2IS55 Software Evolution

Code duplication

Alexander Serebrenik

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

Assignment 3: Reminder

- Deadline: Tonight at midnight
- Assignment 4 (till March 29):
  - Code duplication
  - Replication study of a scientific paper
  - More details to come

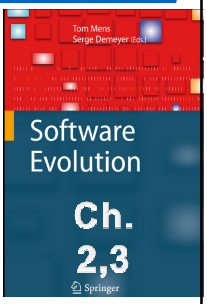
Sources

"Clone detection"

Rainer Koschke
http://www.informatik.uni-bremen.de/st/lehre/re09/softwareklone.pdf

"Program differencing"

Miryung Kim



Where are we now?

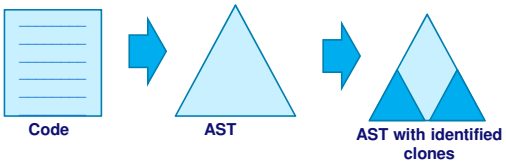
- Last week:
- Code cloning, code duplication, redundancy…
  - Type 1, 2, 3, 4 clones (more refined classif. possible)
  - Useful: reliability, reduced time, code preservation
  - Harmful: more interrelated code, more bugs
  - Ignore, eliminate, prevent, manage
  - Detection mechanisms
    - Text-based
    - Metrics-based
    - Token-based

Today

- Clone detection techniques
  - AST-based
    - [Baxter 1996]
    - AST+Tokens combined [Koschke et al. 2006]
  - Program Dependence Graph
    - [Krinke 2001]
  - Comparison of different techniques

AST-based clone detection [Baxter 1996]

- If we have a tokenizer we might also have a parser!
  - Applicability: the program should be parseable



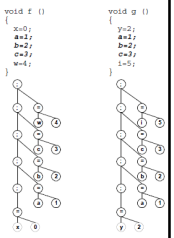
- Compare every subtree with every other subtree?
  - For an AST of n nodes: $O(n^3)$
- Similarly to text: Partitioning with a hash function
  - Works for Type 1 clones

AST-based detection

- Type 2
  - Either take a bad hash function ignoring small subtrees, e.g., names
  - Or replace identity by similarity

$$Similarity(T_1,T_2) = \frac{2 * Same(T_1,T_2)}{2 * Same(T_1,T_2) + Difference(T_1,T_2)}$$

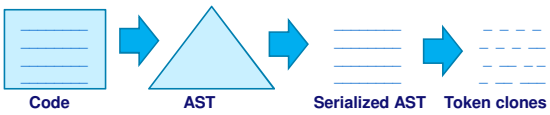
- Type 3
  - Sequences of subtrees
  - Go from Type 2-cloned subtrees to their parents
- Rather precise but still slow



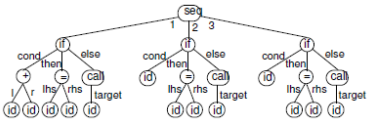
Recapitulation from the last week

- [Baker 1995]
  - Token-based
  - Very fast:
    - 1.1 MLOC, minimal clone size: 30 LOC
    - 7 minutes on SGI IRIX 4.1, 40MHz, 256 MB
- [Baxter 1996]
  - AST-based
  - Precise but slow
- Idea: Combine the two! [Koschke et al. 2006]
  - In fact they do not use [Baker 1995] but a different token-based approach

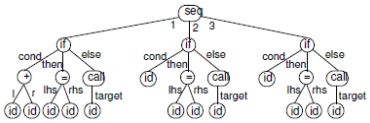
AST + Tokens [Koschke et al. 2006]




```
if x + y then a := i; else foo; end if;
if p     then a := j; else foo; end if;
if q     then z := k; else bar; end if;
```



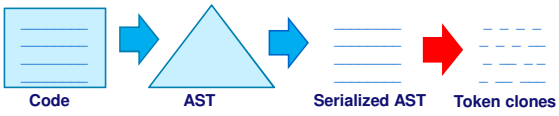
AST + Tokens [Koschke et al. 2006]



- Preorder
- Number = number of descendants

```
seq23
    if8 +2 id0 id0 =2 id0 id0 call1 id0
    if6 id0 =2 id0 id0 call1 id0
    if6 id0 =2 id0 id0 call1 id0
```


AST + Tokens [Koschke et al. 2006]

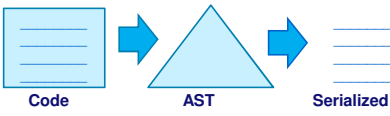



```
seq23
    if8 +2 id0 id0 =2 id0 id0 call1 id0
    if6 id0 =2 id0 id0 call1 id0
    if6 id0 =2 id0 id0 call1 id0
```

```
if6 id0 =2 id0 id0 call1 id0
```

We do not distinguish between Type 1 and Type 2

AST + Tokens [Koschke et al. 2006]




```
seq23
    if8 +2 id0 id0 =2 id0 id0 call1 id0
    if6 id0 =2 id0 id0 call1 id0
    if6 id0 =2 id0 id0 call1 id0
```

```
if6 id0 =2 id0 id0 call1 id0
```

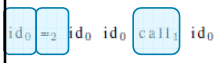
Complete syntactical unit

```
id0 =2 id0 id0 call1 id0
```

Incomplete syntactical unit

Incomplete syntactical units

- "return id ; } int id( ) { int id ;"
  - Correct as a clone but useless for reengineering
  - Should be split:
    - return id; } int id() { int id;



id_0
$=_2$ id_0 id_0
$call_1$ id_0

```
procedure cut (ts, outset) is
le := ts'first;
while le ≤ ts'last loop
  if le + tokens(le) > ts'last then
    le := le + 1;
  else
    ri := le + tokens (le) + 1;
    outset := outset ∪ {ts (le..ri−1)};
    le := ri;
  end if;
end loop
```


AST + Tokens: DIscussion

- Splitting algorithm can be updated to deal with sequences
- Compromise of recall and precision
  - Recall: % of the true clones found
  - Precision: % of clones found that are true
- Reasonably fast (faster than pure AST)

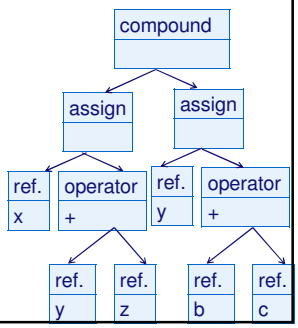
Next step

- AST is a tree is a graph
- There are also other graph representations
  - Object Flow Graph (weeks 3 and 4)
  - UML class/package/… diagrams
  - Program Dependence Graph
- These representations do not depend on textual order
  - { x = 5; y = 7; } vs. { y = 7; x = 5; }

[Krinke 2001] PDG based

- Vertices:
  - entry points, in- and output parameters
  - assignments, control statements, function calls
  - variables, operators
- Edges:
  - immediate dependencies
    - target has to be evaluated before the source

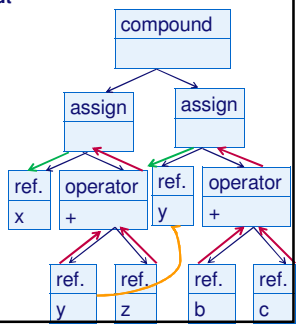
y = b + c;
x = y + z;



[Krinke 2001] PDG based

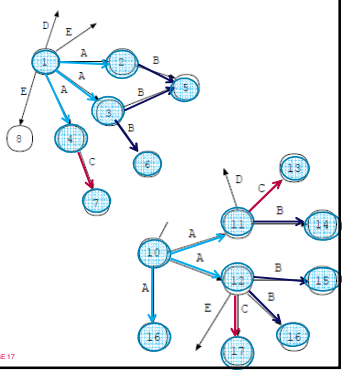
- Vertices:
  - entry points, in- and output parameters
  - assignments, control statements, function calls
  - variables, operators
- Edges:
  - immediate dependencies
  - value dependencies
  - reference dependencies
  - data dependencies
  - control dependencies
    - Not in this example

y = b + c;
x = y + z;



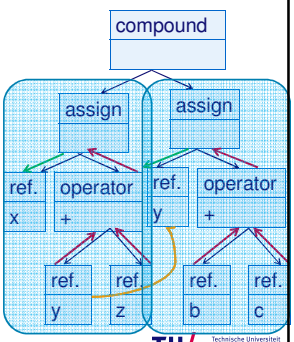
Identification of similar subgraphs – Theory

- Start with 1 and 10
- Partition the incident edges based on their labels
  - Select classes present in both graphs
- Add the target vertices to the set of reached vertices
- Repeat the process
- "Maximal similar subgraphs"



Identification of similar subgraphs – Practice

- Sorts of edges are labels
- We also need to compare labels of vertices
- We should stop after k iterations
  - Higher k ⇒ higher recall
  - Higher k ⇒ higher execution time
  - Experiment: k = 20



Clone detection techniques – what have we seen?

- Text-based
  - [Ducasse et al. 1999, Marcus and Maletic 2001]
- Metrics-based
  - [Mayrand et al. 1996]
- Token-based
  - [Baker 1995, Kamiya et al. 2002]
- AST-based
  - [Baxter 1996]
  - AST+Tokens combined [Koschke et al. 2006]
- Program Dependence Graph
  - [Krinke 2001]

And many more!

Choosing your tools: Precision / Recall

- Quality depends on scenario [Type 1, Type 2, Type 3]
- [Roy, Cordy, Koschke, Science of Comp Progr 2009]
  - Brief summary. 6 is maximal grade, 0 – minimal

			S1	S2	S3
Duploc	Ducasse	Text	4	0	2.8
Marcus and Maletic			2.6	1.8	1.6
Dude	Not in the class		4.6	0	4.4
Simian			4.3	3	0
Dup	Baker	Token	4	2.8	0
CCFinder	Kamiya		5	3.8	0.8
CloneDr	Baxter	AST	6	4.3	3.8
cpdetector	Koschke		6	3.8	0
Mayrand		Metrics	3.3	4.8	3.4
Duplix	Krinke	Graph	5	4.8	4

Which technique/tool is the best one?

- Quality
  - Precision
  - Recall
- Usage
  - Availability
  - Dependence on a platform
  - Dependence on an external component (lexer, tokenizer, …)
  - Input/output format
- Programming language
- Clones
  - Granularity
  - Types
  - Pairs vs. groups
- Technique
  - Normalization
  - Storage
  - Worst-case complexity
  - Pre-/postprocessing
- Validation
- Extra: metrics

Code duplication metrics

- Measuring allows
  - reporting to the business level
  - comparing two systems
  - comparing two versions of the same system
- Clone duplication metrics
  - Per system
    - % duplicated lines
  - Per file
    - Usually will contain clones from different groups
  - Per clone group
    - Usually will contain fragments from different files

Code duplication: File metrics

Given a file F:

- NBR (neighbor):
  - Count of files containing a cloned fragment with F
- RSA (ratio of similarity between another files):
  - % tokens covered by a clone between F and another file.
- RSI (ratio of similarity within the file):
  - % tokens covered by a clone in F.
- CVR (coverage):
  - % tokens covered by any code clone.
  - max(RSA, RSI) <= CVR <= RSA+RSI

Code duplication: Clone group metrics

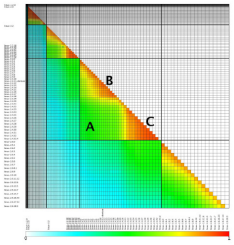
- POP (population):
  - Count of code fragments of the code clone
- NIF:
  - Count of source files that include one or more code fragments of the code clone. By definition, NIF <= POP
- RAD (radius):
  - Range of the source code fragments of a code clone in the directory hierarchy.

Clone detection - conclusions

- Many different techniques
  - Text, metrics, tokens, AST, graphs
- Advantages and disadvantages
  - Precision vs. recall
  - Suitability for the task

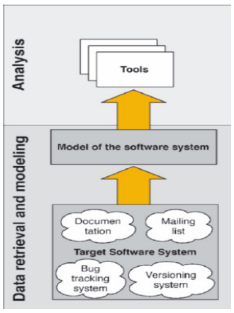
Assignment 4: Code clone coverage of an evolving system

- Measure % clone coverage between subsequent versions of a system
- Visualize using the heat map
- Discuss the patterns observed
- More details on Peach



New Topic: Mining Software Repositories

- Evolution is reflected in
  - version control systems
    - code
    - documentation
  - bug trackers
  - mail archives and forums
  - wiki
    - documentation
    - discussion
  - Twitter
  - …



Mining Software Repositories

- Goals
  - Understanding evolution
  - Predicting future phenomena
- Important topic
  - Series of lectures on different aspects
  - Today and on March 29 - program differencing
  - March 29 – version control systems (invited lecture)

Program differencing

- Why?
  - Version control
    - What have we changed since…
    - How can we merge the changes by Alice and Bob?
  - What do we need to retest?
  - What is the impact of our change?
- Formally
  - Input: Two programs
  - Output:
    - Differences between the two programs
    - Unchanged code fragments in the old version and their corresponding locations in the new
- Similar to clone detection
  - Comparison of lines, tokens, trees and graphs

Diff: Longest common subsequence

- Program: sequence of lines
- Object of comparison: line

- Comparison:
  - 1:1
  - lines are identical
  - matched pairs cannot overlap

- Technique: longest common subsequence
  - Minimal number of additions/deletions steps
  - Dynamic programming

Longest common subsequence

- Programs X (n lines), Y (m lines)
- Data structure C[0..n,0..m]
- Init: C[r,0]=0, C[0,c]=0 for any r and c

```
p0 mA (){
p1   if (pred_a) {
p2       foo()
p3   }
p4 }

X
```

```
c0 mA (){
c1   if (pred_a0) {
c2       if (pred_a) {
c3           foo()
c4       }
c5   }
c6 }

Y
```

C		c0	c1	c2	c3	c4	c5	c6
	0	0	0	0	0	0	0	0
p0	0							
p1	0							
p2	0							
p3	0							
p4	0							

Longest common subsequence

- For every r and every c
  - If X[r]=Y[c] then C[r,c]=C[r-1,c-1]+1
  - Else C[r,c]=max(C[r,c-1],C[r-1,c])

```
p0 mA (){
p1   if (pred_a) {
p2       foo()
p3   }
p4 }

X
```

```
c0 mA (){
c1   if (pred_a0) {
c2       if (pred_a) {
c3           foo()
c4       }
c5   }
c6 }

Y
```

C		c0	c1	c2	c3	c4	c5	c6
	0	0	0	0	0	0	0	0
p0	0	**1**	1	1	1	1	1	1
p1	0	1	1	**2**	2	2	2	2
p2	0	1	1	2	**3**	3	3	3
p3	0	1	1	2	3	**4**	**4**	**4**
p4	0	1	1	2	3	**4**	**5**	**5**

Longest common subsequence

- Start with r=n and c=m
- backTrace(r,c)
  - If r=0 or c=0 then “”
  - If X[r]=Y[c] then backTrace(r-1,c-1)+X[r]
  - Else
    - If C[r,c-1] > C[r-1,c] then backTrace(r,c-1) else backTrace(r-1,c)

```
p0 mA (){
p1   if (pred_a) {
p2       foo()
p3   }
p4 }

X
```

```
c0 mA (){
c1   if (pred_a0) {
c2       if (pred_a) {
c3           foo()
c4       }
c5   }
c6 }

Y
```

C		c0	c1	c2	c3	c4	c5	c6
	0	0	0	0	0	0	0	0
p0	0	**1**	1	1	1	1	1	1
p1	0	1	1	**2**	2	2	2	2
p2	0	1	1	2	**3**	3	3	3
p3	0	1	1	2	3	**4**	**4**	**4**
p4	0	1	1	2	3	**4**	**5**	**5**

Longest common subsequence

- Start with r=n and c=m
- backTrace(r,c)
  - If r=0 or c=0 then “”
  - If X[r]=Y[c] then backTrace(r-1,c-1)+X[r]
  - Else
    - If C[r,c-1] > C[r-1,c] then backTrace(r,c-1) else backTrace(r-1,c)

```
p0 mA (){
p1   if (pred_a) {
p2       foo()
p3   }
p4 }

X
```

```
c0 mA (){
c1   if (pred_a0) {
c2       if (pred_a) {
c3           foo()
c4       }
c5   }
c6 }

Y
```

C		c0	c1	c2	c3	c4	c5	c6
	0	0	0	0	0	0	0	0
p0	0	**1**	1	1	1	1	1	1
p1	0	1	1	**2**	2	2	2	2
p2	0	1	1	2	**3**	3	3	3
p3	0	1	1	2	3	**4**	**4**	**4**
p4	0	1	1	2	3	**4**	**5**	**5**

Diff: Summarizing

- Comparison:
  - 1:1, identical lines, non-overlapping pairs

- Technique: longest common subsequence

- What kind of code modifications will diff miss?
  - Copy & paste: apple ⇒ applple
    - 1:1 is violated
  - Move: apple ⇒ aplep

More than lines: AST Diff [Yang 1992]

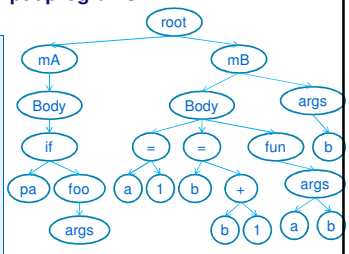
- **Construct ASTs for the input programs**

```
p0 mA (){
p1   if (pa) {
p2       foo()
p3   }
p4 }
p5 mB (b) {
p6   a = 1
p7   b = b+1
p8   fun(a,b)
p9 }
```

X

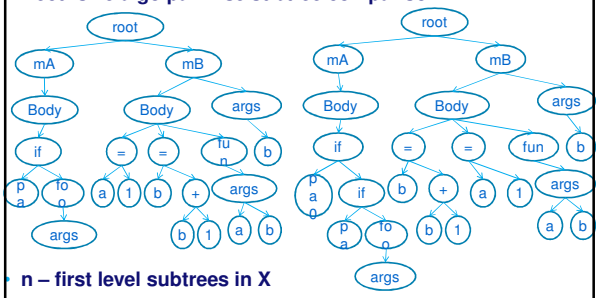
```
c0 mA (){
c1   if (pa0) {
c2       if (pa) {
c3           foo()
c4       }
c5   }
c6 }
c7 mB (b) {
c8     b = b+1
c9     a = 1
c10    fun(a,b)
c11 }
```

Y



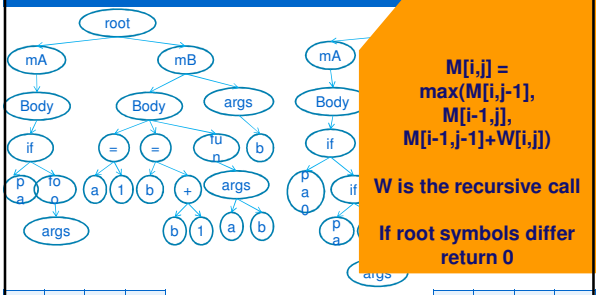
More than lines: AST Diff [Yang 1992]

- **Recursive algo pairwise subtree comparison**



- **n – first level subtrees in X**
- **m – first level subtrees in Y**
- **Array: M[0..n, 0..m]**

More than lines: AST Diff [Yang 1992]



M[i,j] = max(M[i,j-1], M[i-1,j], M[i-1,j-1]+W[i,j])

W is the recursive call

If root symbols differ return 0

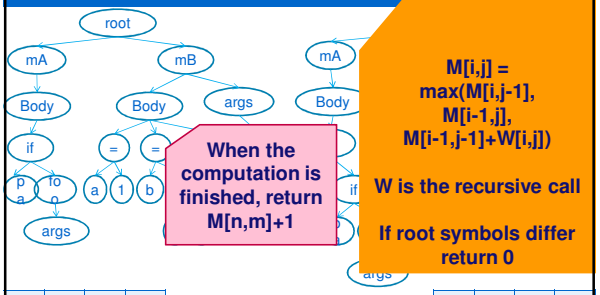
M	0	mA	mB
0	0	0	0
mA	0		
mB	0		

M	0	Body
0	0	0
Body	0	

M	0	if
0	0	0
if	0	

M	0	pa0	if
0	0	0	0
pa	0		
foo	0		

More than lines: AST Diff [Yang 1992]



When the computation is finished, return M[n,m]+1

M[i,j] = max(M[i,j-1], M[i-1,j], M[i-1,j-1]+W[i,j])

W is the recursive call

If root symbols differ return 0

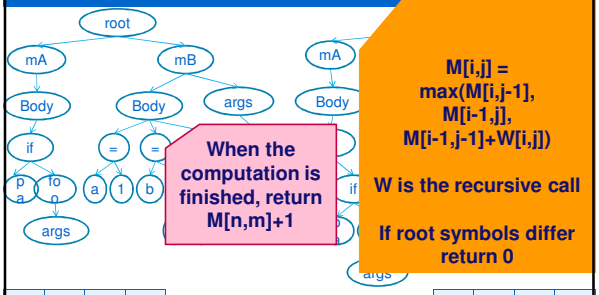
M	0	mA	mB
0	0	0	0
mA	0		
mB	0		

M	0	Body
0	0	0
Body	0	

M	0	if
0	0	0
if	0	1

M	0	pa0	if
0	0	0	0
pa	0	0	0
foo	0	0	0

More than lines: AST Diff [Yang 1992]



When the computation is finished, return M[n,m]+1

M[i,j] = max(M[i,j-1], M[i-1,j], M[i-1,j-1]+W[i,j])

W is the recursive call

If root symbols differ return 0

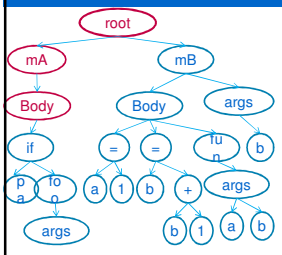
M	0	mA	mB
0	0	0	0
mA	0	3	
mB	0		

M	0	Body
0	0	0
Body	0	2

M	0	if
0	0	0
if	0	1

M	0	pa0	if
0	0	0	0
pa	0	0	0
foo	0	0	0

More than lines: AST Diff [Yang 1992]




```
p0 mA (){
p1   if (pa) {
p2       foo()
p3   }
p4 }
p5 mB (b) {
p6   a = 1
p7   b = b+1
p8   fun(a,b)
p9 }
```

X

```
c0 mA (){
c1   if (pa0) {
c2       if (pa) {
c3           foo()
c4       }
c5   }
c6 }
c7 mB (b) {
c8     b = b+1
c9     a = 1
c10    fun(a,b)
c11 }
```

Y

M	0	mA	mB
0	0	0	0
mA	0	3	
mB	0		

Continuing the process

X	Y
p0 **mA ()**{	c0 **mA ()**{
p1 if (pa) {	c1 if (pa0) {
p2 foo()	c2 if (pa) {
p3 }	c3 foo()
p4 }	c4 }
p5 **mB (b)** {	c5 }
p6 **a = 1**	c6 }
p7 **b = b+1**	c7 **mB (b)** {
p8 **fun(a,b)**	c8 **b = b+1**
p9 }	c9 **a = 1**
	c10 **fun(a,b)**
	c11 }

- **Advantages**
  - **Respect the parent-child relations**
  - **Ignore the order between siblings**
- **Disadvantages**
  - **Sensitive to tree level changes ("if (pa)")**
  - **Ignore dependencies such as data flow, etc**

Even more about the dataflow

```
Program P
public class A {
    void m1() {…}
}
public class B extends A {
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E2 {}
public class D {
    void m3(A a) {
        a.m1();
        try {
            throw new E3();
        }
        catch (E2 e) {…}
        catch (E1 e) {…}
    }
}
```

```
Program P'
public class A {
    void m1() {…}
}
public class B extends A {
    void m1() {…}
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E1 {}
public class D {
    void m3(A a) {
        a.m1()
        try {
            throw new E3();
        }
        catch(E2 e) {…}
        catch(E1 e) {…}
    }
}
```

- **What part of the behaviour is affected by the change?**
  - **Different m1() is called**
  - **Different catch block is relevant**

Comparison [Apiwattanapong et al. 2007]

```
Program P
public class A {
    void m1() {…}
}
public class B extends A {
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E2 {}
public class D {
    void m3(A a) {
        a.m1();
        try {
            throw new E3();
        }
        catch (E2 e) {…}
        catch (E1 e) {…}
    }
}
```

```
Program P'
public class A {
    void m1() {…}
}
public class B extends A {
    void m1() {…}
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E1 {}
public class D {
    void m3(A a) {
        a.m1()
        try {
            throw new E3();
        }
        catch(E2 e) {…}
        catch(E1 e) {…}
    }
}
```

- **Compare P and P', determine matching classes and interfaces, add the pairs to C or I**
  - **matching = fully qualified names coincide**
  - **No match = record as added/removed class or interface**

Comparison [Apiwattanapong et al. 2007]

```
Program P
public class A {
    void m1() {…}
}
public class B extends A {
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E2 {}
public class D {
    void m3(A a) {
        a.m1();
        try {
            throw new E3();
        }
        catch (E2 e) {…}
        catch (E1 e) {…}
    }
}
```

```
Program P'
public class A {
    void m1() {…}
}
public class B extends A {
    void m1() {…}
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E1 {}
public class D {
    void m3(A a) {
        a.m1()
        try {
            throw new E3();
        }
        catch(E2 e) {…}
        catch(E1 e) {…}
    }
}
```

- **For every pair in C or I record matching methods in M**
  - **matching = fully qualified names coincide**
  - **No match = record as added/removed method**

Comparison [Apiwattanapong et al. 2007]

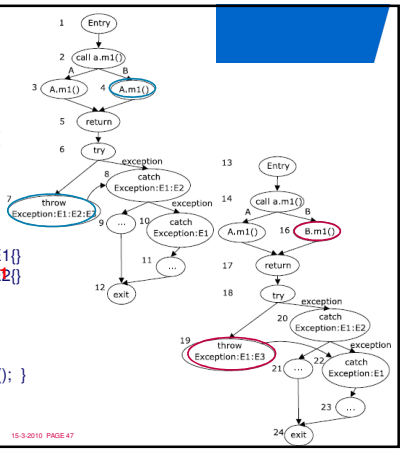
```
Program P
public class A {
    void m1() {…}
}
public class B extends A {
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E2 {}
public class D {
    void m3(A a) {
        a.m1();
        try {
            throw new E3();
        }
        catch (E2 e) {…}
        catch (E1 e) {…}
    }
}
```

```
Program P'
public class A {
    void m1() {…}
}
public class B extends A {
    void m1() {…}
    void m2() {…}
}
public class E1 extends Exception {}
public class E2 extends E1 {}
public class E3 extends E1 {}
public class D {
    void m3(A a) {
        a.m1()
        try {
            throw new E3();
        }
        catch(E2 e) {…}
        catch(E1 e) {…}
    }
}
```

- **For every pair (m, m') of methods in M**
  - **Build enhanced control flow graphs for m and m'**
- **Enhanced control flow graph**
  - **Traditional "control flow graph" + OO-specific enhancements**

ECFG

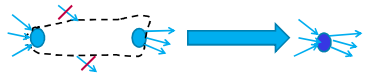
```
public class A {
    void m1() {…}
}
public class B extends A {
    void m1() {…}
    void m2() {…}
}
public class E1 extends
    Exception{}
public class E2 extends E1{}
public class E3 extends E2{}

public class D {
    void m3(A a) {
        a.m1()
        try { throw new E3(); }
        catch(E2 e) {…}
        catch(E1 e) {…}
}
```



How can we compare ECFGs?

- Structure preservation
  - Simplify each one of the ECFGs using reduction rules

Hammock



  - Recursively compare the simplified versions
    - Individual nodes: labels should be the same
    - Aggregated nodes: % matched individuals > threshold
    - No match found: try to match using lookahead
      - Allows matching at different aggregation levels
  - Record whether the nodes have been matched
    - (c,c',"unchanged") vs. (c,c',"modified")

Evaluation: Retesting

- Given:
  - Code: v_1, v_2, v_3, v_4 and a test suite for v_1 (~60% coverage)
- Process
  - Run T on v_1, collect nodes covered by T
  - Calculate differences $v_1 \leftrightarrow v_i$ and estimate coverage
    - (n,n', "unch.") ⇒ n' is covered by the same test case as n
    - (n,n', "modified")
      - Go for the predecessors q' of n' until
        - Either q' is a branch⇒ n' is not covered
        - Or (q,q', "unch") for some q ⇒ n' is covered by all test cases covering q
  - Run T on v_i to check whether the estimates are correct

Evaluation

Pair	Number of Nodes	Avg. Covered	Avg. Correct/ Test Case	Correct/ Test Suite
v1,v2	22026	12591.75	98.57	97.17
v1,v3	22063	12620.75	98.46	97.17
v1,v4	22315	12661.23	98.03	96.20

- Number of nodes in v_i
- Avg. covered – average # nodes covered by a test case
- Avg. correct / Test case – # nodes correctly estimated as being covered by a test case, averaged over all test cases
- Correct / Test suite – for entire suite

JDiff - summary

- Quality of estimates decreases if many changes become larger
- Two parameters: lookahead and threshold
  - Threshold = constant ⇒ larger lookahead = more time
  - Lookahead = constant ⇒
    - Threshold = 0 much faster than Threshold > 0
    - The actual value of threshold is of no importance
- CFG matching with special OO extensions
- Flexible (parameterized)
- Efficient and precise

Conclusion

- Today:
  - Advanced code cloning techniques (AST, graphs)
  - Code cloning metrics
  - Mining software repositories – setting up the scene
  - Program differencing techniques (text, AST, graphs)
- Next week
  - Advanced differencing techniques (groups)
  - Invited talk: Organization of version control systems