Automated Software Engineering Research Group @NCSU

Evolving Testing and Analysis for Evolving Software

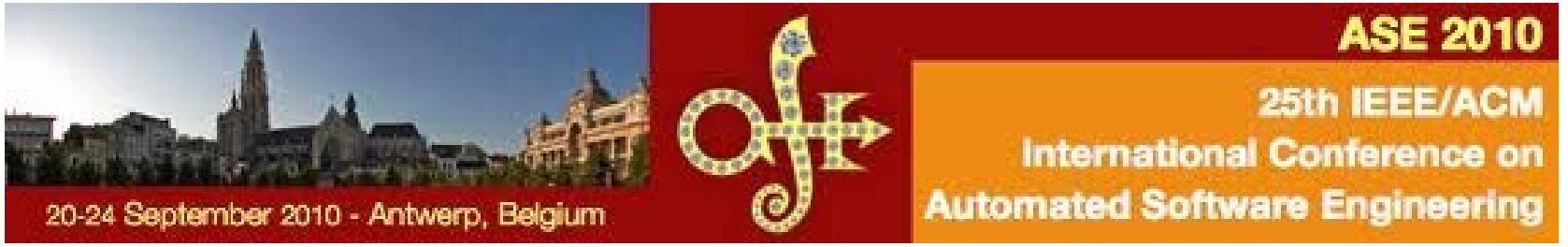
From Ivory Tower to Real World

Tao Xie

Peking University (2011-2012), China
North Carolina State University
Raleigh, NC, USA

In Collaboration with Microsoft Research Redmond/Asia, and Students@NCSU ASE Group

Automation in Software Engineering



Automated Software Engineering Research Group @NCSU

ASP

Automation in Software Testing

ACM SIGSOFT International Symposium on Software Testing and Analysis

Dagstuhl Seminar 10111

Practical Software Testing: **Tool Automation** and **Human Factors**

ICSE Papers: Industry vs. Academia

OSDI 2008 26% vs. xSE ?%

Developers, Programmers, Architects Among All Attendees

ICSE 2009 Keynote

ICSM 2011 Keynote

average 1976-1994

AC 56%

IND 44%

average 1995-2008

AC 83%

IND 17%

Source© Carlo Ghezzi

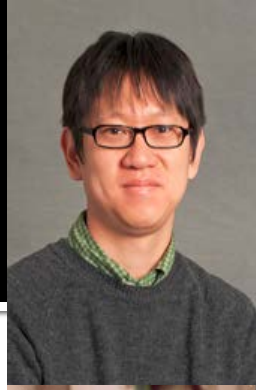
"Are Automated Debugging [Research] Techniques Actually Helping Programmers?"

- 50 years of automated debugging research
  - N papers → only 5 evaluated with actual programmers

> "Programmers have been waiting a long time for usable automated debugging tools, and we have already gone a long way from the early days of debugging. We believe that, to further advance the state of the art in this area, we must steer research towards more promising directions that take into account the way programmers actually debug in real scenarios."

[ISSTA11 Parnin&Orso]

Are Regression Testing [Research] Techniques Actually Helping Industry?



- Likely most studied testing problems
  - N papers

"However, empirical evaluation and application of regression testing techniques at industrial level seems to remain limited [182]. Out of the 159 papers listed in Table IV, V, VI and VII, only 31 papers list a member of industry as an author or a co-author. More importantly, only 12 papers consider industrial software artefacts as a subject of the associated empirical studies [68, 69, 88, 99–102, 104–106, 126, 147]. This suggests that a large scale industrial uptake of these techniques has yet to occur."

[STVR11 Yoo&Harman]

From Ivory Tower to Real World

Unsuccessful cases/experiences on tech transfer/adoption

Learning by Negative Examples

Successful cases/experiences on tech transfer/adoption

Learning by Positive Examples

Using Industrial Artifacts != Technology Adoption

Outline

- Play Around Industrial Tool
  - Parasoft Jtest → Rostra [ASE 04]
- Play Within Industrial Tool
  - Microsoft Research Pex → Fitnex [DSN 09]
- Advise Industrial Tool Developers
  - Microsoft Research Pex For Fun → [CSEE&T 11 Tut]
- Engage Target Users
  - Microsoft Research Asia Software Analytics Group

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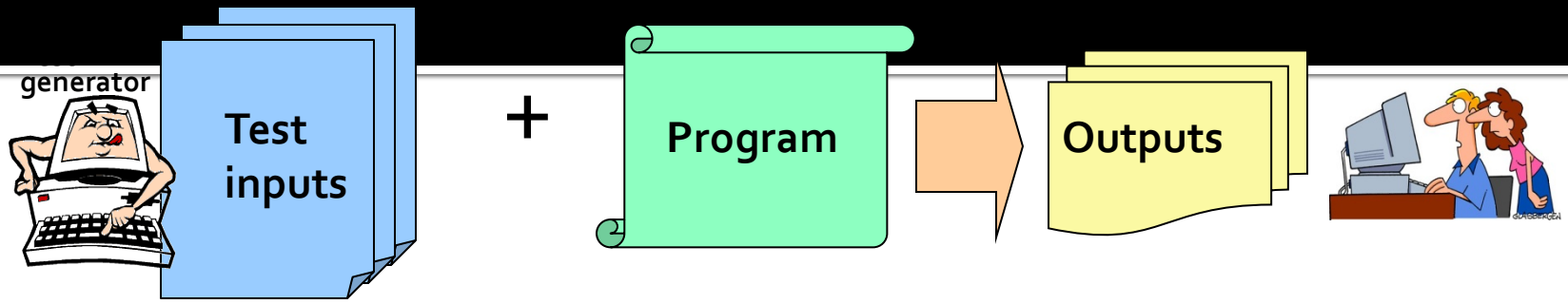
Binary Search Tree Example

```
public class BST implements Set {
  Node root;
  int size;
  static class Node {
    int value;
    Node left;
    Node right;
  }
  public void insert (int value) { … }
  public void remove (int value) { … }
  public bool contains (int value) { … }
  public int  size () { … }
}
```

Example Generated Tests




```
Test 1 (T1):
 BST t1 =
    new BST();
 t1.insert(2);
 t1.insert(1);
 t1.remove(1);
 t1.insert(3);
 t1.size();
```

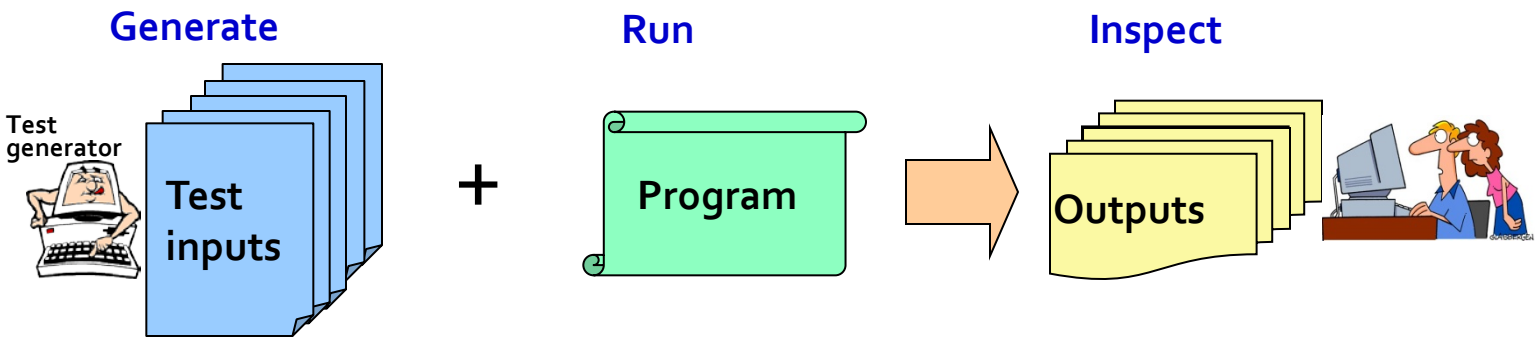
```
Test 2 (T2):
 BST t2 =
    new BST ();
 t2.insert(2);
 t2.insert(3);
```

```
Test 3 (T3):
 BST t3 =
    new BST ();
 t3.insert(2);
 t3.insert(1);
 t3.size();
```

Each test has a method sequence on the objects of the class.

Defining Redundant Tests

- Test *T* is redundant w.r.t. the existing tests if *T* exercises no new program behavior (thus, no new bug)
- Difficulties with redundant tests
  - costly to generate, run, and inspect them
  - may provide false confidence



- Rostra characterizes behavior using input values
  - identify and remove redundant tests

Previous Approaches

- Behavior characterized using code coverage (e.g., statements, branches)
  - False positives: remove many non-redundant tests
  - Reduced test suite can be dramatically worse w.r.t. fault detection capability [Rothermel et al. 98, Jones&Harrold 03]

- Behavior characterized using method sequence
  - False negatives: fail to remove many redundant tests
  - Adopted by most existing test generation tools

```
Test 1:
BST t1 = new BST();
t1.size();
```

```
Test 2:
BST t2 = new BST();
t2.size();
t2.size();
```

Example Generated Tests

```
Test 1 (T1):
 BST t1 =
    new BST();
 t1.insert(2);
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```
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 t3.insert(2);
 t3.insert(1);
 t3.size();
```

Approach using method sequence removes **no tests**

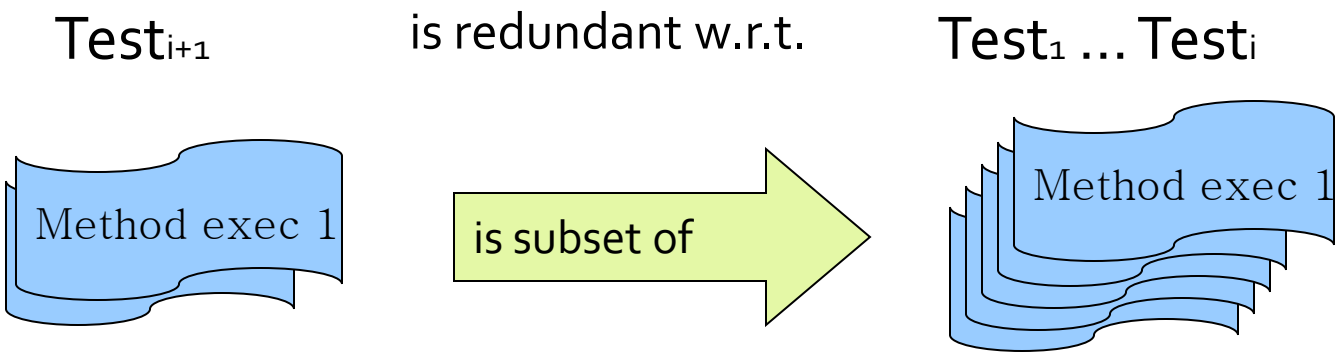
Rostra removes **T2 and T3** because T2 and T3 are redundant w.r.t. T1

Rostra's Rationale for Defining Redundant Tests

- Focus on each method execution individually
- Unnecessary to test a method with the same inputs (same inputs $\Rightarrow$ same behavior)
  - deterministic method execution: no randomness, no multithreading interaction
  - method inputs: incoming program states
    - receiver-object state: transitively-reachable-field values
    - arguments
    - accessed static fields

Redundant Test Defined

- Running a test produces a set of method executions
- A test is redundant w.r.t. a test suite
  - if the method executions produced by the test is a subset of the method executions produced by the test suite



Detecting Redundant Tests

exercised

```
Test 1 (T1):
BST t1 =
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t1.insert(2);
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t1.remove(1);
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t1.size();
```

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Test 2 (T2):
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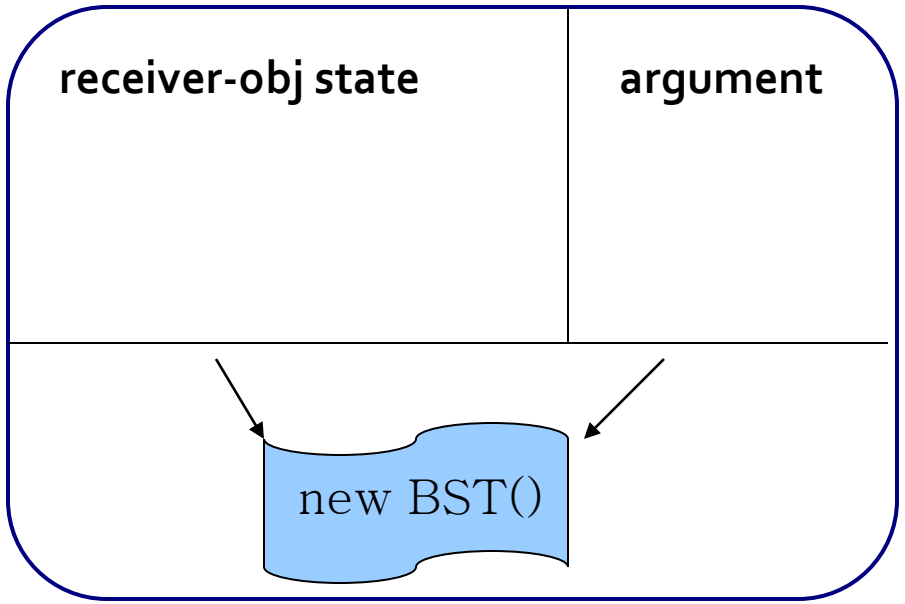
```

Method Exec



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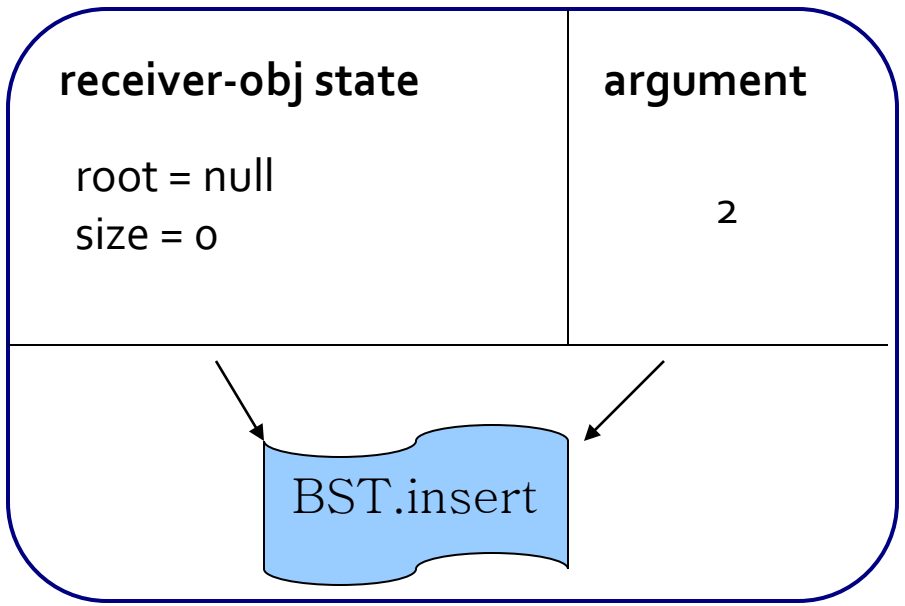

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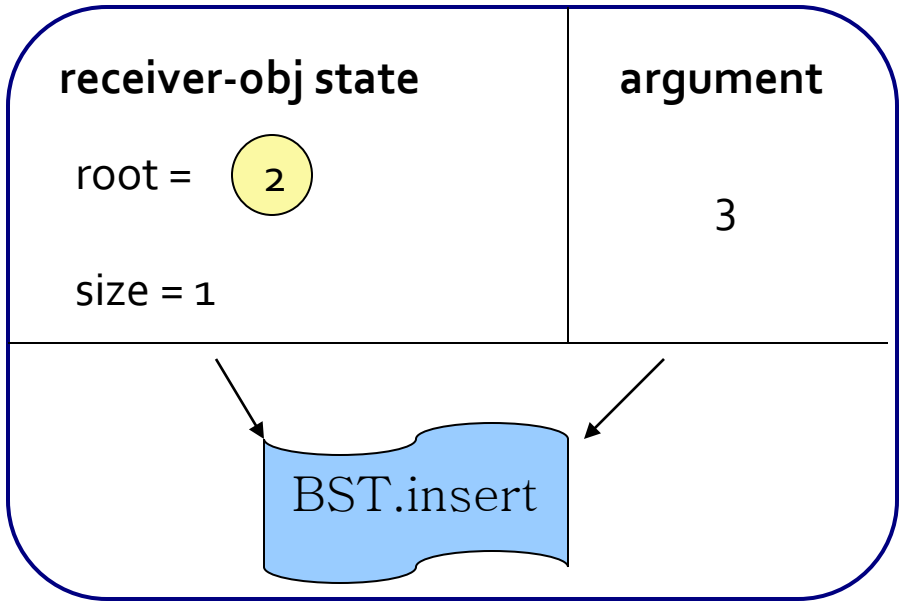

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```

```
Test 2 (T2):
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 t2.insert(3);
```

Test 2 is redundant w.r.t Test 1!

Evaluation Results [ASE 04]

- Industry standard tool adopting previous approach based on method sequences
  - Parasoft Jtest 4.5 www.parasoft.com
    - Generate tests with method-call lengths up to three
- Use Jtest to generate tests for 11 Java classes from various sources (complex data structures)
- Apply Rostra on the generated tests

- 90% of generated tests are redundant!
- Minimized tests preserve the same code (branch) coverage and seeded-bug coverage

Industry Impact — Parasoft Jtest

- People do use Jtest
  - Recognized with numerous awards, including Jolt Product Excellence Award and JDJ Editor's Choice Award in 2004; adopted by thousands of development teams worldwide.

    — businesswire.com

- But don't love its test generation
  - "I can't think of anyone telling me that they love Jtest's test-generating feature."

    —Joe Rainsberger, JUnit book author, 02/05@junit user mailing list

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Parasoft VP later notified us that Parasoft Jtest 6.0 had fixed the test redundancy issue identified by us

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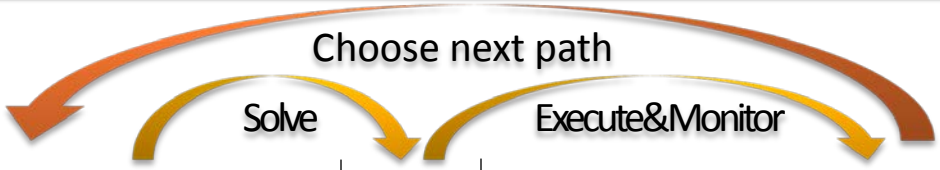
Dynamic Symbolic Execution

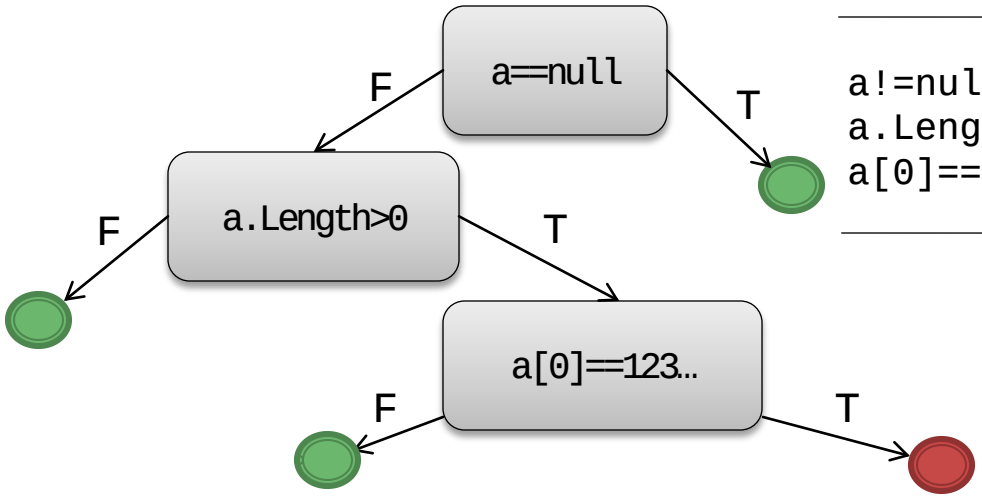
Code to generate inputs for:

```
void CoverMe(int[] a)
{
  if (a == null) return;
  if (a.Length > 0)
    if (a[0] == 1234567890)
      throw new Exception("bug");
}
```



Constraints to solve	Data	Observed constraints
	null	a==null
a!=null	{}	a!=null && !(a.Length>0)
a!=null && a.Length>0		
a!=null && a.Length>0 && a[0]==1234567890	{123..}	a!=null && a.Length>0 && a[0]==1234567890

Negated condition



Done: There is no path left.

Challenges of DSE

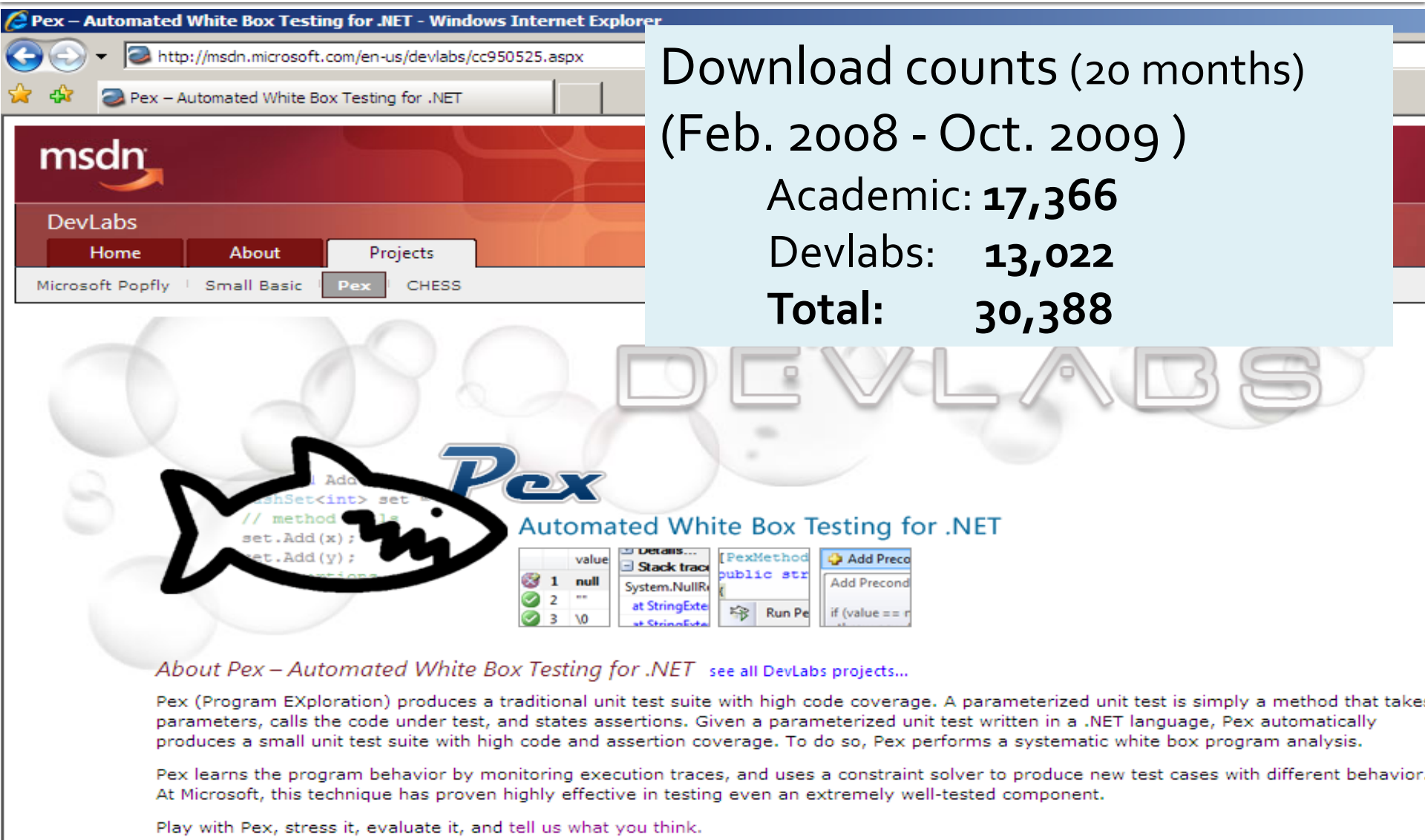
- Loops
  - **Fitnex [DSN 09]**
- Method sequences
  - MSeqGen [ESEC/FSE 09], Seeker [OOPSLA 11]
- Environments
  - Database [ASE 09-sp, ASE 11], Cloud [IEEE Soft 12]

Opportunities

- Regression testing [ISSTA 11]
- Developer guidance (cooperative testing) [ICSE 11]

Pex on MSDN DevLabs

Incubation Project for Visual Studio



Download counts (20 months)
(Feb. 2008 - Oct. 2009)

Academic: **17,366**

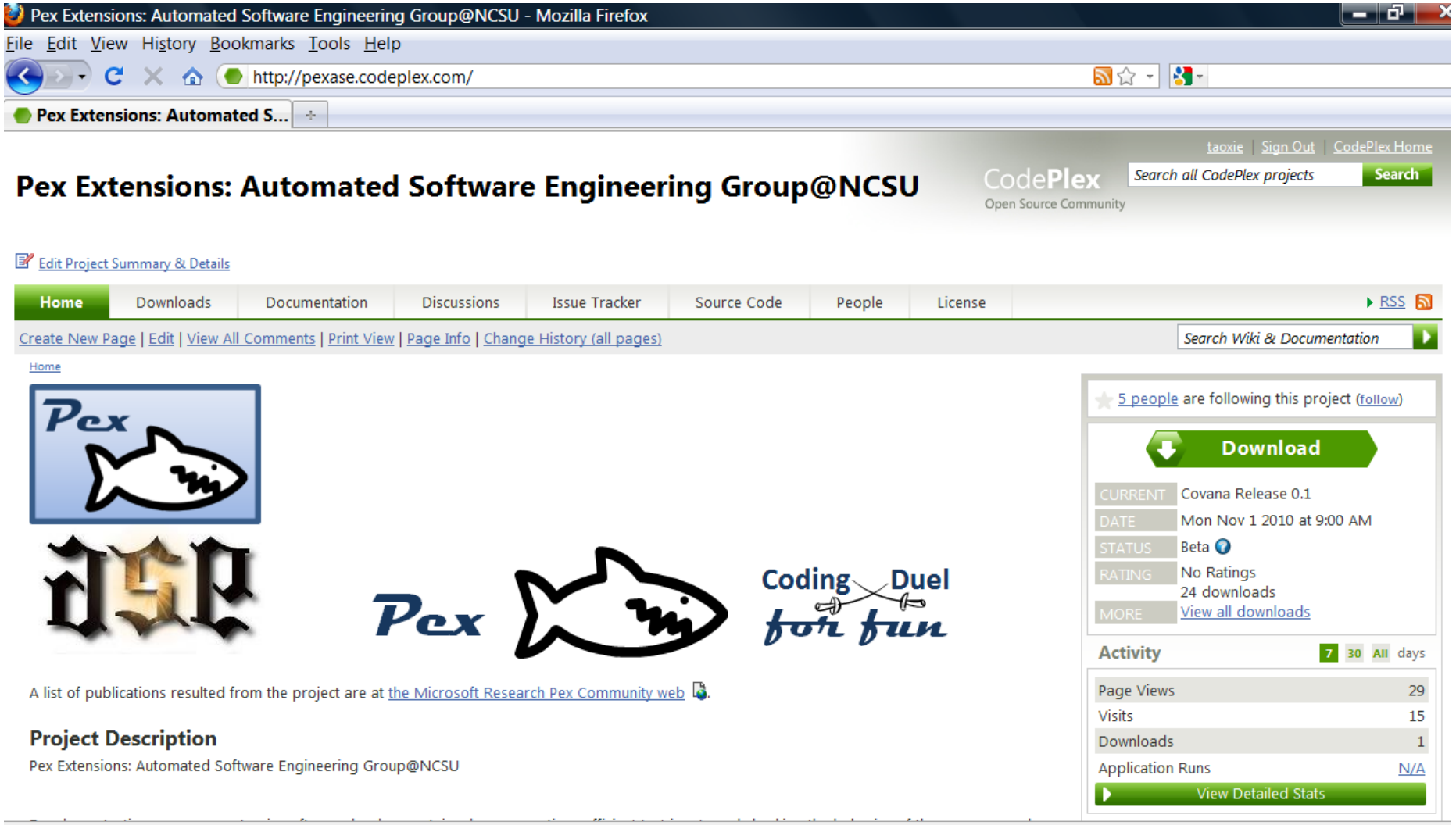
Devlabs: **13,022**

Total: 30,388

Open Source Pex extensions

http://pexase.codeplex.com/

Publications: http://research.microsoft.com/en-us/projects/pex/community.aspx#publications



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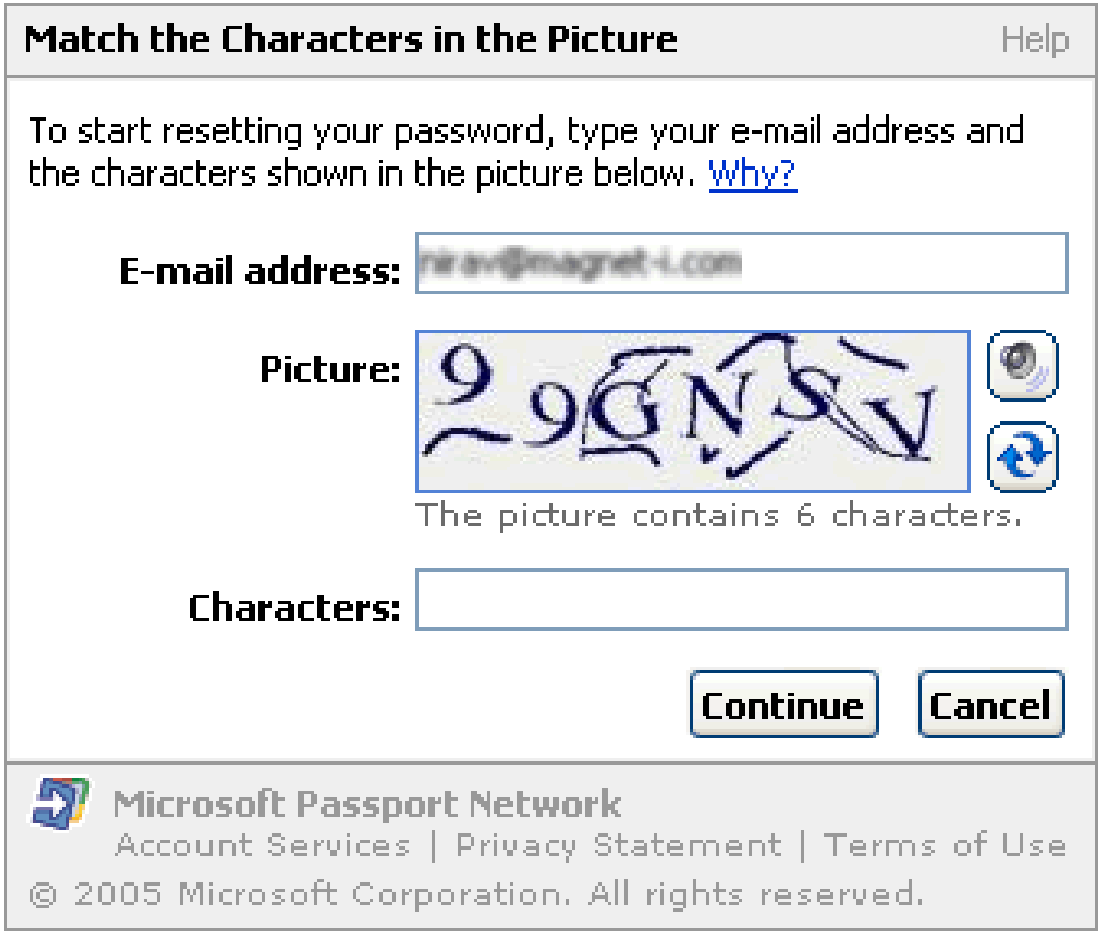
Tools Help Human So Far

- **When are Tools Worse Than Human?**

CAPTCHA

"**C**ompletely **A**utomated **P**ublic **T**uring test to tell **C**omputers and **H**umans **A**part"



Automation in Software Testing

ISSTA 2011

ACM SIGSOFT International Symposium on Software Testing and Analysis

Dagstuhl Seminar 10111

Practical Software Testing: **Tool Automation** and **Human Factors**

Human Factors

Human Factors

Dagstuhl Seminar 10111

Practical Software Testing: **Tool Automation** and **Human Factors**

Human-Centric Computing in Software Engineering

The IEEE Symposium on *Visual Languages and Human-Centric Computing* (VL/HCC)

ACM Symposium on SOFTWARE VISUALIZATION
http://www.softvis.org

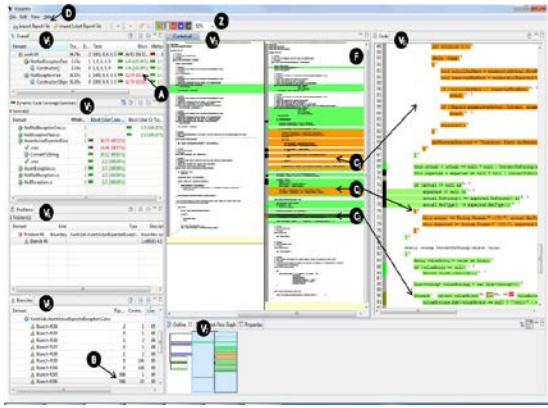
Reality Check

- **Machine is better at task set A**
  - Mechanical, tedious, repetitive tasks, …
  - Ex. solving constraints along a long path
- **Human is better at task set B**
  - Intelligence, human intention, abstraction, domain knowledge, …
  - Ex. local reasoning after a loop

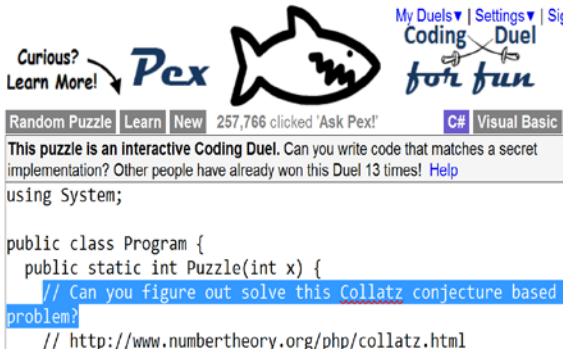
= A U B?

Cooperation Between Human and Machine: Cooperative Testing/Analysis

- **Computing**-Centric **Human**
  - Driver: tool←→ Helper: human
  - Ex. Covana [Xiao et al. ICSE 2011]



- **Human**-Centric **Computing**
  - Driver: human ←→ Helper: tool
  - Ex. Coding duels @Pex for Fun

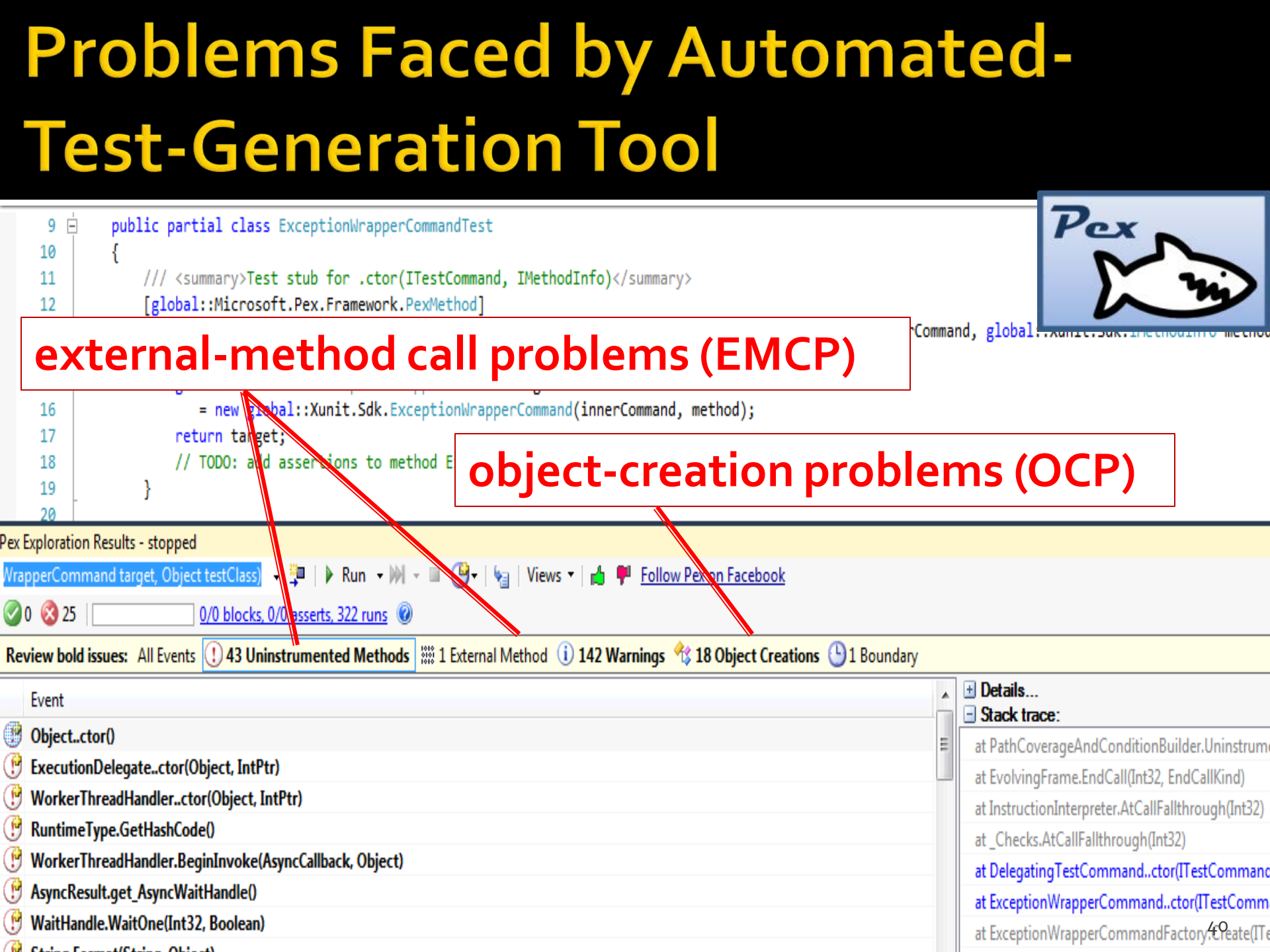


***Interfaces** are important. **Contents** are important too!*

Computing-Centric Human

- Motivation
  - Tools are often not powerful enough (at least for now)
  - Human is good at some aspects that tools are not
- **Task for Tool**: What needs to automate?
- Tool → Human
  - What difficulties does the tool face?
  - How to communicate info to the user to get her help?
- Tool ←Human
  - How does the user help the tool based on the info?
- Iterations to form feedback loop?

Problems Faced by Automated-Test-Generation Tool



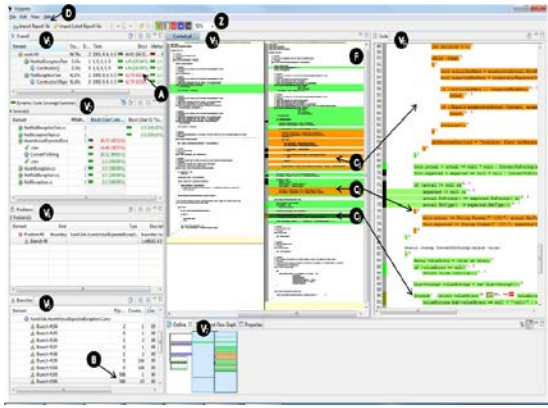
Cooperation Between Human and Machine – Covana

[Xiao et al. ICSE 2011]

- **Task:** What need to automate?
  - Test-input generation
- What difficulties does the tool face?
  - Doesn't know which methods to instrument and explore
  - Doesn't know how to generate effective method sequences
- How to communicate info to the user to get her help?
  - Report encountered problems
- How does the user help the tool based on the info?
  - Instruct which external methods to instrument/write mock objects
  - Write factory methods for generating objects
- Iterations to form feedback loop?
  - Yes, till the user is happy with coverage or impatient

Cooperation Between Human and Machine: Cooperative Testing/Analysis

- **Computing**-Centric **Human**
  - Driver: computer ←→ Helper: human
  - Ex. Covana [Xiao et al. ICSE 2011]



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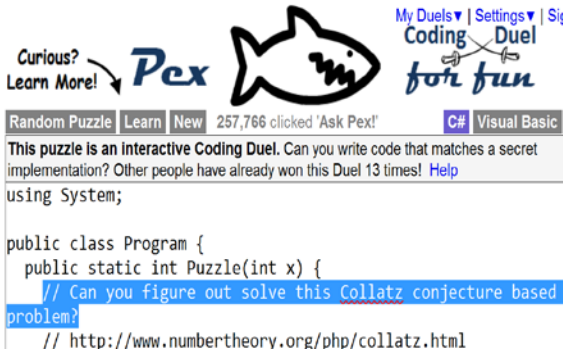


***Interfaces** are important. **Contents** are important too!*

Behind the Scene of Pex for Fun

[ASE 08sp]

Secret Impl $\overset{\text{behavior}}{==}$ **Player Impl?**

Secret Implementation

```
class Secret {
    public static int Puzzle(int x) {
        return x * 3 + 10;
    }
}
```

Player Implementation

```
class Player {
    public static int Puzzle(int x) {
        return x;
    }
}
```

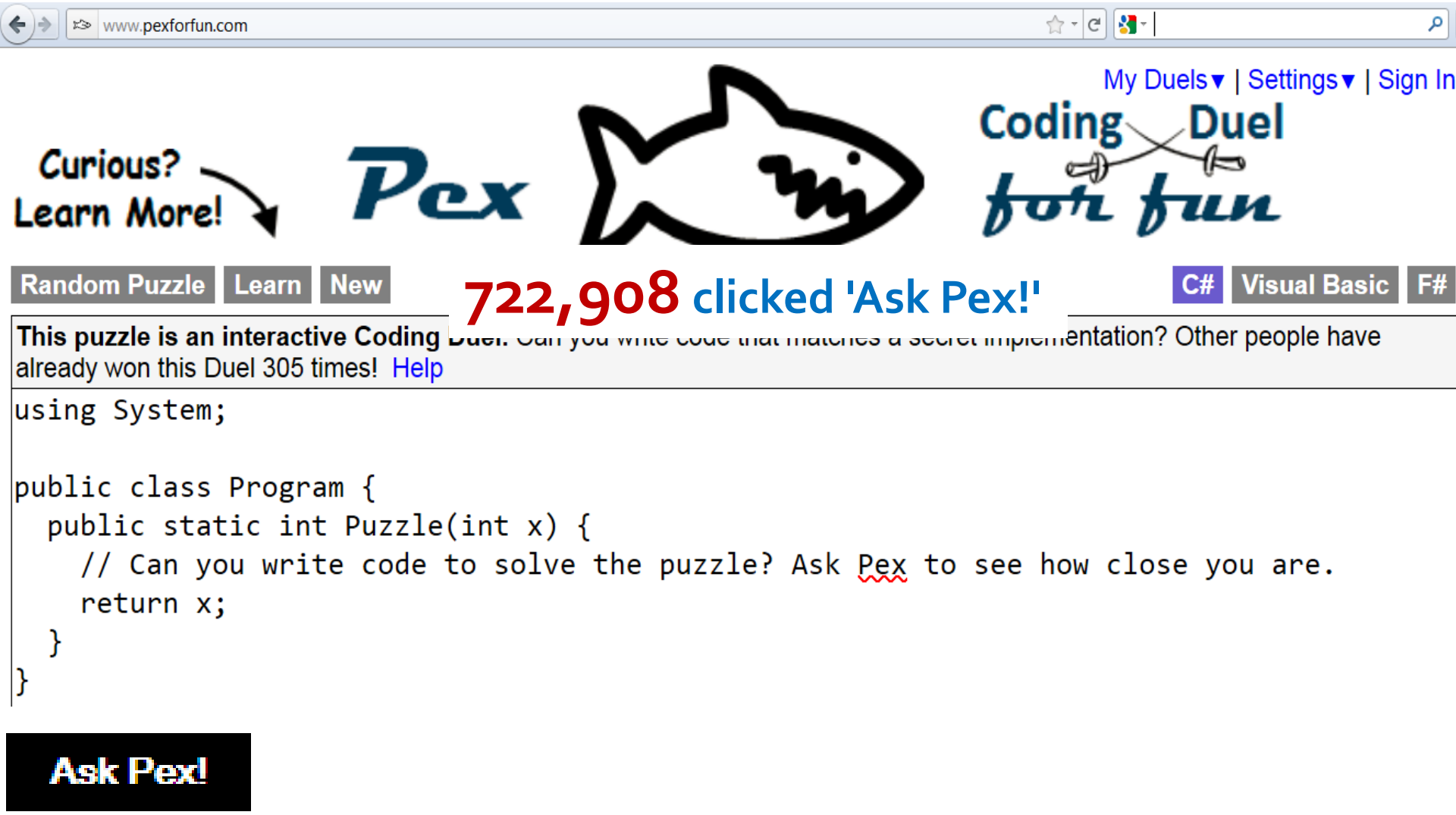

```
class Test {
    public static void Driver(int x) {
        if (Secret.Puzzle(x) != Player.Puzzle(x))
            throw new Exception("Found a Difference");
    }
}
```

Pex found 1 difference between your puzzle method and the secret implementation. Improve your code, so that it matches the other implementation, and 'Ask Pex!' again.

	x	y	your result	secret implementation result	Output/Exception	Error Message
✗	0	0	2	22	Mismatch	Your puzzle method produced the wrong result.
✓	-1458398958	515739696	1378169382	1378169382		

Migrating Pex to the Web/Cloud

Try it at http://www.pexforfun.com/



HCC: Pex for Fun

- Coding duels at http://www.pexforfun.com/
- **Task** for Human: write behavior-equiv code

```
using System;
public class Program {
  public static int Puzzle(int x, int y) {
    /* Could you re-order the statements t
of the secret implementation? */
    y = x * 10;
    y = x;
    x = y + 2;
    return (x + y);
  }
}
```

Ask Pex!

- Human → Tool
  - Does my new code behave differently? How exactly?

Pex found 1 difference between your puzzle method and the secret implementation. Improve your code, so that it matches the other implementation, and 'Ask Pex!' again.

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- Human ← Tool
  - Could you fix your code to handle **failed/passed tests**?

- Iterations to form feedback loop?
  - Yes, till tool generates no failed tests/player is impatient

Human-Centric Computing

- Coding duels [fun.com/](fun.com/)
  - Brain exercisin
  - Fun: iterative, [illegible] criterion
  - Abstraction/ge [illegible] blem solving

CS for Kids Status Live Feed Edit Close

Course Description: This is a complementary course that includes exercises for selected materials for C# from Sharp Kids: http://msdn.microsoft.com/en-us/beginner/bb308756.aspx. Questions and feedback are welcome.

Teacher: TaoXie

Associated Pages:

- CS4Kids Statements
- CS4Kids Code Blocks and Indenting Your Code
- CS4Kids Variables
- CS4Kids Operators
- CS4Kids Converting Between Types
- CS4Kids Branching
- CS4Kids Looping
- CS4Kids The For Loop
- CS4Kids The While Loop
- CS4Kids Whole Program Structure
- CS4Kids Using Class Libraries

Registered Students:

My Students | My Courses | My Pages

Pex

Random Puzzle | Learn | New [illegible]empts by you on this Codi

This puzzle is an interactive Coding Duel. Can you write c implementation? Help

```
using System;
public class Program {
  public static int Puzzle(int x, int y)
    /* Could you re-order the statements
of the secret implementation? */
    y = x * 10;
    y = x;
    x = y + 2;
    return (x + y);
  }
}
```

Ask Pex! *Done. 2 interesting inputs foun*

Brain exercising

Coding Duels Go Wild @ICSE 11

«ICSELevel2Challenge10» - Can you fill the puzzle method to match the secret computation? - *you already made 13 attempts*

Coding Duels	#0	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	#18	#19	#20	#21	#22	#23	#24	#25	#26	#27	#28	#29
TaoXie	3	3	2	3	3	3	5	12	6	2	20	4		13	3	2	24													
Felienne	3	7	4	4	8	10	12	17	25	10	20	7																		
RPortoAbreu	4	3	4	8	12	3	33	40	31	17	112	98	70	161	2	4	7	8	13	3	3	2	11	8	21	10	6	17	23	63
jomaras	4	2	3	4	5	9	8	10	40	8	14	6	3	17	4	2	4	9	10	3	6	2		34		8	3			
chenfucn	3	2	5	5	7	6	2	1	3		18			1																
cdragert	4	6	4	26	8	3	21	24	15	22	4	18	8	180	10	2	50	3	3	2	5	2	5	4	8	16	7	9	10	21
jamshaidm	4																													
JMacFan	2	2	2	18	12	6	18																							
Meilies	11	2	4	5	13	14	18	17	9	1																				
shauvik	2	5	2	3	5	11	6																							
almsantos	4	2	4	3	5	10	4	1		3	2	2	1	5	7	2	22	5	3	5	5	3	15	15	21	8	12		22	1
SCBSUFPE	4	5	3	4	7	7	7	21	18	3	5			14	4	2	5	6	5	3	4	3	9	15	3	11	11	15	19	7
theofour	2	2	2	4	6	12	14	4	7	14	14	37	5	58	2	2	8	6	9	8	2	2	5	4	6	7	4	7	4	12
anchi	6	4	3	4	12	15	6	15	21	7	15	28	2	7	4	2	14	5	7	4	2	3	7	3	10	6	13	17	12	62
malteres	2	5	2	3	6	5	23	18	36	10	17	36	26	224	2	4	12	5	9	2	4	8	9	2	18	15	3	17	29	79
rla4	4	2	2	4	6	7	10	22	11		9	4	12	12	7	2	11	6	8	6	2	1								
krw7c	7	6	8	3	7	7																								
MIKAND	2	2	1	5	8	5	9	7	17	5	9	7	2	9	4	2	4	4	5				5	2	5	5	5	4	13	10
ariboira	6	7	6	14	13	22	26	51	56	11	147	96	61	226	23	3	16	13	21	7	3	11	21	3	7	2	21	26	27	22
Benny	4	5	5	4	13	6	10	13	22	32	53	31	30	9	2	2	7	5	9	2	2	4	7	8	4	14	22	21	11	29
TheRama	3	2	2	3	3	18	4	8	29	7	17	10	3	37	3	2	12	7	6	2	6	2	10	5	3	11	5	22	8	12
madking	2	2	2	5	11	2	8	6	13	15	8	10	4	386	4	2	10	6	6	2	2	2	5	7	4	7	5	3	2	15
nipun	19	9	5	10	2	2	12	12	2	12				8	3	3	10	6					8	4	15				24	
(no nickname)	3	7	2	3																										
eijiadachi	6	3	2	4	7	13	17	11	9	2	3	3	24	1	3	2	3	4	12	8	3	4	6	25	8	16	6	18	134	17
schroeter	3	2	3	6	3	3	6	6	18	4	12																			
Ezzo	3	1	1																											
(no nickname)	3	4	4	11																										

#10
20
20
112
14
18
4
2
5
14
15
17
9
9
147
53
17
8

This is your last attempt

```
using System;

public class Program {
  public static int Puzzle(int x) {
        if (x <= 0) return 0;
    if (x == 1) return 0;//1
    if (x == 2) return 0;//2
    if (x == 3) return 0;//3
    if (x == 4) return 0;//5
    if (x == 5) return 4;//7
    if (x == 6) return 4;//13
    if (x == 7) return 4;//21
    if (x == 8) return 0;//34
    if (x == 9) return 0;//55
    if (x == 10) return 0;//89
    if (x == 11) return 0;//144
    if (x == 12) return 0;//233
    if (x == 72) return (x-8);

    if (x == 963) return (x-3);
    if (x == 964) return (x-4);
    if (x == 965) return (x-1);
    if (x == 966) return (x-2);

    if (x == 995) return (x-3);
    if (x == 996) return (x-4);
    if (x == 997) return (x-1);
    if (x == 998) return (x-2);
    if (x == 999) return (x-3);
    return 0;
  }
```

Data-Driven Software Engineering in the Large **AND Small**

Outline

- Play Around Industrial Tool
  - Parasoft Jtest → Rostra [ASE 04]
- Play Within Industrial Tool
  - Microsoft Research Pex → Fitnex [DSN 09]
- **Advise Industrial Tool Developers**
  - **Microsoft Research Pex For Fun → [CSEE&T 11 Tut]**
- Engage Target Users
  - Microsoft Research Asia Software Analytics Group

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Software Analytics Group @ MSRA

Utilize data-driven approach to help create highly performing, user friendly, and efficiently developed and operated software and services

Software Analytics as a Learning Case in Practice: Approaches and Experiences

Dongmei Zhang[1], Yingnong Dang[1], Jian-Guang Lou[1], Shi Han[1], Haidong Zhang[1], Tao Xie[2]
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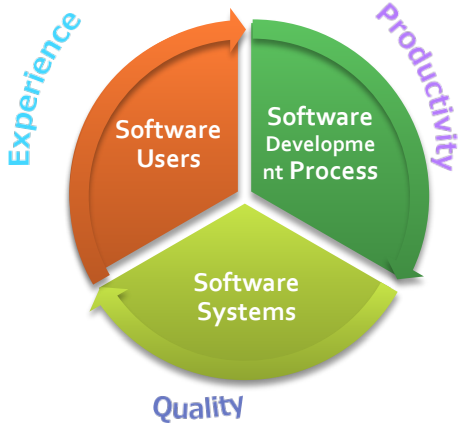
[2]North Carolina State University, Raleigh, NC, USA
{dongmeiz,yidang,jlou,shihan,haizhang}@microsoft.com, xie@csc.ncsu.edu

ABSTRACT

Software analytics is to enable software practitioners to perform data exploration and analysis in order to obtain *insightful* and *actionable* information for data-driven tasks around software and services. In this position paper, we advocate that when applying analytic technologies in practice of software analytics, one should (1) incorporate a broad spectrum of domain knowledge and expertise, analysis in order to obtain *insightful* and *actionable* information for data-driven tasks around software and services[2].

Insightful information is information that conveys meaningful and useful understanding or knowledge towards performing the target task. Typically insightful information is not easily attainable by directly investigating the raw data without aid of analytic technologies. Actionable information is information upon which software

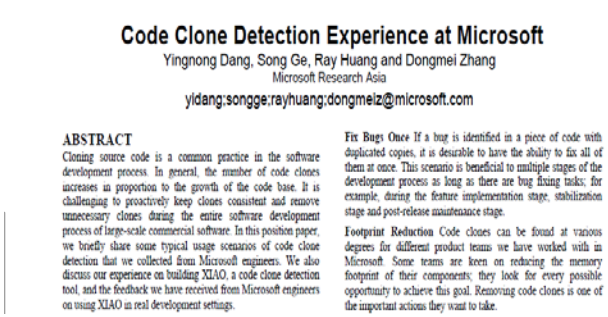


http://research.microsoft.com/groups/sa/

[MALETS'11 Zhang et al.]

XIAO: Code Clone Analysis

- Motivation
  - Copy-and-paste is a common developer behavior
  - A real tool widely adopted at Microsoft
- XIAO enables code clone analysis with
  - High tunability
  - High scalability
  - High compatibility
  - High explorability



Code Clone Detection Experience at Microsoft

Yingnong Dang, Song Ge, Ray Huang and Dongmei Zhang
Microsoft Research Asia
yidang;songge;rayhuang;dongmeiz@microsoft.com

ABSTRACT

Cloning source code is a common practice in the software development process. In general, the number of code clones increases in proportion to the growth of the code base. It is challenging to proactively keep clones consistent and remove unnecessary clones during the entire software development process of large-scale commercial software. In this position paper, we briefly share some typical usage scenarios of code clone detection that we collected from Microsoft engineers. We also discuss our experience on building XIAO, a code clone detection tool, and the feedback we have received from Microsoft engineers on using XIAO in real development settings.

Fix Bugs Once If a bug is identified in a piece of code with duplicated copies, it is desirable to have the ability to fix all of them at once. This scenario is beneficial to multiple stages of the development process as long as there are bug fixing tasks; for example, during the feature implementation stage, stabilization stage and post-release maintenance stage.

Footprint Reduction Code clones can be found at various degrees for different product teams we have worked with in Microsoft. Some teams are keen on reducing the memory footprint of their components; they look for every possible opportunity to achieve this goal. Removing code clones is one of the important actions they want to take.

[IWSC'11 Dang et.al.]

Successful Tech-Transfer Tips

- Engagement of practitioners
- Combination of expertise

What Shall Academia Do?

- Get research problems from real practice
- Get feedback from real practice
- Collaborate across disciplines
- Collaborate with industry

Summary

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Vision: Cooperative Testing/Analysis

- **Computing**-Centric **Human**: Test/Analysis Tools
  - Tool → Human
  - Tool ←Human
- **Human**-Centric **Computing**: Educational Tools
  - Human → Tool
  - Human ← Tool
- **Computing-Computing** (synergetic analysis)
- **Human-Human** (crowdsourcing)

Thank you!

Questions ?

https://sites.google.com/site/asergrp/

Automated Software Engineering Research Group @NCSU

Cooperative Developer Testing

- Developers provide guidance to help tools achieve higher structural coverage

- Apply tools to generate tests
- Tools report achieved coverage & problems
- Developers provide guidance
  - EMCP: Instrumentation or Mock Objects
  - OCP: Factory Methods