Cooperative Bug Isolation

Ben Liblit *et al*.

He-Man

From Wikipedia, the free encyclopedia that anyone can ed

He-Man is the most powerful man in the universe. Imbued with incredible magical power by the Sorceress of Castle Graysku he defends Eternia against evildoers with his friends Man-At-Arms, Teela, and the lovable Orko.

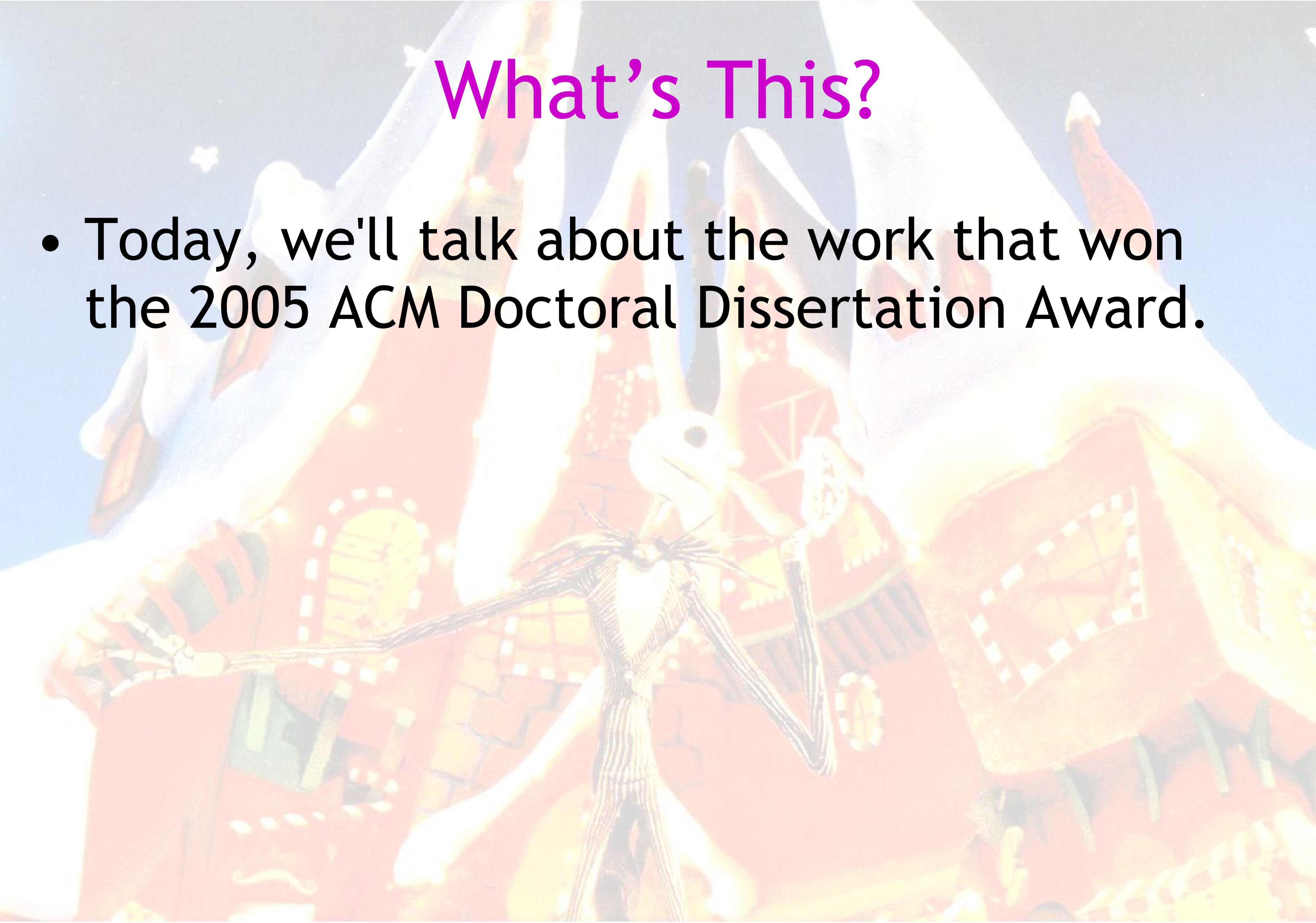
Editing He-Man

From Wikipedia, the free encyclopedia that anyone can edit

He-Man is actually a tremendous jackass and no really that powerful. He hangs out with a bunch of jerks like Peela and Dorko, He has a cat who is also dumb and _

What’s This?

- Today, we'll talk about the work that won the 2005 ACM Doctoral Dissertation Award.



Sic Transit Gloria Raymondi

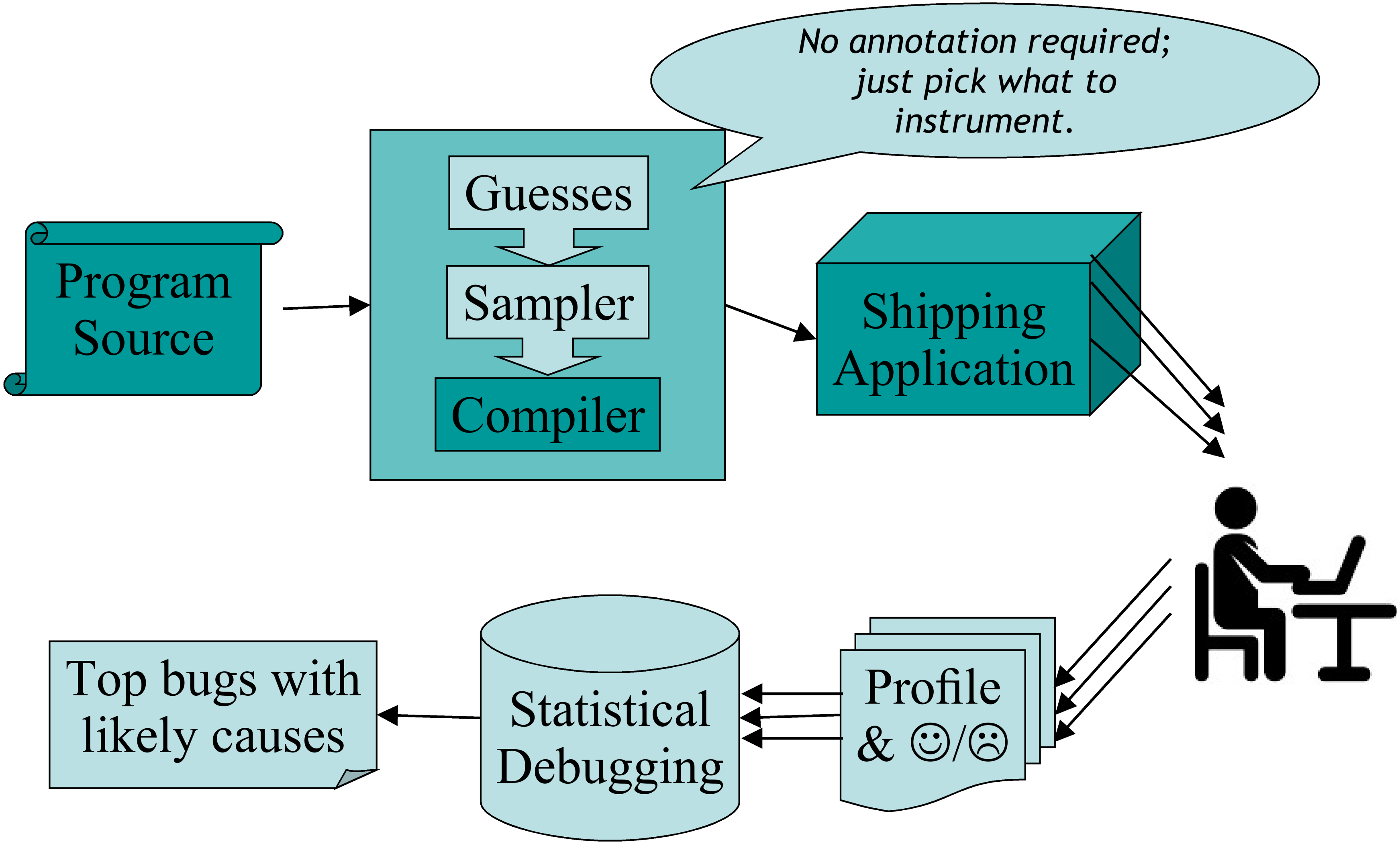
Eric S. Raymond: *"Given enough eyeballs, all bugs are shallow."*

- Bugs experienced by users matter.
- We can use information from user runs of programs to find bugs.
- Random sampling keeps the overhead of doing this low.
- Large public deployments exist.

Today’s Goal: Measure Reality

- We measure bridges, airplanes, cars…
  - Where is flight data recorder for software?
- Users are a vast, untapped resource
  - 60 million XP licenses in first year; 2/second
  - 1.9M Kazaa downloads per week in 2004; 3/s
  - Users know what matters most
    - Nay, users *define* what matters most!
- Opportunity for *reality-directed* debugging
  - Implicit bug triage for an imperfect world

Bug Isolation Architecture



Why Will This Work?

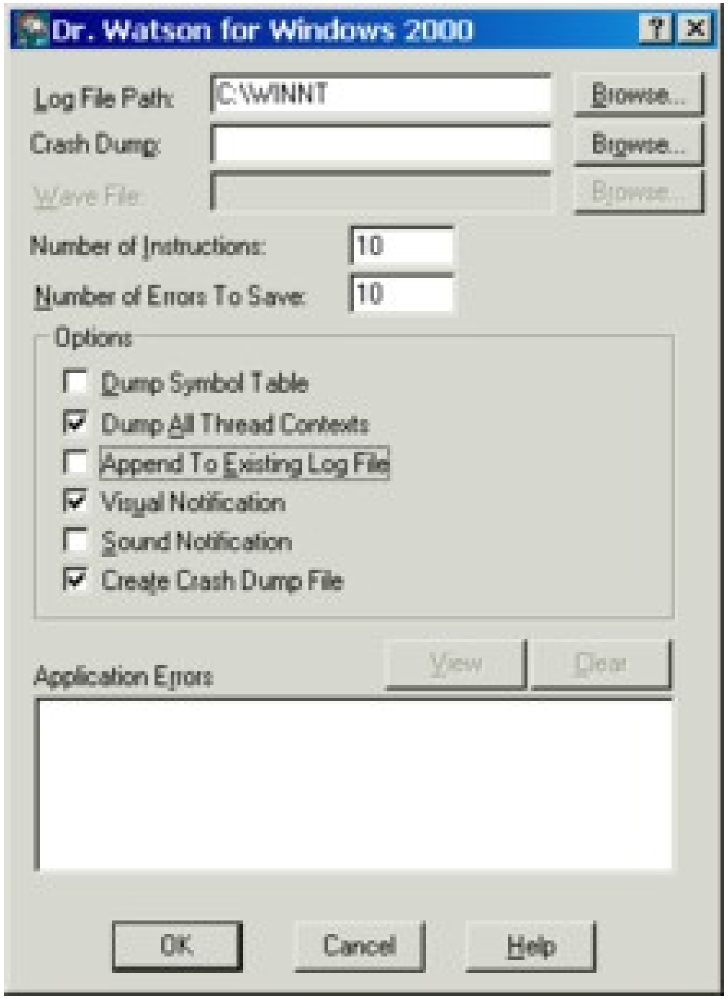
- Good News: Users can help!
- Important bugs happen often, to many users
  - User communities are big and growing fast
  - **User runs vastly exceed testing runs**
  - Users are networked
- We *can* do better, with help from users!
  - cf. crash reporting (Microsoft, Netscape)
  - Today: research efforts

“There are no significant bugs in our released software that any significant number of users want fixed.”

-- Bill Gates in 1995

Crash Reports

- In use since the mid 1990s
- Stack trace, memory address, details about host configuration, ...
- Advantage: fast and easy
- Limitations:
  - Crashes don't always occur “near” the defect
  - Hard to tell which crashes correspond to the same bug



Dr. Watson for Windows 2000

Log File Path: C:\WINNT

Crash Dump:

Wave File:

Number of Instructions: 10

Number of Errors To Save: 10

Options

☐ Dump Symbol Table
☑ Dump All Thread Contexts
☐ Append To Existing Log File
☑ Visual Notification
☐ Sound Notification
☑ Create Crash Dump File

Application Errors

Let’s Use Randomness

- Problem: recording everything is too expensive!

How do profilers work?

- Idea: each user records 0.1% of everything
- Generic sparse sampling framework
  - Adaptation of Arnold & Ryder
- Suite of instrumentations / analyses
  - Sharing the cost of assertions
  - Isolating deterministic bugs
  - Isolating non-deterministic bugs

Sampling Blocks

- Consider this code:

```
check(p != NULL);
p = p -> next;
check(i < max);
total += sizes[i];
```

- We want to sample 1/100 of these checks

Global Counter

- Solution?
  - Maintain a global counter modulo 100

```
for (i=0; i<n; i++) {
  check(p != NULL);
  p = p -> next;
  check(i < max);
  total += sizes[i];
}
```

Global Counter

- Solution?
  - Maintain a global counter modulo 100

```
for (i=0; i<n; i++) {
  check(p != NULL);
  p = p -> next;
  check(i < max);
  total += sizes[i];
}
```

Records the first check 1/50 times.

Never records the other.

Random Number Generator

- Solution? Use random number generator.

```
if (rand(100)==0) check(p != NULL);
p = p -> next;
if (rand(100)==0) check(i < max);
total += sizes[i];
```

Random Number Generator

- Solution? Use random number generator.

```
if (rand(100)==0) check(p != NULL);
p = p -> next;
if (rand(100)==0) check(i < max);
total += sizes[i];
```

Calling rand()
is more expensive
than the check!

Sampling the Bernoulli Way

- Identify the points of interest
- Decide to examine or ignore each site…
  - Randomly
  - Independently
  - Dynamically

✘ Cannot use clock interrupt: no context

✘ Cannot be periodic: unfair

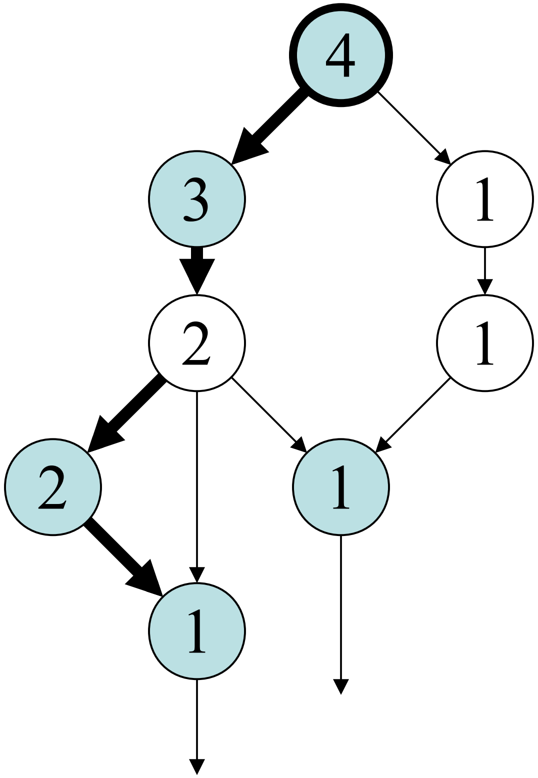
✘ Cannot toss coin at each site: too slow

Anticipating the Next Sample

- Randomized global countdown
- Selected from *geometric distribution*
  - Inter-arrival time for biased coin toss
  - Stores: How many tails before next head?
    - i.e., how many sampling points to skip before we write down the next piece of data?
- Mean of distribution = expected sample rate

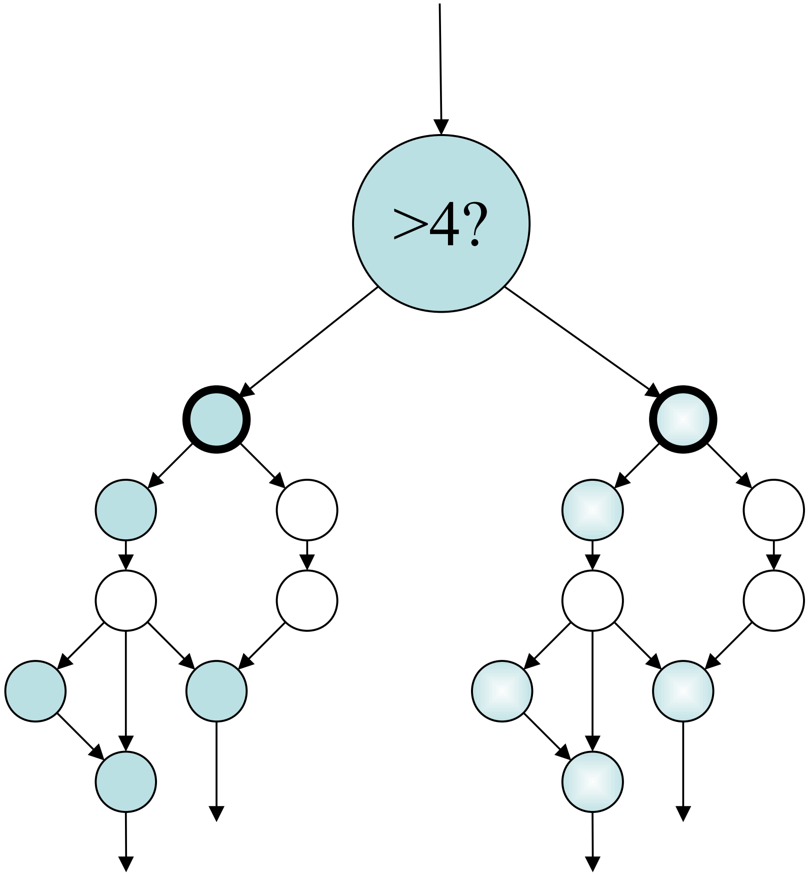
Amortized Coin Tossing

- Each acyclic region:
  - Finite number of paths
  - Finite max number of instrumentation sites
  - Shaded nodes represent instrumentation sites X



Amortized Coin Tossing

- Each acyclic region:
  - Finite number of paths
  - Finite max number of instrumentation sites
- Clone each region
  - “Fast” variant
  - “Slow” sampling variant
- Choose at run time



Two Code Paths

- **Fast Code Path**

```
if (counter > 2) {
  p = p -> next;
  total += sizes[i];
  counter -= 2;
}
```

- **Slow Code Path**

```
if (counter-- == 0)
  check(p != NULL);
p = p -> next;
if (counter-- == 0)
  check(i < max);
total += sizes[i];
```

Optimizations

- Cache global countdown in local variable
  - Global → local at func entry & after each call
  - Local → global at func exit & before each call
- Identify and ignore “weightless” functions
- Avoid cloning
  - Instrumentation-free prefix or suffix
  - Weightless or singleton regions
- Static branch prediction at region heads
- Partition sites among several binaries
- Many additional possibilities …

Q. Computer Science

- Along with Shamir and Adleman, this American Turing-award winner is credited with revolutionizing public key cryptography. He is also responsible for the RC5 symmetric key encryption algorithm (“RC” stands for “*his* Cypher”) and the MD5 cryptographic hash function. He is also a co-author of *Introduction to Algorithms* (aka CLRS).

Q. Philosophy and History

- This Greek (Macedonian) philosopher and scientist is known for writings on many subjects (physics, biology, logic, ethics, rhetoric, etc.). His works form the first comprehensive Western philosophy. Encyclopaedia Britannica claims he, “was the first genuine scientist in history ... [and] every scientist is in his debt.” He is credited with the earliest study of formal logic. Kant said that his theory of logic completely accounted for the core of deductive inference. His *Rhetoric* has been called “the most important single work on persuasion ever written.”

Sharing the Cost of Assertions

- Now we know how to sample things.
- Does this work in practice?
  - Let's do a series of experiments.
- First: microbenchmark for sampling costs!

- What to sample: **`assert()`** statements

- Identify (for debugging) assertions that
  - *Sometimes fail* on bad runs
  - But *always succeed* on good runs

Case Study: CCured Safety Checks

- Assertion-dense C code
- Worst-case scenario for us
  - Each assertion extremely fast
- No bugs here; purely performance study
  - Unconditional: 55% average overhead
  - $^1/_{100}$ sampling: 17% average overhead
  - $^1/_{1000}$ sampling: 10% average; half below 5%

Isolating a Deterministic Bug

- Guess predicates on scalar function returns

  `(f() < 0)` `(f() == 0)` `(f() > 0)`

- Count how often each predicate holds
  - Client-side reduction into counter triples
- Identify differences in good versus bad runs
  - Predicates *observed true* on some bad runs
  - Predicates *never observed true* on any good run

Function return triples aren't the only things we can sample.

Case Study: **`ccrypt`** Crashing Bug

- 570 call sites
- 3 × 570 = 1710 counters
- Simulate large user community
  - 2990 randomized runs; 88 crashes
- Sampling density $^1/_{1000}$
  - Less than 4% performance overhead
- Recall goal: sampled predicates should make it easier to debug the code …

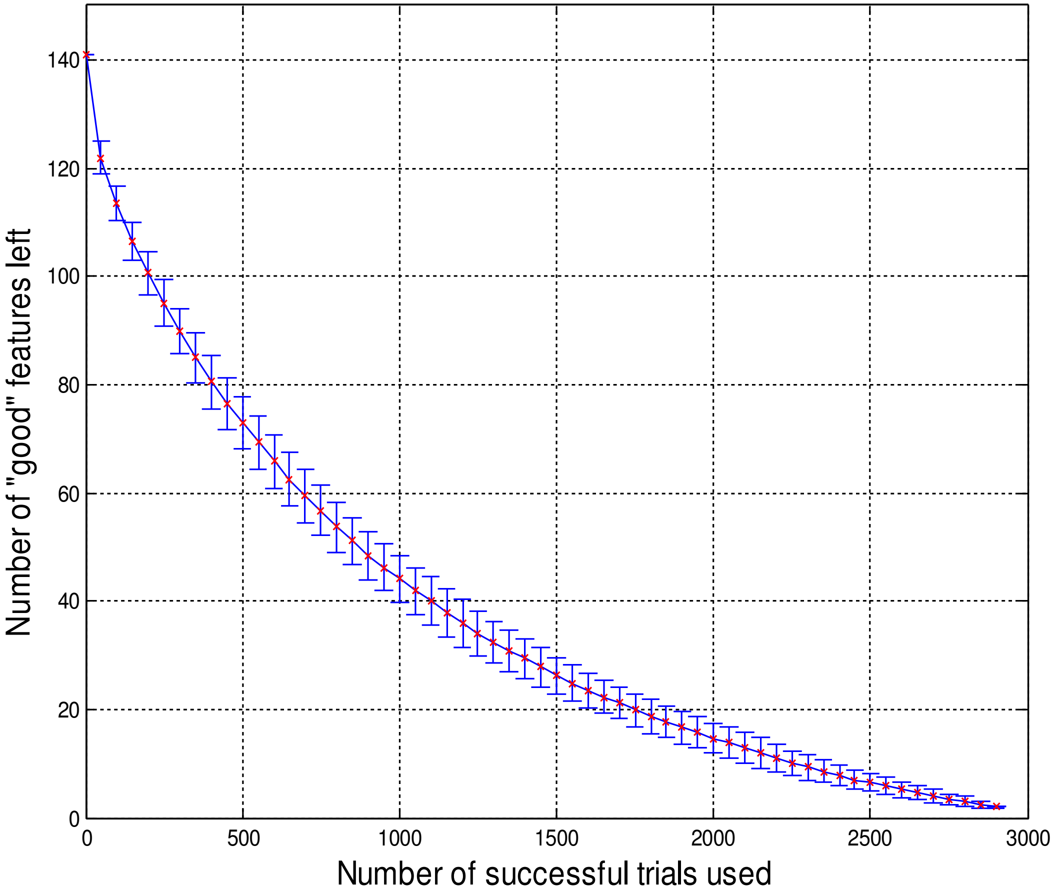
Winnowing Down to the Culprits

- 1710 counters
- 1569 are always zero
  - 141 remain
- 139 are nonzero on some successful run
- Not much left!

  file_exists() > 0

  xreadline() == 0

How do these pin down the bug? You'll see in a second.



Isolating a Non-Deterministic Bug

- Guess: at each direct scalar assignment

  `x = …`

- For each same-typed in-scope variable `y`
- Guess predicates on `x` and `y`

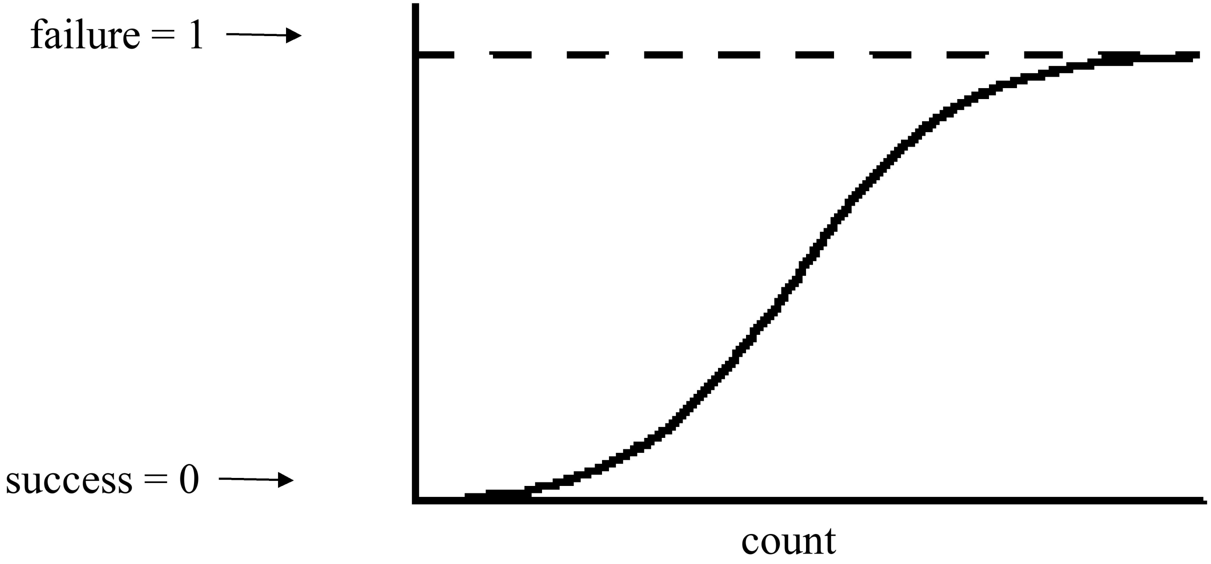
  `(x < y)`   `(x == y)`   `(x > y)`

- Compare: DIG, Daikon (invariant detection)
- Count how often each predicate holds
  - Client-side reduction into counter triples

Case Study: **`bc`** Crashing Bug

- Hunt for intermittent crash in **`bc-1.06`**
  - Stack traces suggest heap corruption
- 2729 runs with 9MB random inputs
- 30,150 predicates on 8910 lines of code
- Sampling key to performance
  - 13% overhead without sampling
  - 0.5% overhead with $^{1}/_{1000}$ sampling

Statistical Debugging via Regularized Logistic Regression



- S-shaped cousin to linear regression
- Predict success/failure as function of counters
- Penalty factor forces most coefficients to zero
  - Large coefficient ⇒ highly predictive of failure

Top-Ranked Predictors

```
#1: indx > scale
#2: indx > use_math
```

```
void more_arrays ()
{
  …

  /* Copy the old arrays. */
  for (indx = 1; indx < old_count; indx++)
    arrays[indx] = old_ary[indx];

  /* Initialize the new elements. */
  for (; indx < v_count; indx++)
    arrays[indx] = NULL;

  …
}
```

Top-Ranked Predictors

```
void more_arrays ()
{
  …

  /* Copy the old arrays. */
  for (indx = 1; indx < old_count; i
    arrays[indx] = old_ary[indx];

  /* Initialize the new elements. */
  for (; indx < v_count; indx++)
    arrays[indx] = NULL;

  …
}
```

#1: `indx > scale`
#2: `indx > use_math`
#3: `indx > opterr`
#4: `indx > next_func`
#5: `indx > i_base`

Bug Found: Buffer Overrun

```
void more_arrays ()
{
  …

  /* Copy the old arrays. */
  for (indx = 1; indx < old_count; indx++)
    arrays[indx] = old_ary[indx];

  /* Initialize the new elements. */
  for (; indx < v_count; indx++)
    arrays[indx] = NULL;

  …
}
```

Moving To The Real World

- Pick instrumentation scheme
- Automatic tool instruments program
- Sampling yields low overhead
- Many users run program
- Many reports ⇒ find bug
- So let's do it!

Multithreaded Programs

- Global next-sample countdown
  - High contention, small footprint
  - Want to use registers for performance

  ⇒Thread-local: one countdown per thread

- Global predicate counters
  - Low contention, large footprint

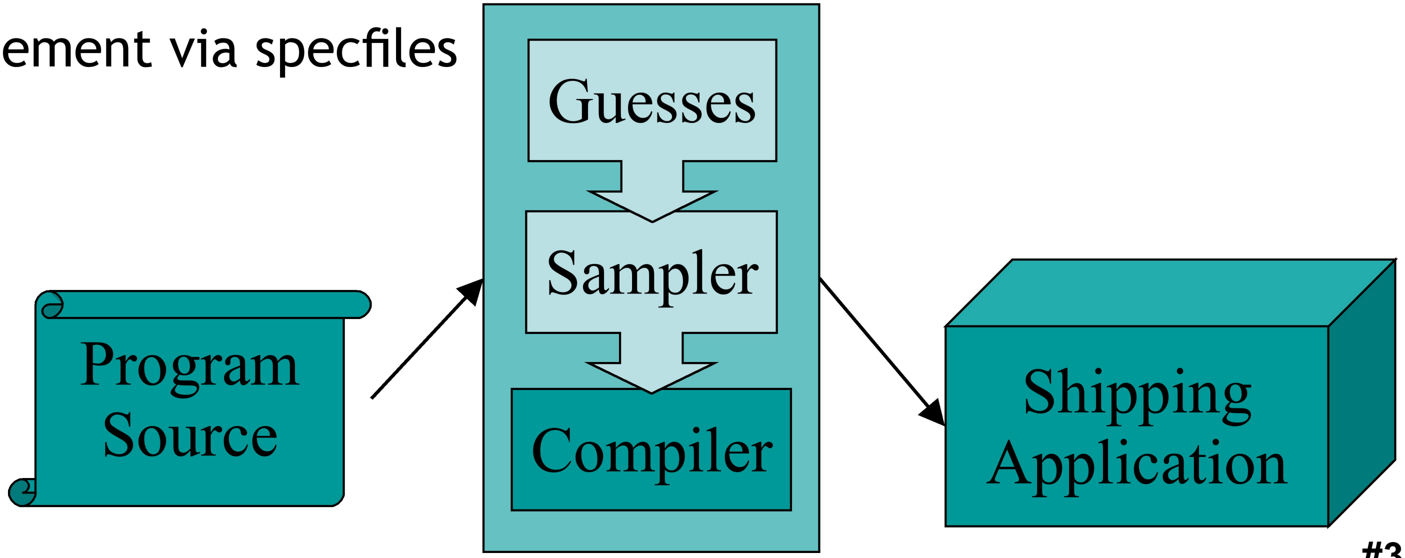
  ⇒Optimistic atomic increment

Multi-Module Programs

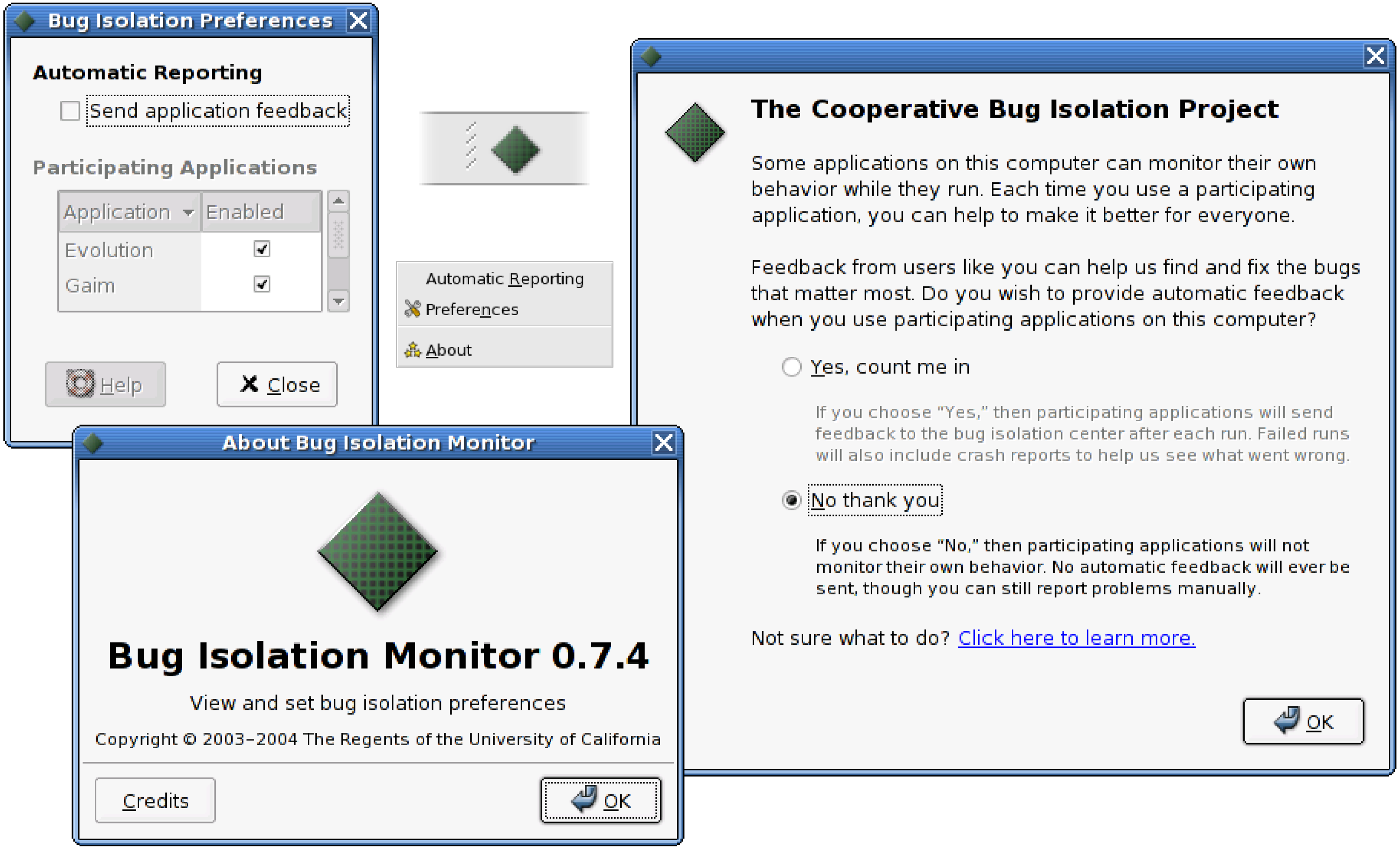
- Forget about global static analysis
  - Plug-ins, shared libraries
  - Instrumented & uninstrumented code
- Self-management at compile time
  - Locally derive identifying object signature
  - Embed static site information within object file
- Self-management at run time
  - Report feedback state on normal object unload
  - Signal handlers walk global object registry

Native Compiler Integration

- Instrumentor must mimic native compiler
  - You don’t have time to port & annotate by hand
- This approach: source-to-source, then native
- Hooks for GCC:
  - Stage wrapping via scripts
  - Flag management via specfiles



Keeping the User In Control



Bug Isolation Preferences

Automatic Reporting

□ Send application feedback

Participating Applications

Application	Enabled
Evolution	☑
Gaim	☑

The Cooperative Bug Isolation Project

Some applications on this computer can monitor their own behavior while they run. Each time you use a participating application, you can help to make it better for everyone.

Feedback from users like you can help us find and fix the bugs that matter most. Do you wish to provide automatic feedback when you use participating applications on this computer?

○ Yes, count me in

If you choose "Yes," then participating applications will send feedback to the bug isolation center after each run. Failed runs will also include crash reports to help us see what went wrong.

● No thank you

If you choose "No," then participating applications will not monitor their own behavior. No automatic feedback will ever be sent, though you can still report problems manually.

Not sure what to do? Click here to learn more.

About Bug Isolation Monitor

Bug Isolation Monitor 0.7.4

View and set bug isolation preferences

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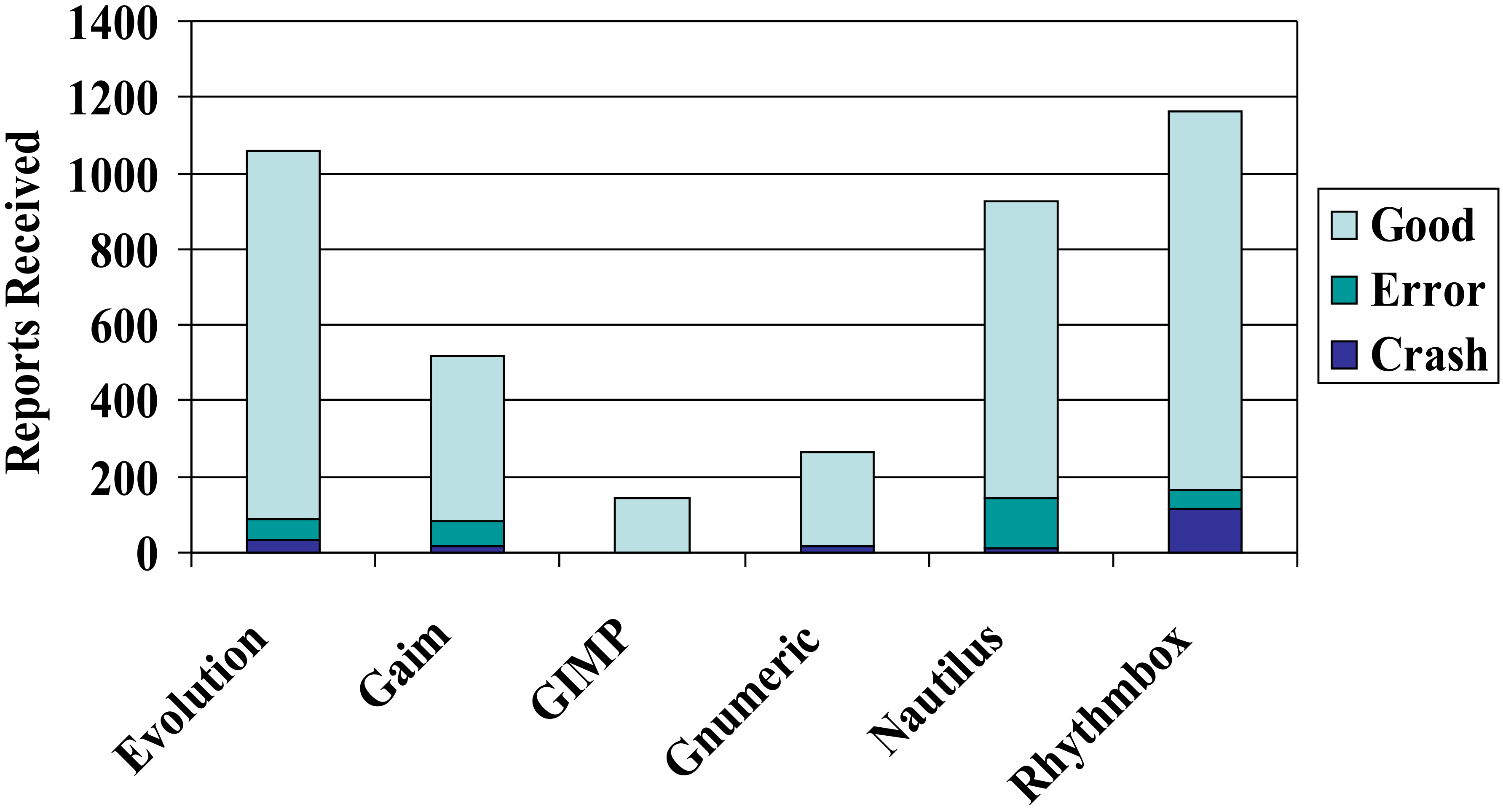
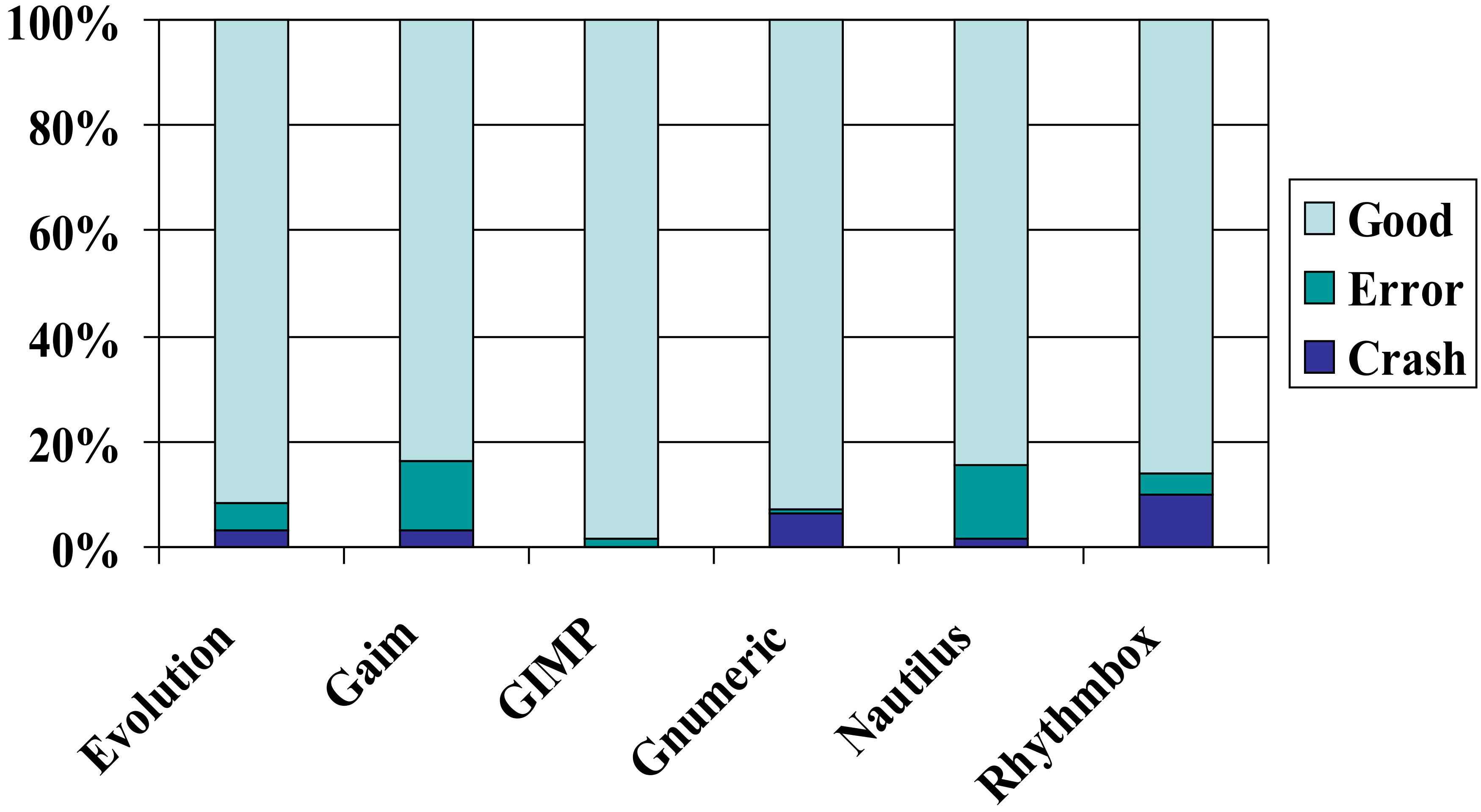
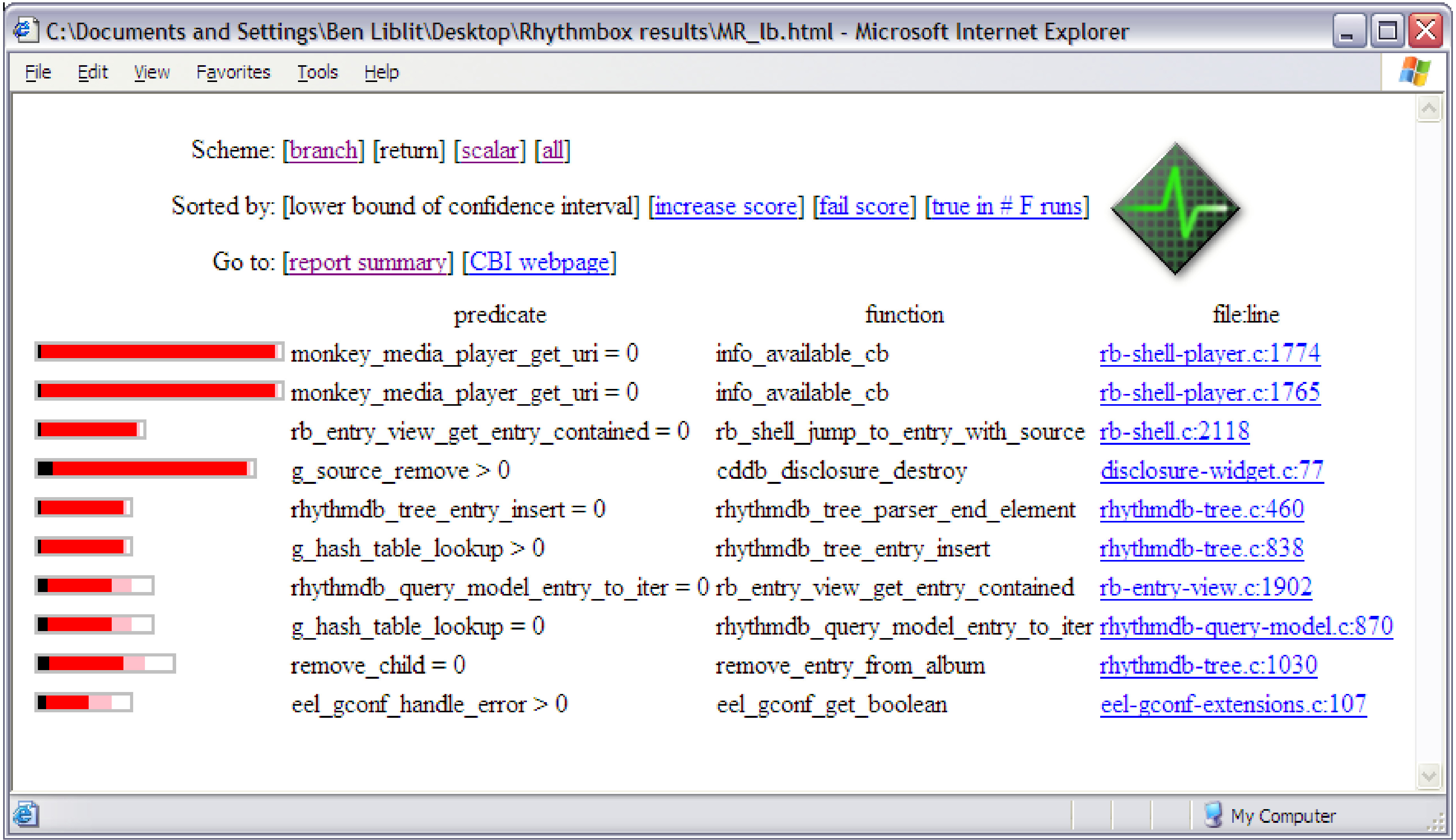
Public Deployment 2004



Public Deployment 2004



Sneak Peak: Data Exploration


C:\Documents and Settings\Ben Liblit\Desktop\Rhythmbox results\MR_lb.html - Microsoft Internet Explorer
File
Edit
View
Favorites
Tools
Help
My Computer

Scheme: [branch] [return] [scalar] [all]

Sorted by: [lower bound of confidence interval] [increase score] [fail score] [true in # F runs]

Go to: [report summary] [CBI webpage]

predicate	function	file:line
monkey_media_player_get_uri = 0	info_available_cb	rb-shell-player.c:1774
monkey_media_player_get_uri = 0	info_available_cb	rb-shell-player.c:1765
rb_entry_view_get_entry_contained = 0	rb_shell_jump_to_entry_with_source	rb-shell.c:2118
g_source_remove > 0	cddb_disclosure_destroy	disclosure-widget.c:77
rhythmdb_tree_entry_insert = 0	rhythmdb_tree_parser_end_element	rhythmdb-tree.c:460
g_hash_table_lookup > 0	rhythmdb_tree_entry_insert	rhythmdb-tree.c:838
rhythmdb_query_model_entry_to_iter = 0	rb_entry_view_get_entry_contained	rb-entry-view.c:1902
g_hash_table_lookup = 0	rhythmdb_query_model_entry_to_iter	rhythmdb-query-model.c:870
remove_child = 0	remove_entry_from_album	rhythmdb-tree.c:1030
eel_gconf_handle_error > 0	eel_gconf_get_boolean	eel-gconf-extensions.c:107

Summary: Putting it All Together

- Flexible, fair, low overhead sampling
- Predicates probe program behavior
  - Client-side reduction to counters
  - Most guesses are uninteresting or meaningless
- Seek behaviors that co-vary with outcome
  - Deterministic failures: process of elimination
  - Non-deterministic failures: statistical modeling

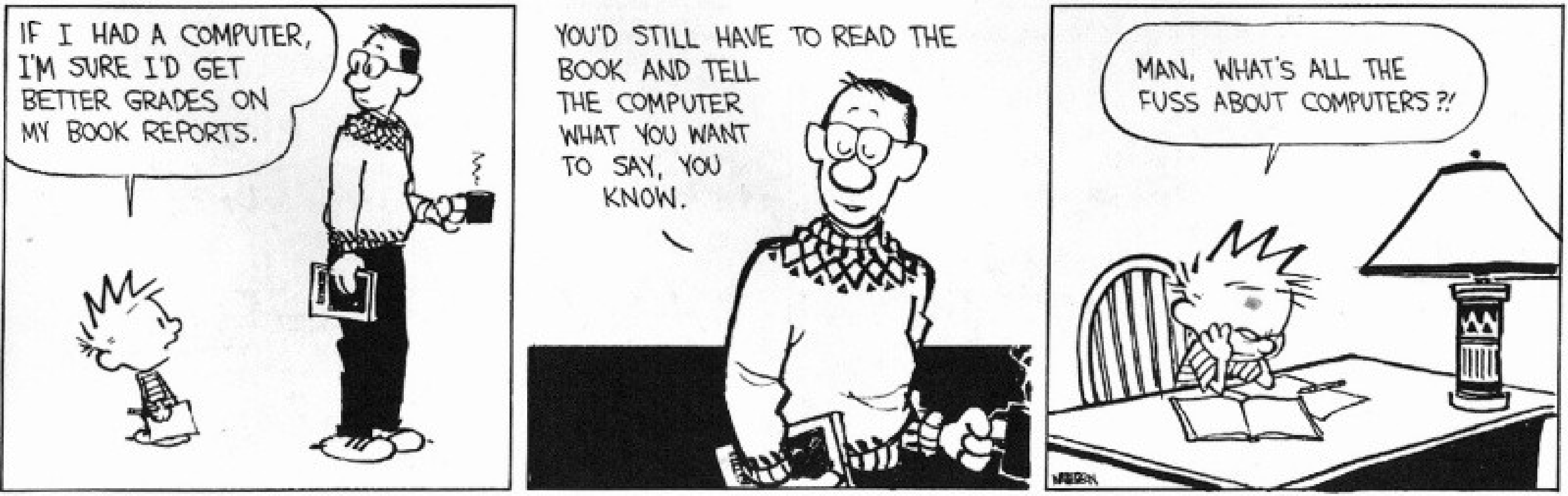
Conclusions

- Bug triage that directly reflects *reality*
  - Learn the most, most quickly, about the bugs that happen most often
- Variability is a benefit rather than a problem
  - Results grow stronger over time
- Find bugs while you sleep!
- Public deployment is challenging
  - Real world code pushes tools to their limits
  - Large user communities take time to build
- But the results are worth it:

“Thanks to Ben Liblit and the Cooperative Bug Isolation Project, this version of Rhythmbox should be the most stable yet.”

Homework

- Projects!


IF I HAD A COMPUTER, I'M SURE I'D GET BETTER GRADES ON MY BOOK REPORTS.
YOU'D STILL HAVE TO READ THE BOOK AND TELL THE COMPUTER WHAT YOU WANT TO SAY, YOU KNOW.
MAN, WHAT'S ALL THE FUSS ABOUT COMPUTERS ?!
WATTERSON