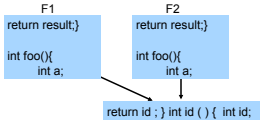
- Combines strengths, overcomes limitations of both text-based and AST-based techniques
  - Proven effective (with high precision and recall) in finding near-miss function clones
- A hybrid parser / text line-based technique
  - And other novel features of other approaches

2. Overview of Existing Methods

Bellon et al. TSE'07, Roy and Cordy ICPC'08, SCP'09, TechReport'07

Approach	Strengths	Limitations
Text-Based	100% Precision	Sensitive to formatting & editing, Non-syntactic clones
Token-Based	Fast, High recall, Normalization	Medium precision, Often not syntactic clones
Tree-Based	Syntactic clones, High precision	Low recall, Fully-fledged parser, Expensive tree comparison
Metrics-Based	Fast, Syntactic clones	Medium precision and recall, Fully-fledged parser
Graph-Based	Might detect semantic clones	Low recall, Not scaled, Expensive graph comparison

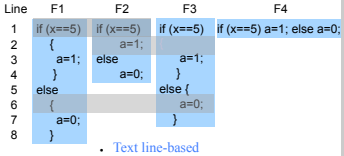
3. Text- and Token-Based Often Detect Non-Syntactic Clones



We Do: Structural Extraction

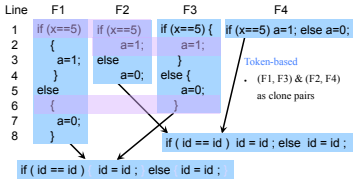
- Use robust island grammars to isolate and extract
  - Meaningful units for comparison
  - Example: begin-end block, function block or any structured block
  - Source coordinate of the units
- No need of fully-fledged parser
  - Standalone, only TXL grammar

4. Text-Based: Sensitive to Formatting Changes

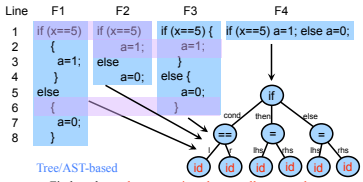


- Text line-based
  - Not clones

Token-Based: Not Fully Robust to Formatting Changes



Tree-Based: Robust to Formatting Changes



- Find as clones, but expensive , low recall, not good for finding near-miss clones

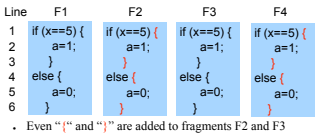
We Do: Standard Pretty-Printing

- Parser eliminates commenting (if any) and input formatting differences
  - Pretty-printing to preserve tree structure in text

```
redefine if_statement                    [IN][NL]
  if ( [expr] ) {                        [EX]
    [statement]
  }
  [opt else_statement]
end redefine
```

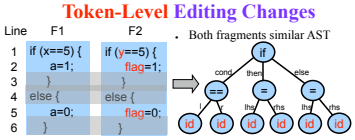
```
redefine else_statement                  [IN][NL]
  else {                                 [EX]
    [statement]
  }
end redefine
```

Standard Pretty-Printing



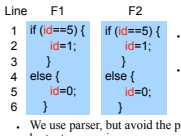
- Even "{" and "}" are added to fragments F2 and F3
- Text-line comparison now finds them exactly similar
- Form a clone class, {F1, F2, F3, F4} as of tree-based method but avoids expensive tree comparison
- Because of text-comparison, precision is now 100%

5. Token- and Tree-Based: Robust to Token-Level Editing Changes



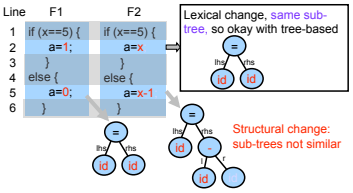
- Both fragments similar AST
- Text-based are sensitive to any changes
- Token-based methods give lots of false positives, Bellon et al. TSE'07
- Tree-based methods are expensive, low recall, and not as high precision as of text-based methods

We do: Flexible Token-Normalization

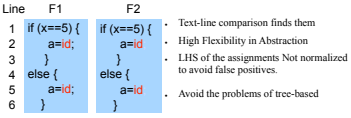


- We use parser, but avoid the problems of tree-based methods by text-comparison
- As we first extract structural units for comparison, we avoid problems of classical text-based and token-based methods
- Text-line comparison now finds them as clone pair
- High flexibility in token-normalization

Text-, Token- and Tree-Based are Sensitive to Structural Changes

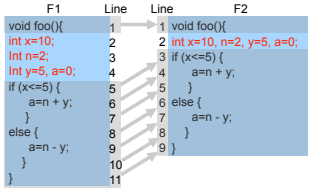


We Do: Flexible TXL Rules for Structural Normalization



- Text-line comparison finds them
- High Flexibility in Abstraction
- LHS of the assignments Not normalized to avoid false positives.
- Avoid the problems of tree-based

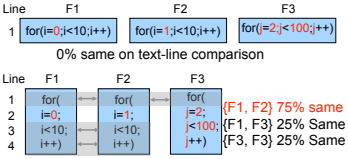
6. Flexible Code Filtering



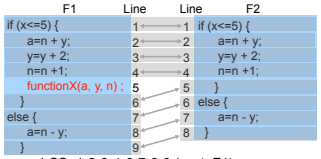
- After removing the declaration statements, text-line comparison will find them as clone pair with high accuracy

7. Flexible Pretty-printing

- Example, "for" headers



8. Text-Line Comparison with Gaps



LCS: 1-2-3-4-6-7-8-9 (w.r.t. F1)

$$UPI_F1 = \frac{\text{No. of unique items/lines in F1 w.r.t. F2}}{\#Lines(F1)} \times 100$$

$$= \frac{\#Lines(F1) - \#Lines(LCS)}{\#Lines(F1)} \times 100$$

Similarly, for fragment F2,

$$UPI_F2 = \frac{\#Lines(F2) - \#Lines(LCS)}{\#Lines(F2)} \times 100$$

- **Definition of Clone**
  - Given a UPI threshold UPI_T, fragments F1 and F2 form a clone pair if and only if,

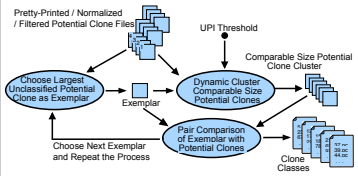
  (UPI_F1 <= UPI_T) AND (UPI_F2 <= UPI_T)

- E.g., if UPI_T is 20%, then two fragments considered clones if 80% of pretty-printed text lines identical.

For the running example, #Lines(LCS)=8
UPI_F1=11% and UPI_F2=0%
If UPI_T==10%, not clone pair
If UPI_T==15%, {F1, F2} clone pair

9. Comparing the Potential Clones

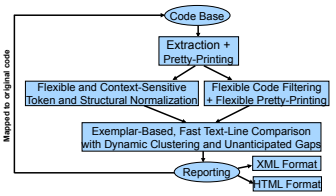
- LCS algorithm compares two extracted units /potential clones at a time
  - In principle, must compare every pair of potential clones => quadratic w.r.t. no. of potential clones
- Three major strategies to improve
  - Apply dynamic clustering based on the size of a chosen exemplar and the UPI threshold
  - Farm out pair comparisons to multiple processors
  - Make comparisons one-pass using exemplars



10. Reporting/Output Generation

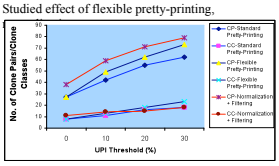
- Two forms of output
  - XML database of clone classes with source coordinate information (file name, begin-end line numbers)
    - Suitable for use by IDEs, statistical analysis / reporting tools
  - HTML website report of clone classes
- Original raw source code reported
  - Using source coordinate annotations from potential clones

11. Conceptual Diagram of NICAD



12. First Experimental Results

- Weltab
  - Studied effect of flexible pretty-printing,



13. Large Empirical Studies

- Comprehensive in-depth evaluation of clone properties -Roy and Cordy WCRE'08
  - In different dimensions
  - Three different languages (10 C, 7 Java and 7 C#)
  - Diverse varieties of applications
  - All open source systems including complete Linux Kernel
  - 4 KLOC- 6.3 MLOC
  - In varying UPI thresholds
- Also evaluated with a mutation / injection based evaluation framework, Roy and Cordy, Mutation'09
  - NICAD was found very good both for precision and recall for different types of fine-grained clones

References

- C.K. Roy and J.R. Cordy. NICAD: Accurate Detection of Near-Miss Intentional Clones Using Flexible Pretty-Printing and Code Normalization. In *ICPC*, pp. 172-181, 2008.
- C.K. Roy and J.R. Cordy. An Empirical Study of Function Clones in Open Source Software. In *WCRE* , pp. 81-90, 2008 (Invited for special issue).
- C.K. Roy and J.R. Cordy. Near-miss Function Clones in Open Source Software: An Empirical Study. In JSME , 23 pp., 2009 (submitted).