User Interaction Issues in Defect Detection Tools

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My first program analysis tool

- Implemented in Prolog
- Input: syntax tree for the program
  - (manually translated into Prolog representation)
- Output: complexity metrics
- Sample session:

```
> compute_metrics(Program, Metrics)
no.
```


Some more recent background: PREfix

- C/C++ defect detection via static analysis
- Powerful inter-procedural analysis
  - Incomplete
  - Unsound
  - Useful in practice
- Typically run as part of a centralized build
- V1.0: command-line tool
  - … no significant adoption
- V2.0 … V4.0: whole system (UI, DB)
  - … broad adoption

Even more recent background: PREfast

- Lightweight, “desktop” defect detection
- Simple intra-procedural analyses
- Compared to PREfix:
  - fewer defects
  - higher noise
  - fast
- V1.0: UI, XML log; fast adoption
- Infrastructure: plugins
  - New defects (e.g., I18N)
  - Platform for other tools

PREfast as an experiment

- What had we learned from PREfix?
  - Which defects people care about
  - Build integration techniques
  - User interaction techniques
  - Scalable, powerful analyses
- Replace the analyses with weak, fast ones
  - Leverage build integration, user interaction, knowledge
- Result: surprisingly well accepted

(yeah, yeah, I know, it’s not a controlled experiment …)

“Analysis is necessary, but by no means sufficient”

- Actual analysis is only a small part of any “program analysis tool”.
  - In PREfix, < 10% of the “code mass”
- No matter what the power of the analyses, make sure to consider other aspects as well

Stepping back a little …

- Why do people use a tool? If
  - it helps them get their work done …
  - … more efficiently than they would otherwise
  - … without making them look (or feel) bad.

User interaction is key to all of these points

Aside: See Alan Cooper's books, e.g. *About Face*

Successful tools

- Provide value …
- … at sufficiently low cost
- … and work in the target environment

  … which typically means with "average" developers

User interaction is once again key

From an internal presentation: Progress in "static analysis"

Integration
Use Model
Comprehension
Noise
Scalability

Defects

Usability Barriers

Capability

Apologies in advance

- My examples are by no means exhaustive
- I'm a tools junkie, not a research junkie
  - Please don't be offended if I fail to cite you!
- Examples are typically drawn from tools I've worked on or used
  - It's just familiarity, not any belief that these are better!

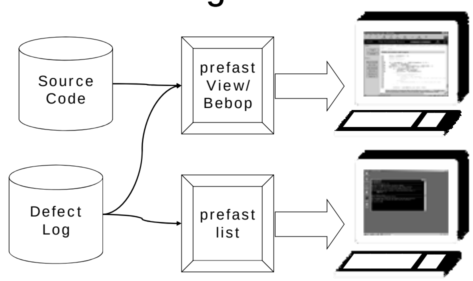
Key areas of user interaction for defect detection tools

- Specifying what properties to check
- Controlling the analysis
- Dealing with the results of the analysis
  - Viewing individual defects
  - Dealing with noise
  - Managing sets of defects

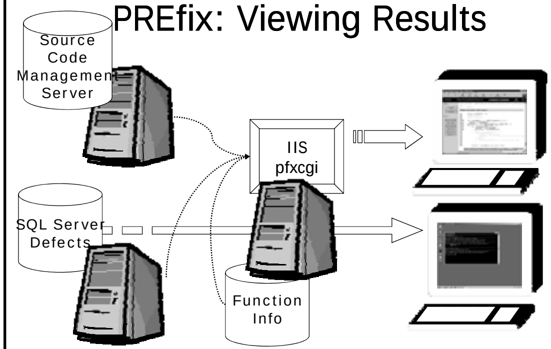
This presentation's focus

- Static analysis tools
- Dealing with the results of the analysis
  - Viewing individual defects
  - Dealing with noise
  - (Managing sets of defects?)

PREfast, SLAM, ESP: Viewing Results



PREfix: Viewing Results



Viewing individual defects

- An interesting question:

  Why don't static analysis tools report results as clearly and concisely as the compiler?

Sample compiler-reported defect

```
void f(char *p)
{
float f;
f = p;
}

example.c(4) : error C2115: '=' : incompatible types
```


Sample compiler-reported defect

```
#include <set>
std::set<const int> set;

xmemory(57) : error C2535: 'const int *__thiscall
   std::allocator<int const >::address(const int &) const': member
   function already defined or declared
        xmemory(54) : see declaration of 'address'
        xtree(51) : see reference to class template instantiation
   'std::allocator<int const >' being compiled
        set(33) : see reference to class template instantiation
   'std::_Tree<int const ,int const ,struct std::set<int const ,struct
   std::less<int const >,class std::allocator<int const > >::_Kfn,struct
   std::less<int const >,class std::allocator<int const > >' being compiled
        constint.cpp(2) : see reference to class template instantiation
   'std::set<int const ,struct std::less<int const >,class
   std::allocator<int const > >' being compiled
```


Sample compiler-reported defect

```
SymbolInfo *Find(ISymbolPtr id);
SymbolInfo *Find(char *name);
main() {
   const char* n = “a constant”;
   Find(n);
}

comip.h(690) : error C2227: left of '->QueryInterface'
   must point to class/struct/union
 comip.h(75) : see reference to function template
   instantiation 'long __thiscall _com_ptr_t<class
   _com_IIID<struct ISymbol,&struct __s_GUID
   _GUID_bd136bac_431b_4d58_af70_9cec395c3828>
   >::_QueryInterface(const char *const & )' being compiled
```

Sample compiler-reported defect

```
void f(char *p)
{
float f;
f = p;
}

example.c(4) : error C2115: '=' : incompatible types
```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   'std::_Tree<int const ,int const ,struct std::set<int const ,struct
   std::less<int const >,class std::allocator<int const > >::_Kfn,struct
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Sample compiler-reported defect

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   _GUID_bd136bac_431b_4d58_af70_9cec395c3828>
   >::_QueryInterface(const char *const & )' being compiled
```


Viewing individual defects

- A more relevant question – and answer
  - Why don’t static analysis tools (including the compiler) report complex defects as clearly and concisely as easy ones?
  - Because they’re complex, of course!

Sample defect #1

```
int f(int i)
{
int n;
if (i == 0)
   n = 1;
return n;
}
```


Sample defect #1: compiler warning

```
int f(int i)
{
int n;
if (i == 0)
   n = 1;
return n;
}

uwmsrsi1.c(6) : warning C4701: local variable 'n'
  may be used without having been initialized
```

Sample defect #1: PREfix warning

```
int f(int i)
{
int n;
if (i == 0)
   n = 1;
return n;
}
uwmsrsi1.c(6):warning 1: using uninitialized memory 'n'
  uwmsrsi1.c(3) : stack variable declared here
  Problem occurs when the following condition is true:
      uwmsrsi1.c(4) : when 'i != 0' here
  Path includes 2 statements on the following lines:
        4 6
```


Sample defect #1: PREfast/PREfix GUI

Sample defect #1: Comments

- Compiler warning doesn't give enough info
  - *When* is n uninitialized?
  - As a result, often not fixed
- Key techniques
  - Additional detailed information
  - Path
  - Link to additional information
- There's an information management problem
  - Even in simple example, output is very verbose

Sample defect #2

```
extern int phase_of_moon(void);

/* initialize the buffer; or return failure */
static int initialize(char *buff)
{
if (phase_of_moon())
   return 0;
buff[0] = 0;
return 1;
}
```


Sample defect #2 (cont.)

```
void uwsmsrsi2(void)
{
char buff[100];
initialize(buff);
if (buff[0] != 0)
   return;
/* ... */
}
```


Sample defect #2 : PREfix message

```
void uwsmsrsi2(void)
{
char buff[100];
initialize(buff);
if (buff[0] != 0)
   return;
/* ... */
}

uwmsrsi2.c(17) : warning 1: using uninitialized memory
        '(buff)[0]'
   problem occurs in function 'uwsmsrsi2'
   uwmsrsi2.c(15) : stack variable declared here
   Path includes 2 statements on the following lines:
         16 17
```

Sample defect #2: PREfix GUI

Sample defect #2: Comments

- Where's the defect?
  - The failure to initialize **buff** before calling **initialize**?
  - **initialize**'s failure to initialize **buff** in the error case?
  - The fact that **initialize** can fail?
  - The failure to check the return value of **initialize**?
  - What if the caller of uwmsrsi2 has previously verified that phase_of_moon() == 0
- Key technique:
  - Navigation across functions
  - (But how does the user know where to look?)
- Is there a way to present this in a single screen?

Sample defect #3

```
...
CHAR buff[MAX_PATH];
GetWindowsDirectory(buff, sizeof(buff));
SetCurrentDirectory(buff, sizeof(buff));
```


Sample defect #3: original PREfix message

```
...
CHAR buff[MAX_PATH];
GetWindowsDirectory(buff, sizeof(buff));
SetCurrentDirectory(buff, sizeof(buff));
```

Warning: using uninitialized memory buff[0]
Problem occurs in call to SetCurrentDirectory

Sample defect #3: explanation

```
...
CHAR buff[MAX_PATH];
GetWindowsDirectory(buff, sizeof(buff));
SetCurrentDirectory(buff, sizeof(buff));
```

GetWindowsDirectory can fail,
in which case it doesn't initialize its output

Sample defect #3: explanation

```
...
CHAR buff[MAX_PATH];
GetWindowsDirectory(buff, sizeof(buff));
SetCurrentDirectory(buff, sizeof(buff));
```

GetWindowsDirectory can fail,
in which case it doesn't initialize its output

But most people don't think of this, so think the message is noise

Sample defect #3: revised PREfix message

...

CHAR buff[MAX_PATH];

GetWindowsDirectory(buff, sizeof(buff));

Warning: Failure to check return value

SetCurrentDirectory(buff, sizeof(buff));

Sample defect #3: explanation

...

CHAR buff[MAX_PATH];

GetWindowsDirectory(buff, sizeof(buff));

SetCurrentDirectory(buff, sizeof(buff));

GetWindowsDirectory can fail,
So the return value must be checked

But most people don't BELIEVE this, so still think the message is noise

Sample defect #3: re-revised PREfix message

...

CHAR buff[MAX_PATH];

GetWindowsDirectory(buff, sizeof(buff));

Warning: Failure to check return value
  GetWindowsDirectory can fail in low-memory situations

SetCurrentDirectory(buff, sizeof(buff));

Sample defect #3: What I'd really like to see

PREfix' display mechanisms don't yet support this, but I'd rather see something like ...

CHAR buff[MAX_PATH];

GetWindowsDirectory(buff, sizeof(buff));

Warning: Failure to check return value
  GetWindowsDirectory can fail in low-memory situations

SetCurrentDirectory(buff, sizeof(buff));

Warning: using uninitialized memory buff[0]
  Problem occurs in call to SetCurrentDirectory
  Due to previous failure to check return value

Sample defect #3: Comments

- Key technique:
  - Iterative, detailed, defect-specific info
- But can the tool know all of that up front?
  - I tend to think not – instead, provide hooks for people to provide this information

PREfast "defect description"

- An XML description of each defect, with
  - Brief description (mandatory; everything else is optional)
  - Additional details
  - Effect of the defect
  - Hypothesis about cause (phrased as question)
  - Severity
  - One or more examples (erroneous and corrected code)
  - Documentation (as XHTML, RTF, or reference)
  - Help URL for more information
  - Owner's e-mail address
  - GUID

Sample defect #4

```
void uwmsrsi4(LPCTSTR in) {
TCHAR buff[100];
_tcsncpy(buff, in, sizeof(buff));
/* ... */
}
```

TCHAR is typedef'ed as either char or wchar_t, depending on whether UNICODE is defined

_tcsncpy expands to either strncpy or wcsncpy

Sample defect #4 PREfix 3.5 message

```
void uwmsrsi4(LPCTSTR in) {
TCHAR buff[100];
_tcsncpy(buff, in, sizeof(buff));
/* ... */
}
uwmsrsi4.c(10) : warning 23: bounds error
  (overflow): 'buff'
  used as parameter 1 (dest) of call to 'wcsncpy'
  size of buffer 'buff' is 200 bytes
  reference is 399 bytes from start of buffer
  uwmsrsi4.c(9) : stack variable declared here
```


Sample defect #4 PREfix 4.0 message

```
void uwmsrsi4(LPCTSTR in) {
TCHAR buff[100];
_tcsncpy(buff, in, sizeof(buff));
}

uwmsrsi4.c(10) : warning 51:  using number of bytes
  instead of number of characters for 'buff'
  used as parameter 1 (dest) of call to 'wcsncpy'
  size of buffer 'buff' is 200 bytes
  reference is 399 bytes from start of buffer
  uwmsrsi4.c(9) : stack variable declared here
  problem occurs when the following condition is true:
     uwmsrsi4.c(10) : when 'wcslen(in) >= 200'
          during call to 'wcsncpy' here
```


Sample defect #4: Comments

- Key technique:
  - Additional precision in the warning message
- The fact that it's a *stack* buffer is important for prioritizing the warning
  - There are well-known techniques for exploiting stack buffer overruns

Sample defect #5

```
#define CHECK(hr)  \
    {if (! SUCCEEDED(hr)) goto bail; }

int uwmsrsi_macro(void) {
  int i;
  CHECK(initialize(&i));
  return ++i;

bail:
  return 0;
}
```


Sample defect #6

```
int uwsmrsi_loop(void) {
int arr[5];
int i, total = 0;

arr[0] = 3; arr[1] = 1;
arr[3] = 4; arr[4] = 2;

for (i = 0; i < 5; i++)
   total += arr[i] * i;
return total;
}
```

Additional complexities

- Templates
- Value derivation
- Recursion
- Long functions
- Source code changes

What about more complex properties?

- Race conditions
- Deadlocks
- Arbitrary properties

SLAM "debugger" UI

Summarize vs. navigate?

- Ideally, want to summarize and hide unimportant details
  - But which details are important?
- Developers often think sequentially ...
  - ... even when this is less efficient

Noise

- Noise = "messages people don't care about"
  - (not just "bogus" messages)
- Usually, noise is worse than missing a defect

Too much noise
  => people won't use the tool
  == missing *all* the defects

Noise can result from

- Incorrect requirements
- Integration issues
- Usability issues (e.g., unclear messages)
- Parser incompatibilities
- Analysis inaccuracies
- ...

Dealing with noise

- Improving analysis is usually not sufficient
  - Sometimes, it's necessary
- Successful user interaction techniques:
  - Prioritization
  - History
  - Filtering
  - Improving presentation, navigation
  - Providing more detail

Message Prioritization

- Which messages correspond to defects that will actually be fixed?
- "Rank": a synthetic metric of a message's "goodness"
  - Better-ranking messages are more likely to identify defects that will actually get fixed
- Multiple dimensions:
  - Severity of consequences
  - Likelihood that message is correct
  - Comprehensibility of message
  - ...

Noise and history

- Noise naturally increases over time
  - People fix the real defects
- A history mechanism avoids these problems
  - Distinguish newly-occurring messages
  - Goal: avoid re-examining noise messages
  - "Fuzzy" notion of equality survives code changes
- Code modification is also possible

Noise Example

- In 1999, 30% of PREfix-reported bugs in the "RAID" bug tracking system were being misdiagnosed
  - Real defects rejected as bogus
  - Unnecessary fixes for false messages
- Why? A surprising reason:
  - The URL describing a PREfix message wasn't self-descriptive, so couldn't be stored in RAID
  - Most people weren't even seeing the PREfix UI!
- Solution:
  - Make the URL's self-descriptive (duh)
  - Automatically store specific information and the URL as part of the RAID entry
- Result: misdiagnosis rate dropped below 5%

Approaches to sets of defects

- List
- GUI
  - List
  - Tabular
  - Tree
  - Filtering, Sorting, ...
- Database and query language
- Statistical analyses

Example: sets of defects

- Textual compiler output
- Compiler output in a dev environment
  - (emacs, Visual Studio, ...)
- Typo.pl: tabular view
- PREfix: tree/list, with filtering and sorting
  - Note: PREfix 4.0 moves to a tabular view
- PREfast: tabular, filtering

Observations

- Others have looked at this problem
  - Spreadsheets
  - OLAP/Data mining
  - "Information agent" work
- Improvements here are very highly leveraged
  - Reducing the number of defects to examine by an order of magnitude is much easier than reducing the time to examine a single defect by an order of magnitude …
- Prioritization and statistical analysis can make a big difference

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