Testing and Analysis of Next Generation Software

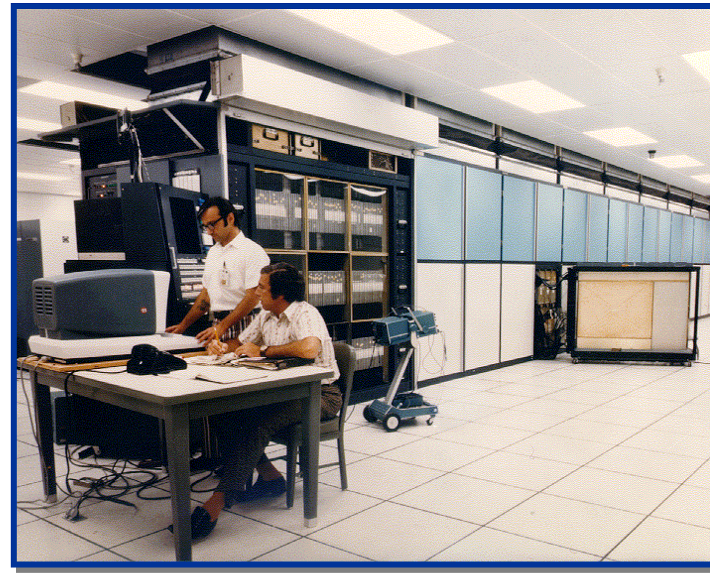
Mary Jean Harrold
College of Computing
Georgia Tech

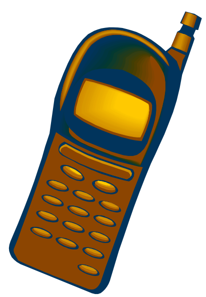
harrold@cc.gatech.edu

Joint work with T. Apiwattanapong, J. Bowring, J. Jones, D. Liang, R. Lipton, A. Orso, J. Rehg, and J. Stasko

Computing (so far)

- **Big Iron (‘40s/’50s)**
- **Mainframe (’60s/’70s)**
- **Workstations (’70s/’80s)**
- **Individual PCs (’80s/’90s)**
- **Internet (’90s)**
- ***Implicit, ubiquitous, everyday computing** (21st century)*





Some Features/Challenges

Features

- **Scope**
  - embedded in everyday devices
  - many processors/person
- **Connectivity**
  - mobile, interconnected
  - coupled to data sources
  - implicit interactions
- **Computational resources**
  - powerful
  - embedded intelligence

Lucy Dunne
Cornell University
Smart Jacket

Some Features/Challenges

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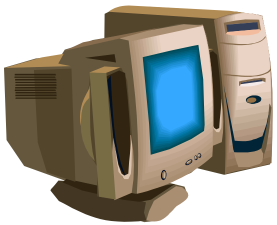
- **Connectivity**
  - mobile, interconnected
  - coupled to data sources
  - implicit interactions
- **Computational resources**
  - powerful
  - embedded intelligence

Challenges

- many environments in which to run
- short development and evolution cycles
- requirement for high quality
- dynamic integration of components
- increased complexity of components, interactions, and computational resources

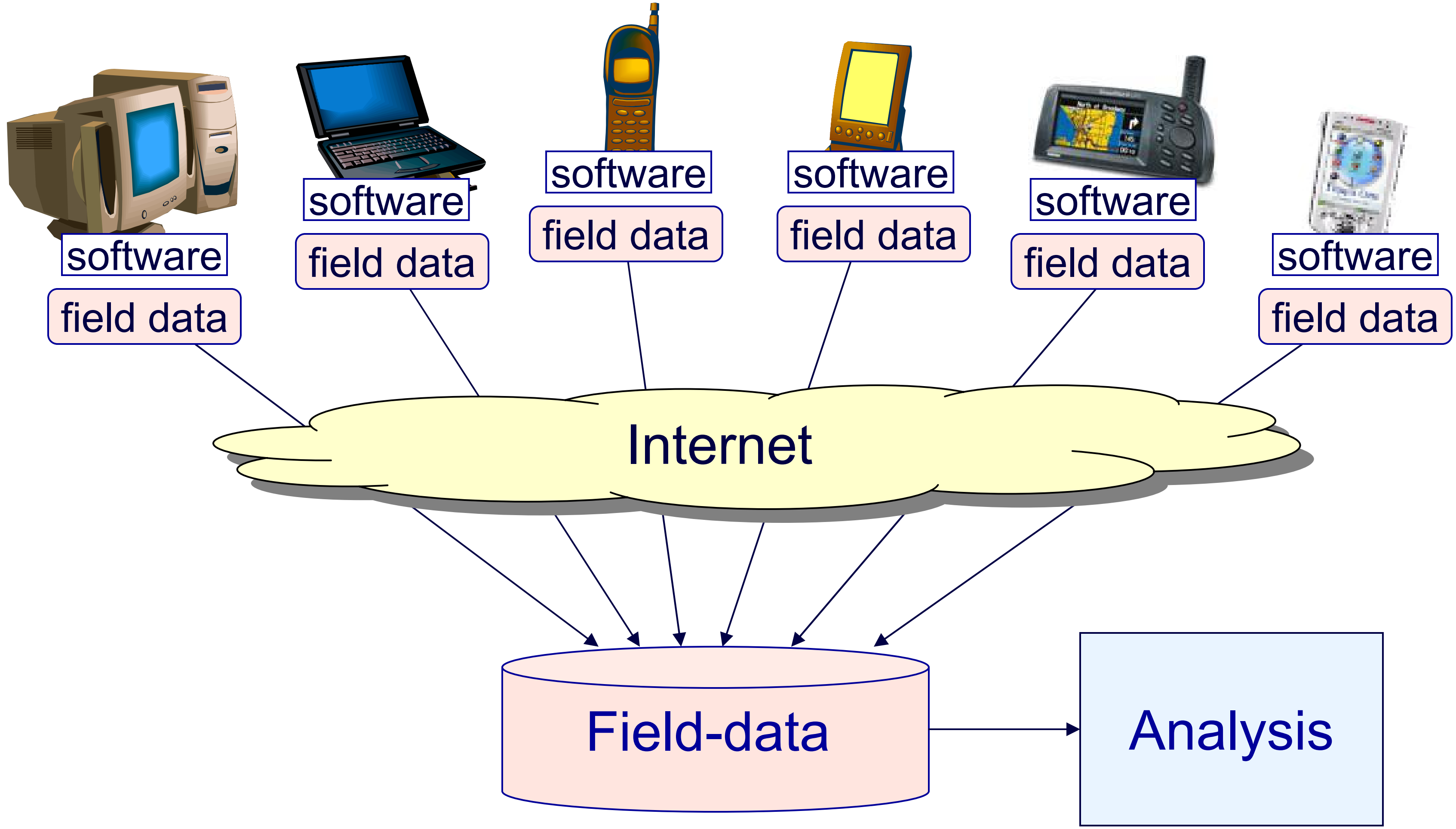
Testing/Analyzing NGS



Before deployment

- test-driven development
- modular testing of components
- formal methods

The Gamma Project

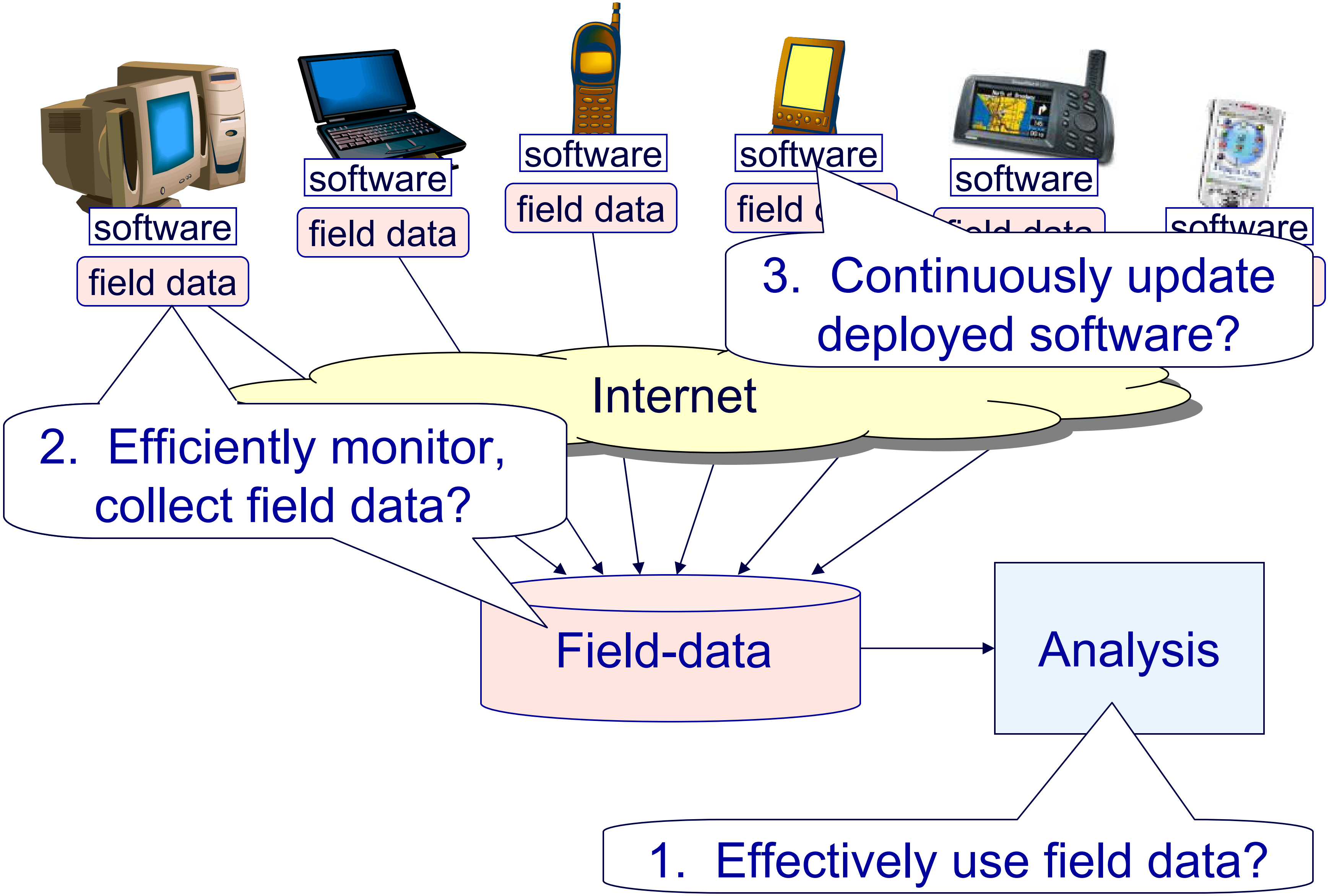


Outline

- **Gamma project**
  - Overview, problems

    [Orso, Liang, Harrold, Lipton; ISSTA 2002]
  - Summary of current projects
- **Visualization of field data**
- **Related work**
- **Summary, Challenges**
- **Questions**

The Gamma Project



Gamma Research

1. Effective use of field data

Analysis

- Measurement of coverage

  [Bowring, Orso, Harrold, PASTE 02]

- Impact analysis, regression testing

  [Orso, Apiwattanapong, Harrold, FSE 04]

✓ Classify/recognize software behavior

  [Bowring, Rehg, Harrold, TR 03]

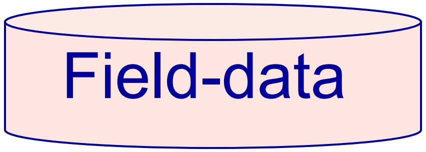
☑ Visualization of field data

  [Jones, Harrold, Stasko, ICSE 02]

  [Orso, Jones, Harrold, SoftVis 03]

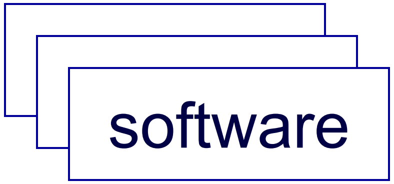
Gamma Research

2. Efficient monitoring/collecting of field data



- Software tomography
  - *[Bowring, Orso, Harrold, PASTE 02]*
  - *[Apiwattanapong, Harrold, PASTE 02]*
- Capture/replay of users' executions
  - *[Orso, Kennedy, in prepration]*

3. Continuous update of deployed software

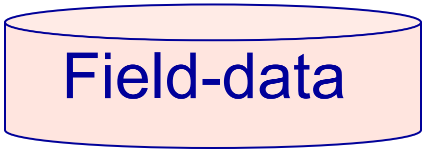


- Dynamic update of running software
  - *[Orso, Rao, Harrold, ICSM 02]*

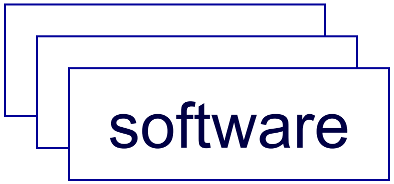
Gamma Research

1. **Effective use of field data**
   - Measurement of coverage
   - Impact analysis, regression testing
   - → Classify/recognize software behavior
   - ☑ Visualization of field data

2. **Efficient monitoring/collecting of field data**
   - Software tomography
   - Capture/replay of users’ executions



3. **Continuous update of deployed software**
   - Dynamic update of running software



Classify/Recognize Behavior

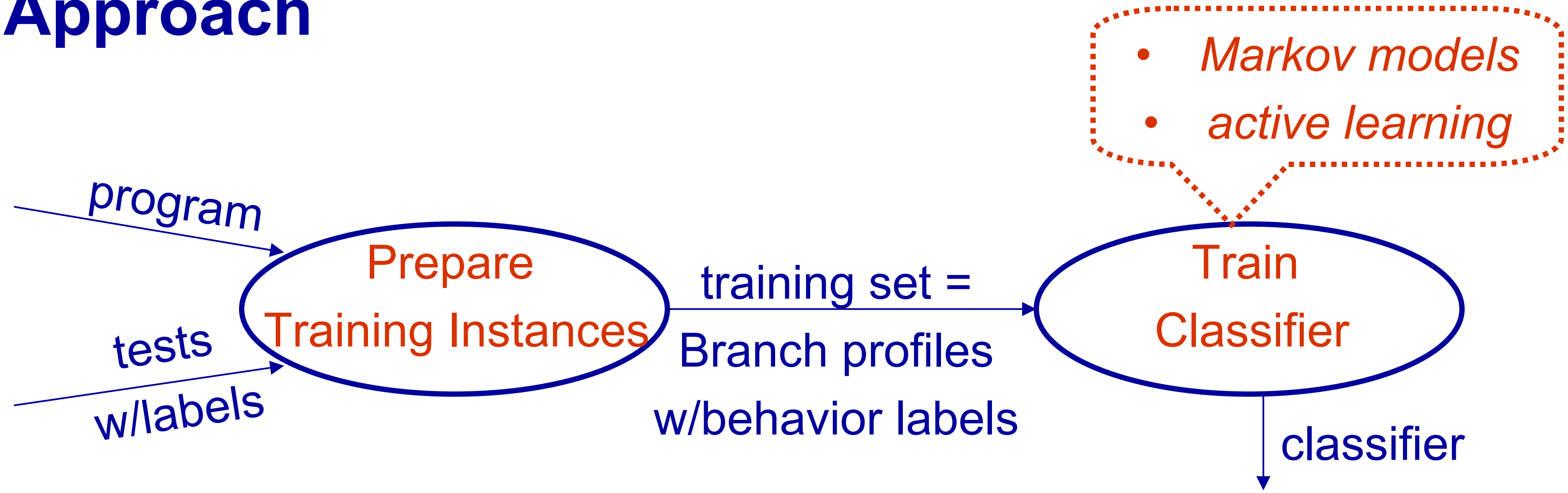
Problem

- Behavior classification, recognition difficult, expensive
- Recognize behavior without input/output needed

For classifying and recognizing behavior

- Behaviors are the results of executing program

Approach



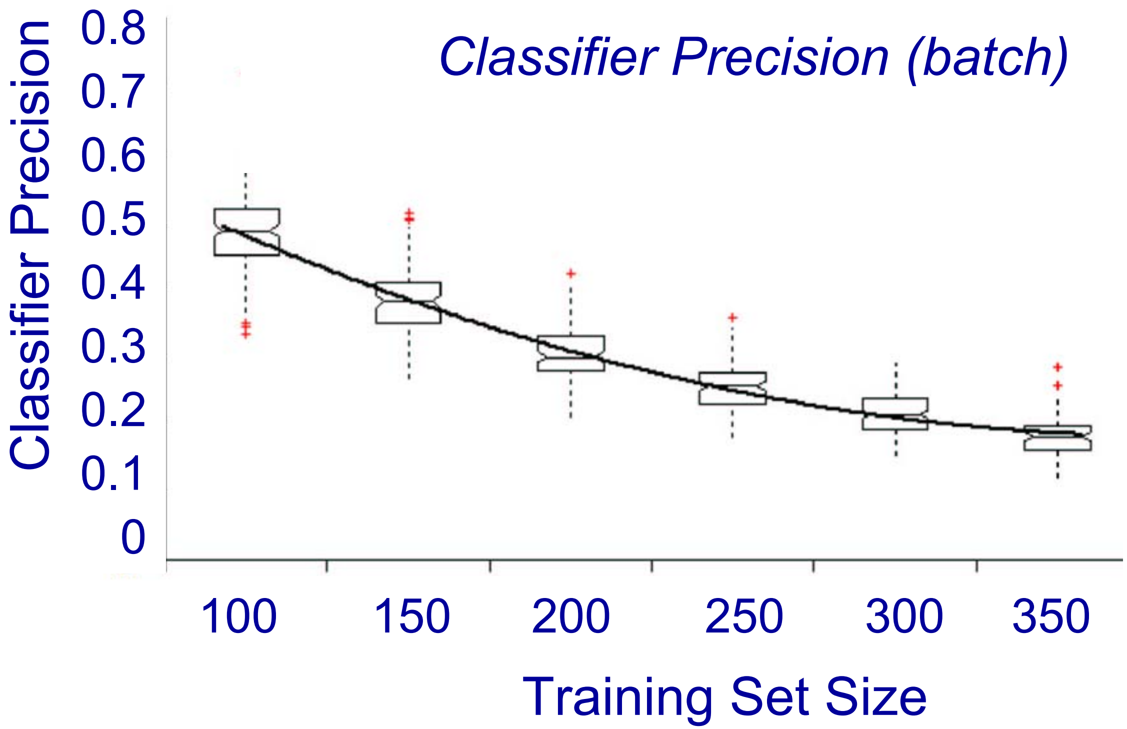
Empirical Studies

- **Research questions**
  1. What is classification rate and classifier precision of trained classifier on different-size subsets of test suite?
  2. How does active learning improve training?
- **Subject program: Space**
  - 8000 lines of executable code
  - Test suite contains 13,500 tests
  - 15 versions
- **Experimental Setup**
  1. For each version (repeated 10 times)
     - trained classifier on (random) subsets 100-350
     - evaluated classifier on rest of test suite
  2. Compared batch, active learning

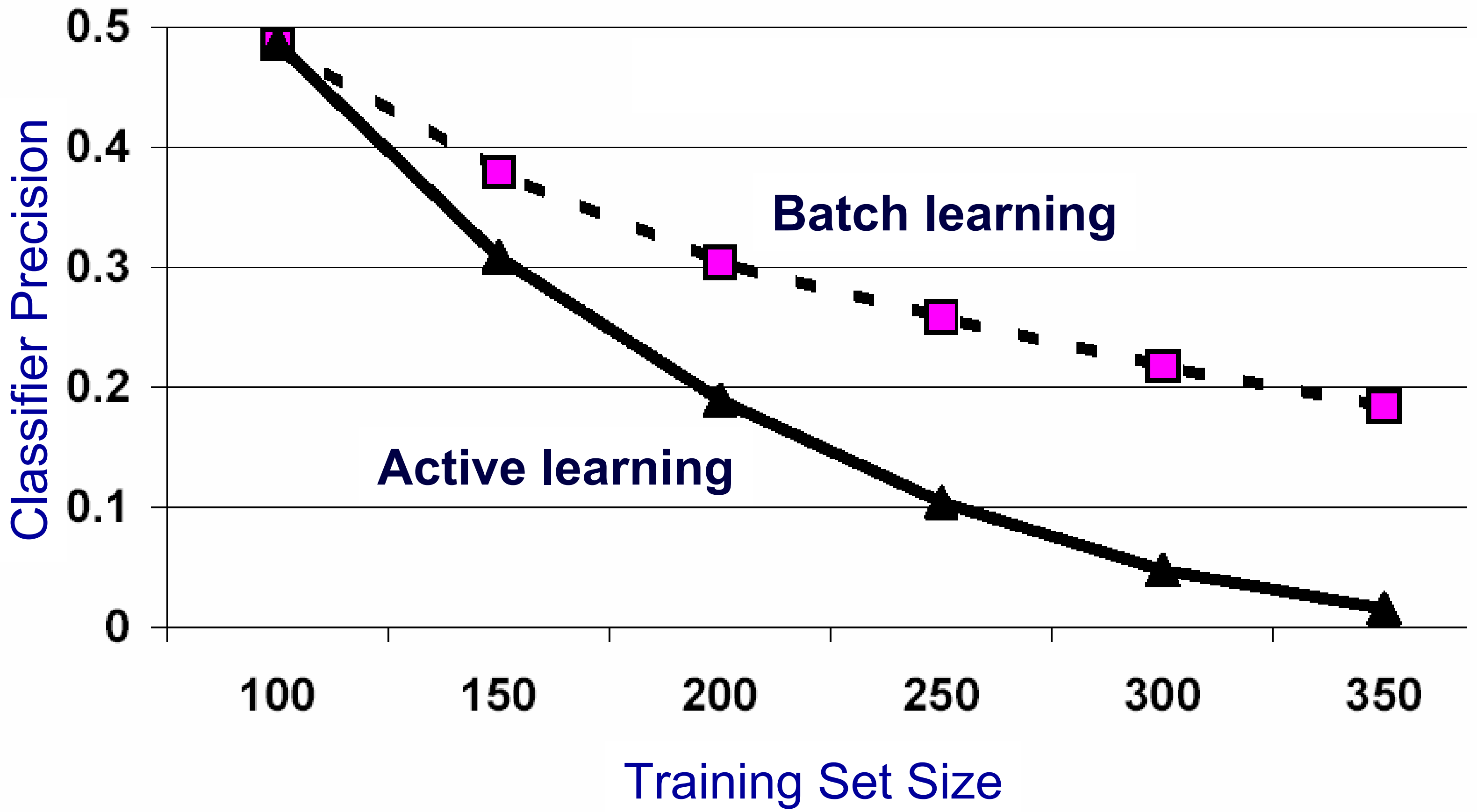
Results

Classification Rate

Training set size	# of classifiers	Mean
100	150	0.976
. . .	. . .	. . .
350	150	0.976



Results


Classifier Precision
0.5
0.4
0.3
0.2
0.1
0
Batch learning
Active learning
100
150
200
250
300
350
Training Set Size

Outline

- **Gamma project**
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- **Visualization of field data**
- **Related work**
- **Summary, Challenges**
- **Questions**

Visualization of Field Data

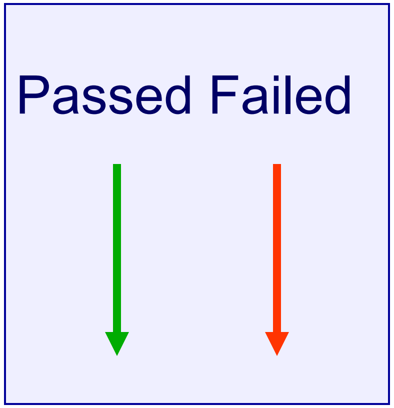
Problem

- Huge amount of execution data difficult to understand, inspect manually
- Developers need help in finding faults

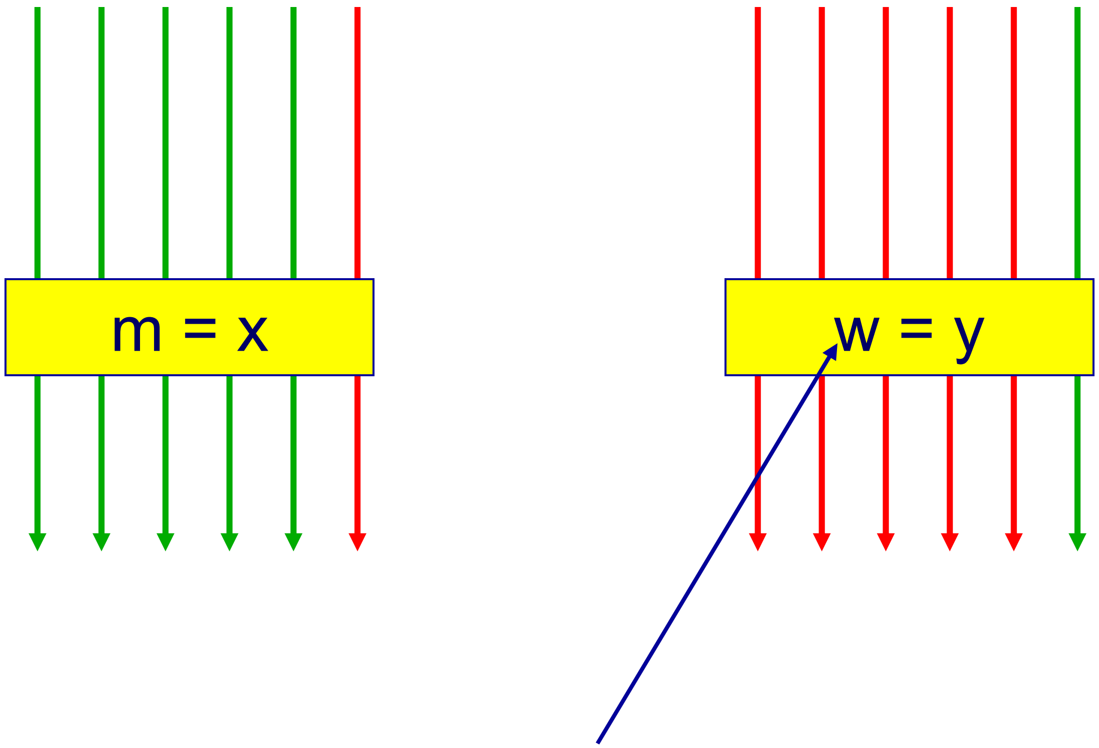
Visualize field data for fault localization

- Visualization for fault localization
  [Jones, Harrold, Stasko; ICSE 02]
- Visualization of field data (Gammatella)
  [Orso, Jones, Harrold; SoftVis 03]

Visualization for Fault Localization



Consider two statements



More suspicious of being faulty

Visualization for Fault Localization

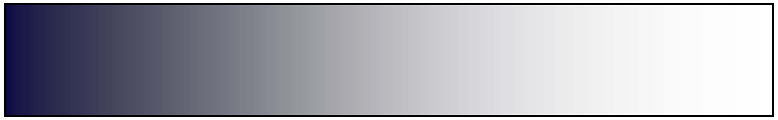
- **Uses**
  - Pass/fail results of executing test cases (actual or inferred)
  - Coverage/profiles provided by those test cases (statement, branch, def-use pairs, paths, etc.)
  - Source code of program
- **Computes**
  - Likelihood that a statement is faulty
  - Summarizes pass/fail status of test cases that covered the statements
- **Maps to visualization (Tarantula)**
  - Using two variables

Tarantula Approach

For statement *s*:

Hue summarizes pass/fail results of test cases that executed *s*

Brightness presents the “confidence” of the hue assigned to *s*



Example

	Test Cases					
	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	2,1,3
`mid() {`						
`int x,y,z,m;`						
`1: read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•
`2: m = z;`	•	•	•	•	•	•
`3: if (y<z)`	•	•	•	•	•	•
`4:     if (x<y)`	•	•			•	•
`5:         m = y;`		•				
`6:     else if (x<z)`	•				•	•
`7:         m = y;`	•					•
`8: else`			•	•		
`9:     if (x>y)`			•	•		
`10:        m = y;`			•			
`11:    else if (x>z)`				•		
`12:        m = x;`						
`13: print("Middle number is:", m);`	•	•	•	•	•	•
`}`						
Pass Status	P	P	P	P	P	F

Statement-level View

	Code	3,3,5	1,2,3	3,2,1	5,5,5	5,3,4	2,1,3
	`mid() {`						
	`int x,y,z,m;`						
1:	`read("Enter 3 numbers:",x,y,z);`	•	•	•	•	•	•
2:	`m = z;`	•	•	•	•	•	•
3:	`if (y<z)`	•	•	•	•	•	•
4:	`if (x<y)`	•	•			•	•
5:	`m = y;`		•				
6:	`else if (x<z)`	•				•	•
7:	`m = y;`	•					•
8:	`else`			•	•		
9:	`if (x>y)`			•	•		
10	`m = y;`			•			
11:	`else if (x>z)`				•		
12:	`m = x;`						
13:	`print("Middle number is:", m);`	•	•	•	•	•	•
	`}`						
	Pass Status	P	P	P	P	P	F

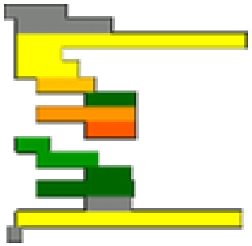
Test Cases

File-level View

SeeSoft view

- each pixel represents a character in the source

```
mid() {
 int x,y,z,m;
 read(“Enter 3 numbers:”,x,y,z);
 m = z;
 if (y<z)
     if (x<y)
            m = y;
     else if (x<z)
            m = y;
 else
     if (x>y)
            m = y;
     else if (x>z)
            m = x;
 print(“Middle number is:”, m);
}
```



File-level View

SeeSoft view

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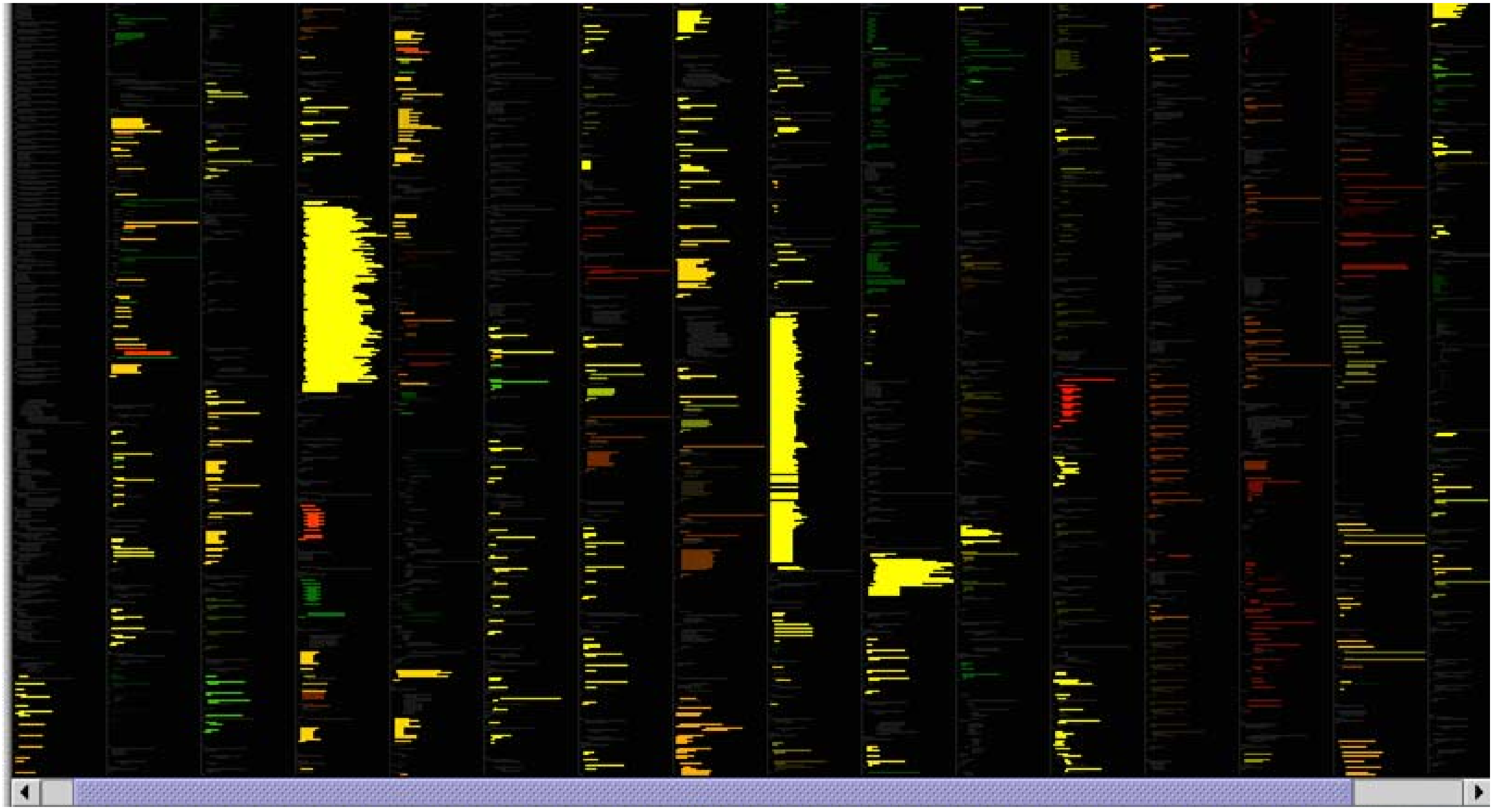
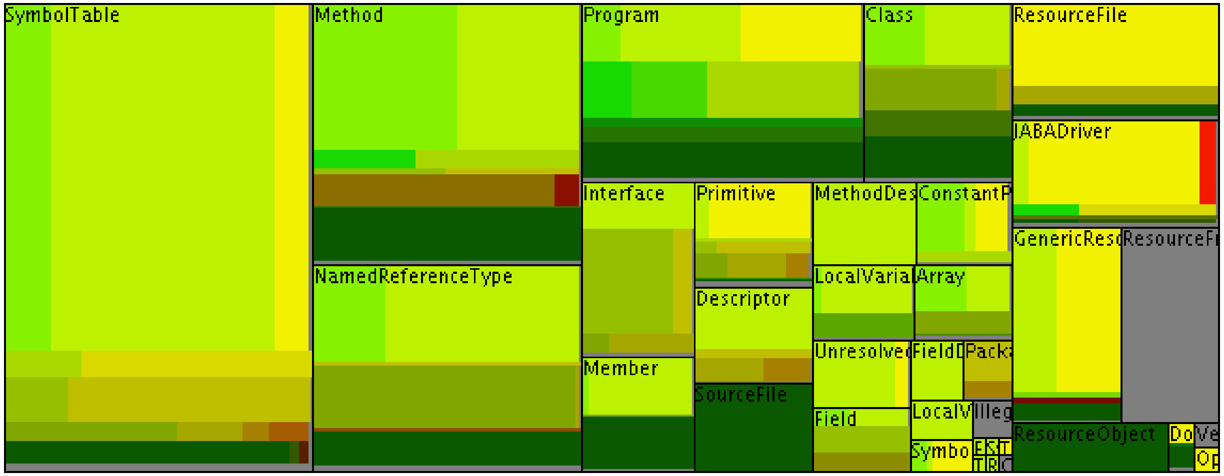


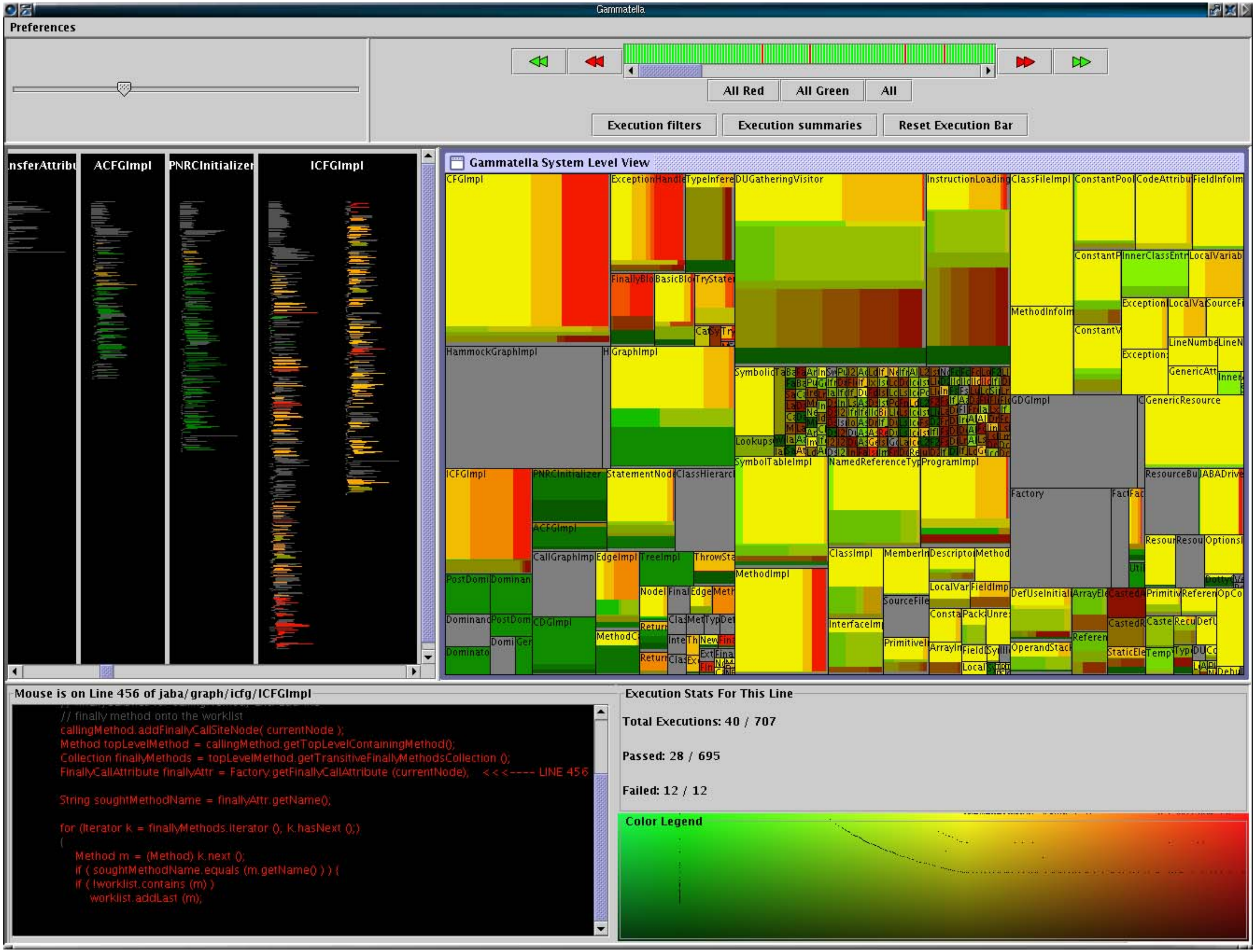
System-level View

TreeMap view

- **each node**
  - represents a file
  - is divided into blocks representing color of statements



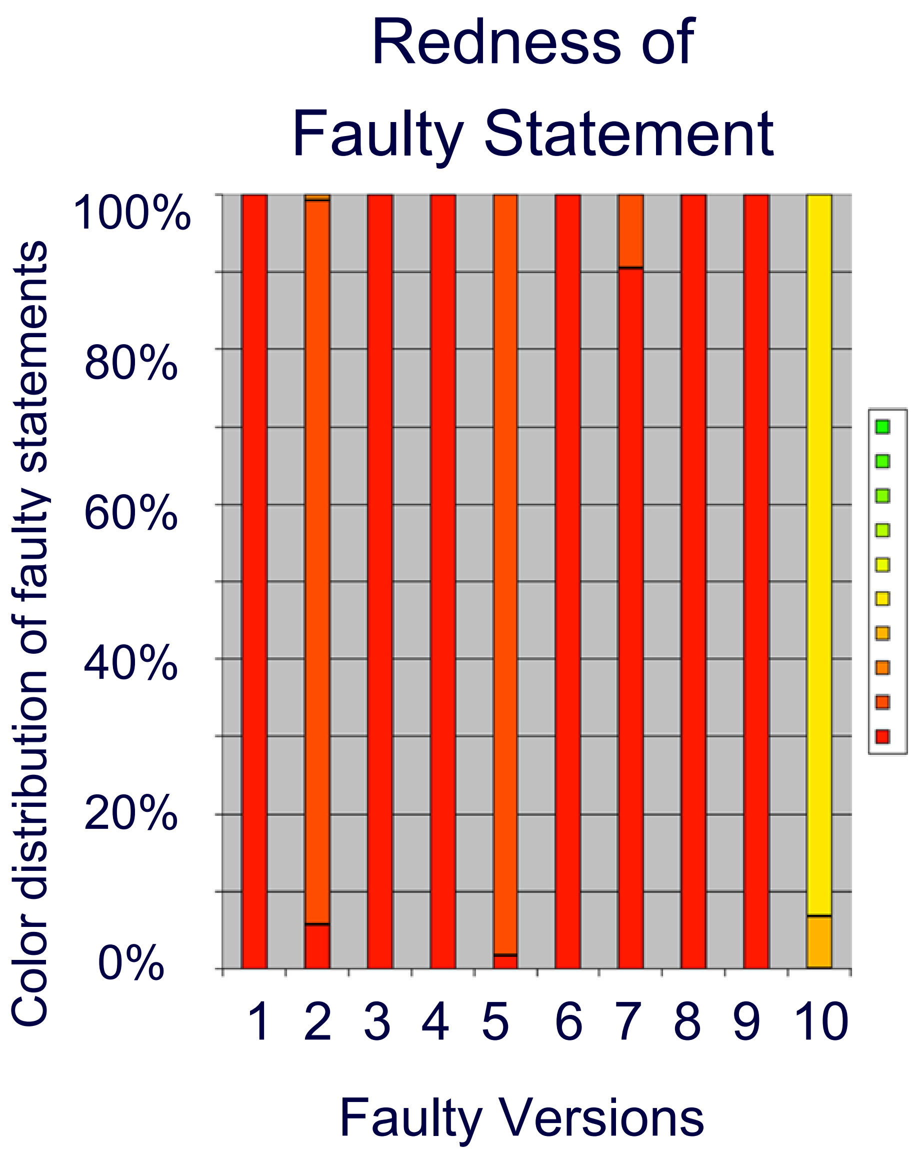
Tarantula


Gammatella
Preferences
All Red
All Green
All
Execution filters
Execution summaries
Reset Execution Bar
ACFGImpl
PNRCInitializer
ICFGImpl
Gammatella System Level View
Mouse is on Line 456 of jaba/graph/icfg/ICFGImpl
// finally method onto the worklist
callingMethod.addFinallyCallSiteNode(currentNode);
Method topLevelMethod = callingMethod.getTopLevelContainingMethod();
Collection finallyMethods = topLevelMethod.getTransitiveFinallyMethodsCollection ();
FinallyCallAttribute finallyAttr = Factory.getFinallyCallAttribute (currentNode); <<<---- LINE 456
String soughtMethodName = finallyAttr.getName();
for (Iterator k = finallyMethods.iterator (); k.hasNext ();)
{
Method m = (Method) k.next ();
if (soughtMethodName.equals (m.getName())) {
if (!worklist.contains (m))
worklist.addLast (m);
Execution Stats For This Line
Total Executions: 40 / 707
Passed: 28 / 695
Failed: 12 / 12
Color Legend

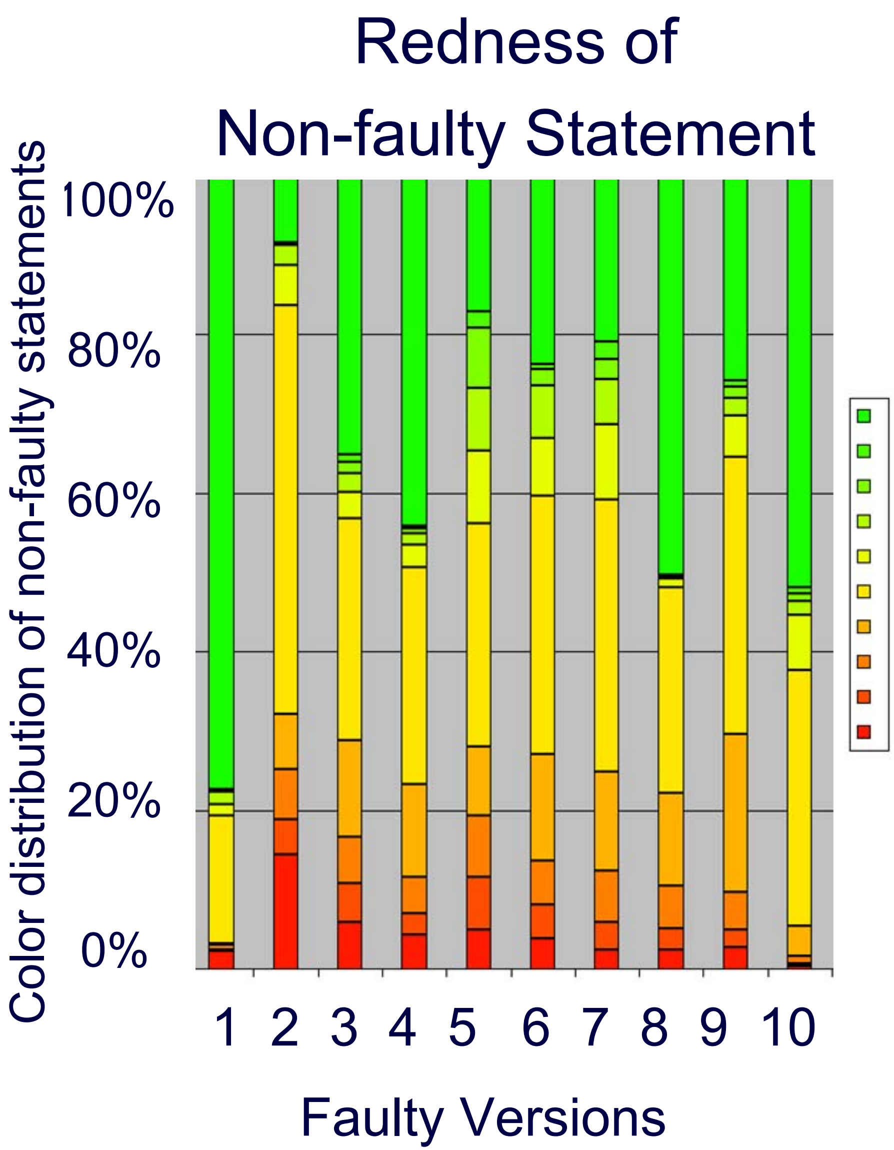
Tarantula: Empirical Studies

- **Research questions**
  1. How red are the faulty statements?
  2. How red are the non-faulty statements?
- **Subject program: Space**
  - 8000 lines of executable code
  - 1000 coverage-based test suites of size 156-4700 test cases
  - 20 faulty versions (10 shown here)
- **Experimental Setup**
  - Computed the color for each statement, each test suite, each version
  - For each version, computed the color distribution of faulty, non-faulty statements

Results

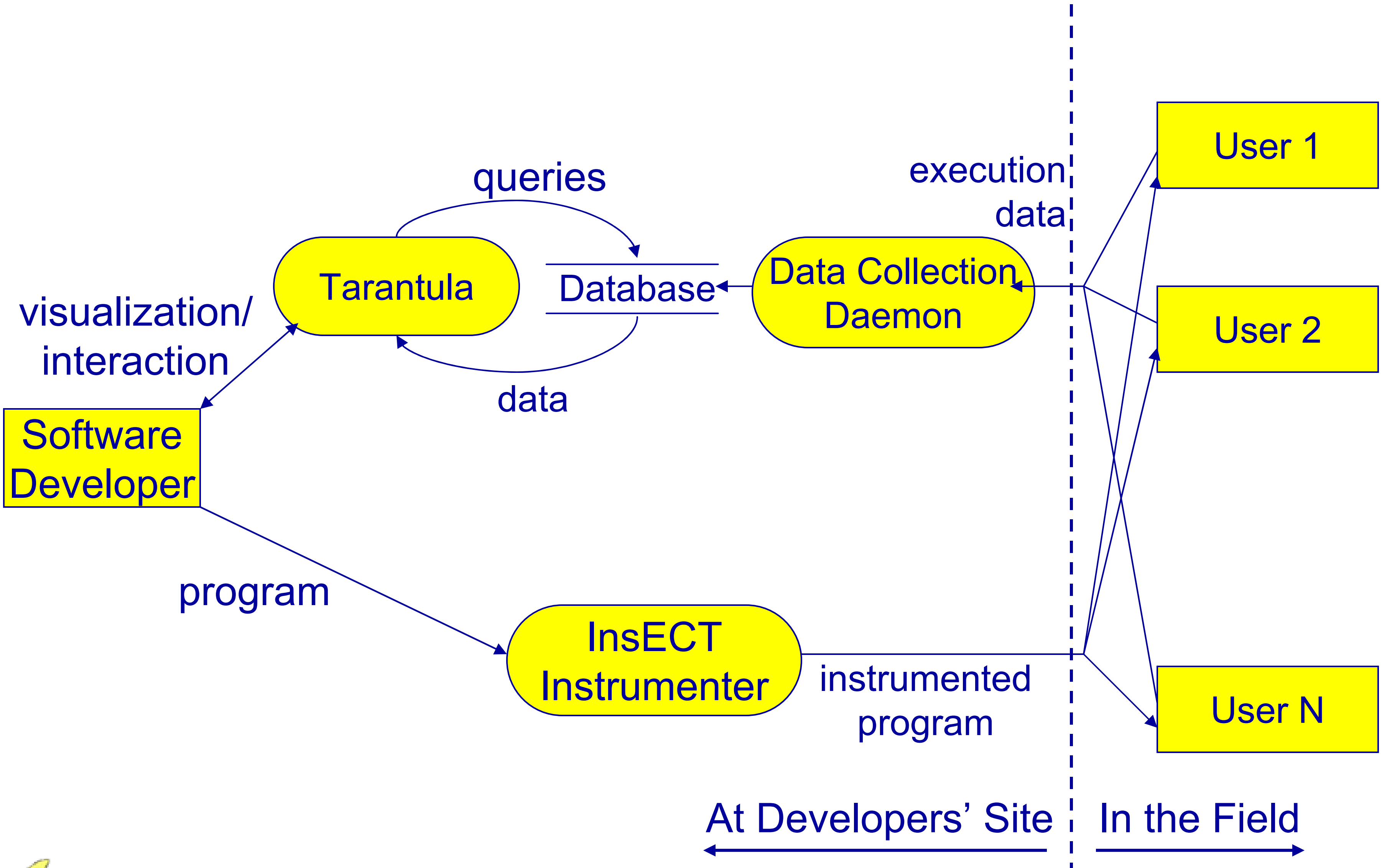


Redness of
Faulty Statement
100%
80%
60%
40%
20%
0%
Color distribution of faulty statements
1 2 3 4 5 6 7 8 9 10
Faulty Versions



Redness of
Non-faulty Statement
100%
80%
60%
40%
20%
0%
Color distribution of non-faulty statements
1 2 3 4 5 6 7 8 9 10
Faulty Versions

Gammatella



queries
execution data
Tarantula
Database
Data Collection Daemon
User 1
User 2
visualization/ interaction
data
Software Developer
program
InsECT Instrumenter
instrumented program
User N
At Developers' Site
In the Field

Gammatella: Experience

- **Subject program: JABA**
  - Java Architecture for Bytecode Analysis
  - 60,000 LOC, 550 classes, 2,800 Methods
- **Data**
  - field data: > 2000 executions (15 users, 12 weeks)

Results

- **Use of software**
  - identified unused features of JABA
  - redesigned into a separate plug-in module
- **Error**
  - identified specific combination of platform and JDK predictably causes problems

Aristotle Research Group

Results

Public display monitors deployed software

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Related Work

Gamma Project

- Perpetual/Residual testing (Clarke, Osterweil, Richardson, Young)
- Expectation-Driven Event Monitoring (EDEM) (Hilbert, Redmiles, Taylor)
- Remote Monitoring/Measurement of Deployed Software (Notkin, Porter, Schmidt)
- Bug Isolation (Liblit, Aiken, et al.)

Visualization

- Seesoft, SeeSys (Eick, Sumner, Baker)
- Treemap (Schneiderman)
- Bloom, ALMOST, … (Reiss, Renieris)
- Jinsight (DePauw et al.)

Behavior Modeling, Instrumentation, Profiling

- Too numerous to list

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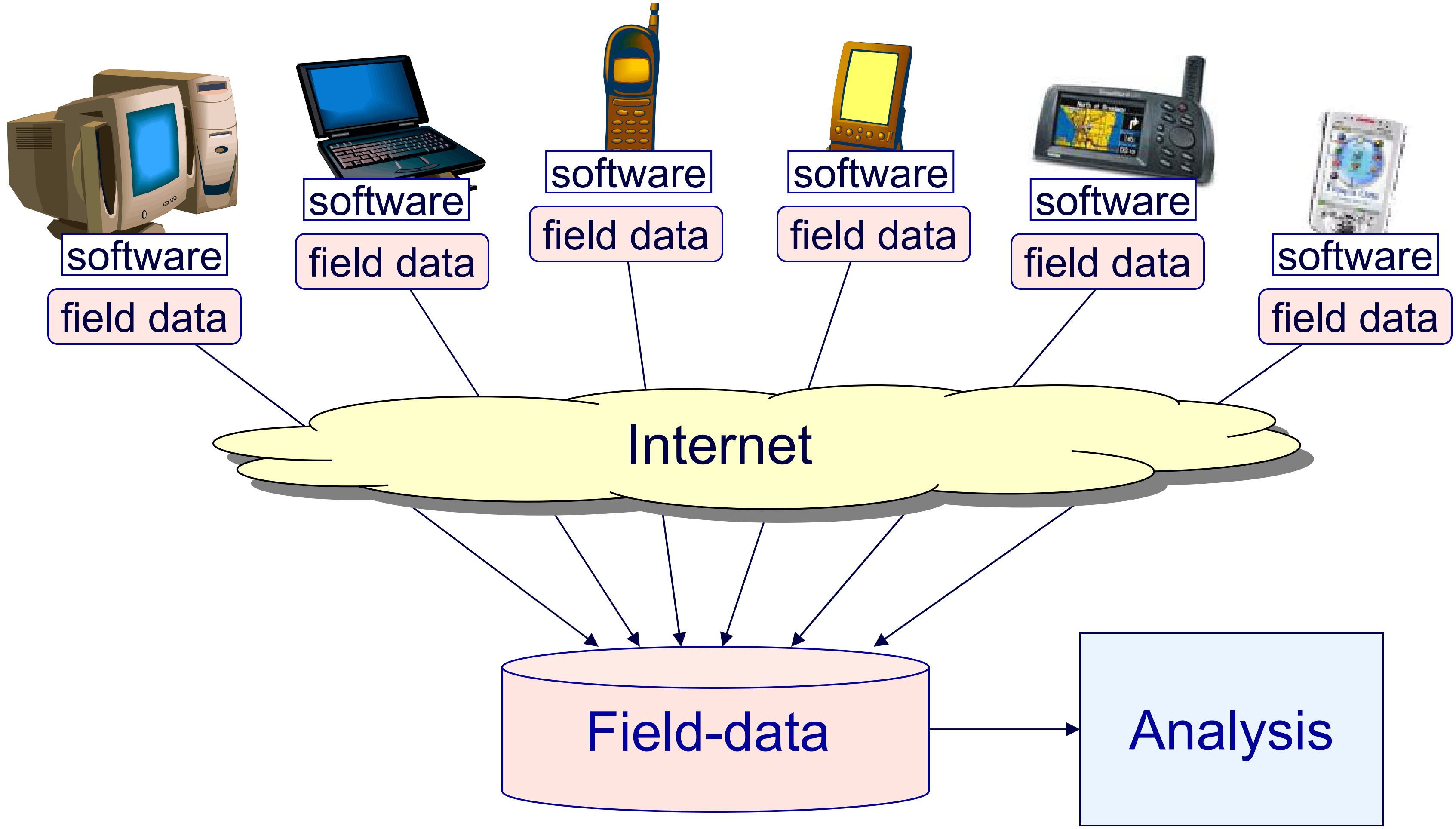
Summary

- **Motivated need for new kind of testing for next generation software**
- **Described new kind of testing---Gamma testing**
  - addresses challenges of testing next generation software: many environments, short development cycles, high-quality requirements, dynamic integration, and complexity
  - a collaborative effort between developer and users
- **Presented problems that must be solved**
- **Described several Gamma projects**

(Some) Challenges

- **Effective use of field data**
  - very preliminary results so far
  - effective techniques will be mix of
    - in-house analysis (static and dynamic) and
    - analysis of field data (dynamic, aggregate)
- **User participation in analysis of field data**
  - filtering before sending to developer
  - initiating new analyses in response to events at their sites or due to interactions with other users
  - creating their own test suites to be run locally
- **Privacy of users**
  - techniques that protect users data
  - user-specific analysis/testing for privacy

Questions


software
field data
software
field data
software
field data
software
field data
software
field data
software
field data
Internet
Field-data
Analysis