Advanced clone-analysis to support object-oriented system refactoring

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WCORE – October 2010
Clones

- Clones occur
Refactoring

• … casual refactoring?
Refactored clones

• That’s better!
  – … bigger, though …
WCRE 2000 context

• Techniques
  – Metrics
  – AST
  – Strings matching
  – Token matching
  – Fingerprints
WCRE 2000 context

- Literature from 1994 to 2000

- Previous studies on software duplication and similarity analysis have been reported
WCRE 2000 approach

• Metrics-based similarity analysis produced clone clusters today called “classes”
• Clones in the same clone class were post-processed using token based DP matching
  – Insertions
  – Deletions
  – Substitutions
WCRE 2000 approach - 2

• Differences between clones were computed with respect to one random representative in a class
• Token based clone differences were projected over the corresponding ASTs
WCRE 2000 approach - 3

• Re-factoring opportunity were evaluated using
  – Classification of differences
    • Superficial differences
    • Signature changes
    • Type changes
  – Number of differences
  – Size of candidate clones
• Selected clones were automatically re-factored using "strategy" and "template" design patterns
• Experimental evaluation had been performed on JDK1.1.5 from Sun Microsystems
Software Clones

• Definition
  – Two software code fragments are clones if they satisfy some similarity criterion

• Metrics based definition
  – Two code fragments are clones if their associated vectors of metrics satisfy some similarity criterion
Clone Detection

• Identification of duplicated or near-duplicated components

• Duplicated components, often indicate:
  – Some sort of implicit software reuse
  – Some sort of implicit management practices (roles and responsibilities of different corporate structures)
Metrics for Clone Detection

- Volume
- Complexity
- Module/function interface
- Call graph structure
- Local memory
- Global memory
- Dataflow
Clone Identification

Source code → Parsing and Analysis → Abstract Syntax Tree → Metrics Extraction → Clones Extraction → Clones → Metrics

- \( F_1 m_{11} m_{12} \ldots \ldots M_{ik} \)
- \( F_j m_{j1} m_{j2} \ldots \ldots m_{jk} \)

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Clone Comparison

- Code fragment 1
  - Lexical analysis
  - Vector of tokens 1
  - Parsing
  - AST 1
  - Projection
  - Differences as AST subtrees

- Code fragment 2
  - Lexical analysis
  - Vector of tokens 2
  - Dynamic matching
  - Optimal match
  - Parsing
  - AST 2
DP Matching Algorithm

- Compute the optimal sets of lexical changes using dynamic programming
  - Sub-optimal and heuristic ones exist
Matching Example
AST Comparison

• Project lexical changes onto AST’s to obtain tree changes

• Definition:

\[
\begin{align*}
\text{tree} &= (V, E) \\
\text{ast_node_changed}(v) \leftrightarrow \\
(\exists p = < v, ..., v_i, ..., v_t > | \\
(v_i \in V) \land \\
(\text{lex_changed(token}(v_T)))),
\end{align*}
\]

• Comparison computation is linear in the size of V
func-decl

func_header

type_id  func_name  l_par  param_list  body  r_par  l_cur

param

type_id  param_name

comma_sep

param_list

type_id  param_name  type_id  param_name

ID

int  restore_list  (  int  index  ,  object  info  )  {
```c
func-decl(func_header(func_name, l_par, param_list), body, r_par, l_cur)
  param_list(param, comma_sep, param_list)
    type_id(param_name, ID)
      type_id(param_name, ID)
        type_id(param_name, ID)
          type_id(param_name, ID)
            type_id(param_name, ID)
              int
        int
      int
    index
      object
        info
          )
    )
  restore_list(int)
```

AST Projection - 2

Ettore Merlo, Ecole Polytechnique de Montreal, (C) Copyright, October 2010
int restore_stack ( object info ) {

Ettore Merlo, Ecole Polytechnique de Montreal, (C) Copyright, October 2010
int restore_stack ( object info )

```c
func-decl
  func-header
    func-name
      l_par
      param-list
        r_par
      l_cur
        ID
      param
        type_id
        param-name
          ID
        l_cur
          ID
```

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## Clone Classification Scheme

<table>
<thead>
<tr>
<th>Category number</th>
<th>Type of clones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Identical</td>
</tr>
<tr>
<td>2</td>
<td>Superficial changes</td>
</tr>
<tr>
<td>3</td>
<td>Called methods</td>
</tr>
<tr>
<td>4</td>
<td>Global variable</td>
</tr>
<tr>
<td>5</td>
<td>Return type</td>
</tr>
<tr>
<td>6</td>
<td>Parameters type</td>
</tr>
<tr>
<td>7</td>
<td>Local variables</td>
</tr>
<tr>
<td>8</td>
<td>Constants</td>
</tr>
<tr>
<td>9</td>
<td>Type usage</td>
</tr>
<tr>
<td>10</td>
<td>Interface changes</td>
</tr>
<tr>
<td>11</td>
<td>Implementation changes</td>
</tr>
<tr>
<td>12</td>
<td>Interface and implementation changes</td>
</tr>
<tr>
<td>13</td>
<td>One long difference</td>
</tr>
<tr>
<td>14</td>
<td>Two long differences</td>
</tr>
<tr>
<td>15</td>
<td>Several long differences</td>
</tr>
<tr>
<td>16</td>
<td>One long difference, Interface and implementation</td>
</tr>
<tr>
<td>17</td>
<td>Two long differences, Interface and implementation</td>
</tr>
<tr>
<td>18</td>
<td>Several long differences, Interface and implementation</td>
</tr>
</tbody>
</table>
### Classification Results for JDK 1.1.5

<table>
<thead>
<tr>
<th>Category</th>
<th>LOCs</th>
<th>Percent clones</th>
<th>Methods</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>432</td>
<td>6.0</td>
<td>42</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>42</td>
<td>0.6</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>464</td>
<td>6.4</td>
<td>36</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>198</td>
<td>2.6</td>
<td>26</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>54</td>
<td>0.7</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>229</td>
<td>3.2</td>
<td>24</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>146</td>
<td>2.0</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>0.2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>0.2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>135</td>
<td>1.9</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>326</td>
<td>4.5</td>
<td>43</td>
<td>10</td>
</tr>
<tr>
<td>13</td>
<td>106</td>
<td>1.5</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>130</td>
<td>1.8</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>33</td>
<td>0.5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>828</td>
<td>11.4</td>
<td>65</td>
<td>24</td>
</tr>
<tr>
<td>17</td>
<td>158</td>
<td>2.2</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>224</td>
<td>3.1</td>
<td>19</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>N/A</strong></td>
<td><strong>N/A</strong></td>
<td><strong>N/A</strong></td>
<td><strong>115</strong></td>
</tr>
</tbody>
</table>

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Classification Results

- Category 1 ("Identical") contains significantly more redesign opportunities than any other category.
- Categories 16, 3, 10 and 12 also contain the majority of opportunities.
- Category 7 ("Local variable type") is empty, in all considered systems.
- Clones may belong to more than one class
Redesign

- Factor out common parts of clones
- Encapsulate differences
- Decouple context
- Synthesize new design
Automatic Redesign Process

- ASTs
  - Differences as AST subtrees
    - Cloned methods factorization
      - IdStrategy methods
      - Factored method
      - DiffStrategy methods
        - Original classes modification
        - CloneHandler creation
        - DiffStrategies creation
          - New system architecture
Strategy Design Pattern

Context

ContextInterface()

Strategy

AlgorithmInterface()

ConcreteStrategyA

AlgorithmInterface()

ConcreteStrategyB

AlgorithmInterface()
Use of « Strategy » in Automatic Redesign

<< interface >>
DiffStrategy
DiffInterface()

<< uses >>
CloneHandler
ClonedMethod()

<< interface >>
IdStrategy
IdInterface()

<< uses >>
CloneHandler
ClonedMethod()

<< uses >>
OriginalClass1
ClonedMethod1()
IdInterface()

ConcreteDiffStrategy1
DiffInterface()

ConcreteDiffStrategy2
DiffInterface()

<< interface >>
DiffStrategy
DiffInterface()

<< uses >>
CloneHandler
ClonedMethod()

<< uses >>
OriginalClass2
ClonedMethod2()
IdInterface()
High Impact Categories

• All opportunities are not equivalent
• High impact categories present a potentially better impact for redesign
  – Ease of manipulation of a fair amount of code
  – Large volume of code
  – Large number of methods
  – Highly clustered clones
  – Large methods
Applying the Redesign Process

• Selected categories
  – Identical clones (1)
  – Names of parameters (2)
  – Names of local variables (2)
  – Names of methods (3)
  – Use of global variables (4)
Experimental Context

• Candidate system: SUN’s JDK 1.1.5
  – Java language
  – 145 KLOC (size)

• Platform
  – Pentium Pro 180 MHz
  – 64 Mbytes RAM
  – Linux 2.0.27
Redesign Results

Partial redesign of Jdk 1.1.5.

<table>
<thead>
<tr>
<th>Candidate clones</th>
<th>120 clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redesigned clones</td>
<td>11 clusters</td>
</tr>
<tr>
<td></td>
<td>(28 methods)</td>
</tr>
<tr>
<td>Source code variation</td>
<td>+1057 lines</td>
</tr>
<tr>
<td>Percent source code variation</td>
<td>+0.7</td>
</tr>
<tr>
<td>Methods created</td>
<td>84</td>
</tr>
</tbody>
</table>
Advantages of Automatic Redesign

- Software maintainability may be increased
- Further reuse may be facilitated
- Source code reuse is made explicit
- Common parts of clones are factored
- Differences are parameterized in the shared component
- Context is decoupled
Disadvantages of Automatic Redesign

- Powerful analyses are necessary
- Many redesign opportunities occur with a very low frequency
- The size of the system can be slightly increased
Limitations

• Syntactic approach
  – Tokens
  – AST
  – Metrics

• Metrics matching
  – post-processing (DP matching)
Limitations - 2

• Semantics
  – Clone definition
  – Method
    • Given a definition, then search
    • Given human matched clones, then compare algorithms

• Good precision, but moderate recall
State of art

• In recent years, new relevant research contributions were published
• Several interesting surveys can be found in the literature together with a list of problems many of them are still open
Surveys

• Publications and open problems


Surveys - 2

- http://students.cis.uab.edu/tairasr/clones/literature/
Topics

• Scalability of clone detection approaches
  – Complexity
  – Execution time performance
  – Memory usage
  – Incremental approaches
• Clone visualization
Topics - 2

• Latent semantic analysis
• Prefix and suffix trees
• Clone identification using program dependence graphs
• Bugs caused by inconsistent modifications
  – Clones in a systems
  – Fragments in several software releases
Topics - 3

• Empirical studies
  – Somehow controversial empirical findings
  – Evaluation of clone detection approaches

• Web applications

• Evolution aspects
  – Evolution of clones and their lifetime over several versions of a system
  – Software evolution by computing some similarity measures between versions
  – Product lines
  – Genealogies
  – Origin analysis
Topics - 4

• Domain specific clones
  – Automotive
  – Business

• Clone management
  – Harmfulness of clones

• Intellectual property issues
  – License infringement
  – Plagiarism detection

• Malware analysis
  – Similarity of malicious code
Topics - 5

- Hybrid approaches
- Scripting languages
- Canonical representation of clones used for matching and comparison
- Similarity of structured software artifacts
  - Trees
    - Kernel based approaches
  - Graphs
- High precision hashing schemes
Topics - 6

• Specialized workshops and conferences
  – 4th IEEE International Workshop on Software Clones (IWSC 2010)
  – 7th IEEE Working Conference on Mining Software Repositories (MSR 2010)
  – 3rd ACM Workshop on Refactoring Tools (WRT'09)
Confirmed points

- Taxonomies of clones
- Taxonomies of differences
  - Tree based
  - Priorities
- Re-factoring
- Trade-off precision and recall vs. performance
  - Need for fast performance
  - Scalability
Confirmed points - 2

• Metrics based approaches
  – Similarity measures (similarity functions) are useful
  – Precise and efficient with respect to memory usage and execution time performance
  – Robust, and stable, and inherently comparable against thresholds
  – Hashing on metrics is intrinsically easy to be incrementally computed
  – Possible agile integration in Integrated Development Environments (IDE)
Confirmed (negative) point

• Optimal choice of representative for computing differences
  – Multiple pattern alignment
  – Many clones are very similar
  – Optimal strategy was not worth the computational cost
Current issues

- Formal definition of clones
  - Representations
    - Strings
    - Tokens
    - Syntactic
    - Semantic
    - Etc.
Current issues - 2

• Formal definition of clones (cntd)
  – Similarity definitions
    • Representation
    • Metrics
    • Feature-based
    • Behavior
    • Semantics
      – Definitions and measures are open problems
  • Execution similarity
    – Traces
    – Profiles
    – Dynamic analyses
  – Distances and thresholds
Current issues - 3

• Types III and IV clones
  – Taxonomies
  – Differences
    • Patterns of uninteresting clones
      – Low interest automatic filtering
  – Statistics
    • Statistics of intentional clones
      – Frequencies
      – Intentions
  – Multilingual flexibility
Current issues - 4

- Applications to software engineering
  - Refactoring
  - Development process
  - Management
    - Harmfulness of clones
    - Impact of code clones on software quality
    - Inconsistent modifications
  - Industrial adoption
Current issues - 5

• Evolution of clones
  – Evolution in industrial systems
  – Evolution and the development organization
  – Reliable predictors of clone evolution

• Empirical studies
  – Reference data bases
  – Comparison data
Current issues - 6

• Standard benchmarks
  – Pairs
  – Classes
  – Boolean data
  – Degrees of confidence
  – Relevance ratings
  – Type III and IV measures of similarity
  – Extensibility
    • More systems
    • More languages
Current issues - 7

• Need for effective time and memory performance
  – Low complexity algorithms
  – Scalability to large software
  – Ultra-scalable approaches
  – Distributed approaches
CLone ANalysis (CLAN) tools

• Family of software similarity analysis and related applications
  – Metrics
  – Syntactic
  – Centroids
  – DP matching
CLAN applications

- Clone detection
- Software evolution
  - Analysis of versions and releases
- Plagiarism detection
- Refactoring
  - Re-design
  - Libraries identification
- Development process
• Clone detection
  – Cloning ratio
    • % of clones in a system using different and increasing thresholds
    • Take “noise” around the origin of metrics into account
CLAN applications - 3

• Software evolution
  – Comparison between different versions of the same system
    • Subsequent versions
    • Reference versions
  – Issues
    • Define fragment identification
      – A function signature is not enough, neither is a position in the file system
    • Code motion across files and directories
    • Systematic renaming
• Software evolution (cntd)
  – Comparison between different versions of the same system
    • Subsequent versions
    • Reference versions
• Plagiarism Detection
  – Comparison of sets of syntactic blocks
  – Spectral analysis of similarity
    • Increasing thresholds
    • Spectral shape parameters are computed
  – Projects are ranked by similarity spectrum
  – The most similar projects are considered as candidates for plagiarism
• Refactoring
  – Redesign
    • Pattern based re-design
    • Automatic source code synthesis
    • Make the reuse explicit
  – Libraries identification
• Development Process
  – Problem mining
    • Issues
      – Bugs may be propagated by copies
      – Bug fixes may not be propagated in copies
    • Approach
      – If a modification is required in a code fragment, check also clones for modification opportunities (useful for bug fixes)
• Development Process (cntd)
  – Preventive control
    • Issue
      – Control the clone propagation
    • Approach
      – When a code fragment is delivered, check for existing similar fragments to prevent clones from being added to a system (if appropriate)
CLAN current research

- Definition of clones
- Type III (similar) and simple type IV (semantic) clones
  - Detection algorithms
  - Performance and scalability
  - Classification
  - Taxonomies
  - Statistics
  - Frequent patterns
• Properties of clone detection
  – Scalability
  – Performance
    • Time
    • Memory
    • Asymptotic
    • Practical
  – Incremental aspects
  – Robustness (tolerance to less frequent variations of representation patterns)
• Properties of clone detection (cntd)
  – Stability (small variations imply small differences in output)
  – Precision
    • Discretization error under thresholds
  – Recall
  – Clone maximality issues under thresholds
    • Clone redundancy
    • Clone subsumption
• Architectural analysis
  – Similarity + AST projection
  – API similarity
    • UML similarity
    • API rationalization
  – Refactoring
    • Assisted re-factoring

• Software evolution
  – Inconsistent modifications of clones
  – Taxonomy of some identifiable bugs
• Inconsistent modifications of clones
  – Bug reporting
  – Consistency of replacements
  – Identifiers
    • Identifier vs. constant
    • Identifier vs. identifier
  – Numeric constants
  – String constants
    • User messages
    • Error messages
• Inconsistent modifications of clones (cntd)
  – Patterns of inconsistent changes
  – Statistics on relevance
CLAN current research - 7

• Plagiarism detection
  – Spectral clone analysis
  – Relation with clone normalization problem
  – Web services

• Parallel approaches
  – Graphical Processing Unit (GPU)

• Distributed approaches
• Distribution of CLAN
  – Licensing parsers
    • Many sources
  – Licensing software (university and students issues)
CLAN current limitations

• Discretization error in the multi-dimensional space of fragments
  – Thresholds and neighboring classes

• False positives exist (noise)
  – Noise increases with increasing thresholds
• Limits of metric based approaches
  – Difference between metrics equivalence and representation distances
  – Similarity of metrics doesn't necessarily imply representation similarity of clone
  – The converse hold (somehow): similarity of representation implies similarity of metrics
CLAN further research

- Increasing the precision
  - Increasing the number of highly discriminating dimensions
  - High data dimensionality
  - Complexity issues
  - Neighboring clusters
  - Dimensions compression

- Increasing the recall rate
  - Increasing the thresholds
    - Precision issues
Conclusions

• A perspective on the WCRE 2000 paper has been presented
• Advancement during the last 10 years have been briefly outlined
• Current status of CLAN has been described
• Some open problems and research issues have been discussed
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