

Software Security

Program Analysis with PREfast & SAL

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Static analysis aka source code analysis

Automated analysis *at compile time* to find *potential bugs*

Broad range of techniques, from light- to heavyweight:

1. simple syntactic checks, incl. grep or CTRL-F

```
grep " gets(" *.cpp
```

2. type checking

eg. adding an `int` and a `bool`

3. more advanced analyses taking into account semantics

using: dataflow analysis, control flow analysis, abstract interpretation, symbolic evaluation, constraint solving, program verification, model checking...

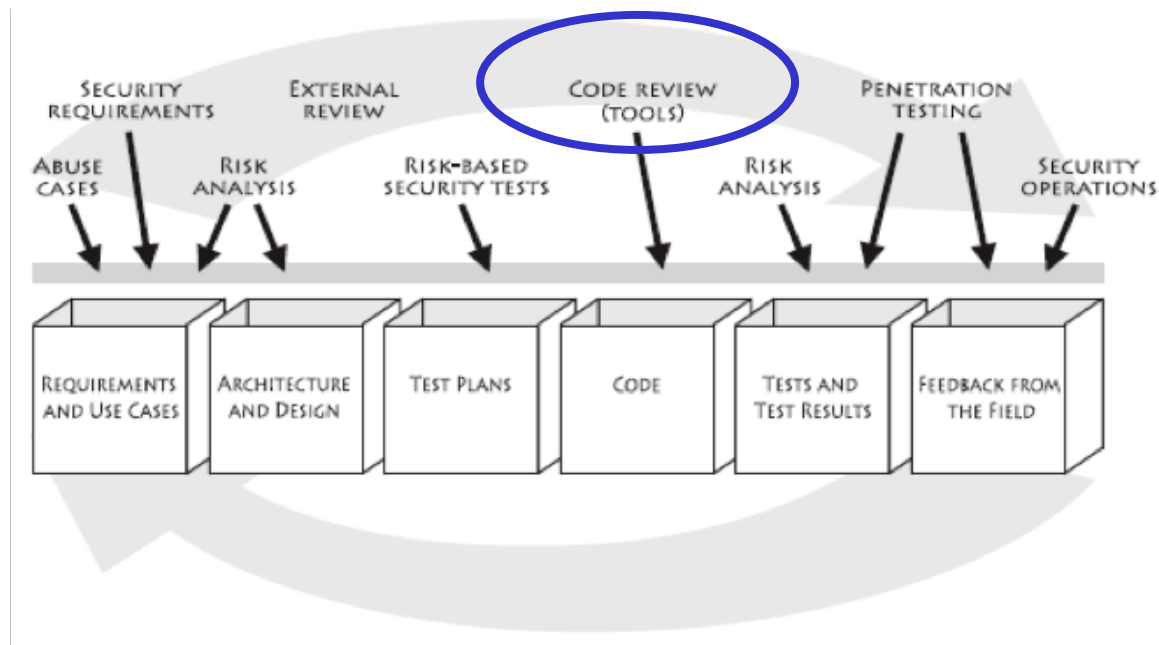
All compilers do some static analysis

Lightweight static analysis tools also called **source code scanners**.

Tools aiming at security: **SAST (Static Application Security Testing)**

Static analysis in the SDLC

In terms of McGraw's Touchpoints: **code review tools**



These tools can be applied *before* testing, or indeed even before the code can be run

Why static analysis? (1)

Traditional methods of finding errors:

- testing
- code inspection

Security errors can be hard to find by these methods, because they

- **only arise in unusual circumstances**
 - particular inputs uncommon execution paths, ...
- **code base is too large for a human code inspection**

Here static analysis can provide major improvement

Evolution of quality assurance at Microsoft

- **Original process: manual code inspection**
 - effective when team & system are small
 - too many paths/interactions to consider as system grew
- **Early 1990s: add massive system & unit testing**
 - Test took weeks to run
 - different platforms & configurations
 - huge number of tests
 - Inefficient detection of security holes
- **Early 2000s: serious investment in static analysis**

False positives & false negatives

Important quality measures for a static analysis:

A. rate of **false positives**

- **tool complains about non-error**

B. rate of **false negatives**

- **tool fails to complain about error**

Which do you think is worse?

False positives are worse, as they kill usability !!

Alternative terminology: an analysis can be called

- sound it only finds *real* bugs, ie no false positives
- complete it finds *all* bugs, ie. no false negatives

Very simple static analyses

- Warning about **bad names & violations of conventions**, eg
 - constants not written in ALL CAPS
 - Java method starting with capital letter
 - C# method starting with lower case letter
 - ...
- Enforcing other (company-specific) naming conventions and coding guidelines

This is also called **style checking**

More interesting static analyses

- Warning about **unused variables**
- Warning about **dead/unreachable code**
- Warning about **missing initialisation**
 - possibly as part of language definition (eg in Java) and checked by compiler

This may involve

control flow analysis


```
if (b) { c = 5; } else { c = 6; }   initialises c
if (b) { c = 5; } else { d = 6; }   does not
```

data flow analysis

```
d = 5;  c = d;           initialises c
c = d;  d = 5;           does not
```


Spot the defect!

```
BOOL AddTail(LPVOID p) {  
    ...  
    if(queue.GetSize() >= this->_limit);  
    {  
        while(queue.GetSize() > this->_limit-1)  
        {  
            ::WaitForSingleObject(handles[SemaphoreIndex], 1);  
            queue.Delete(0);  
        }  
    }  
}
```



Suspicious code in xpdfwin found by PVS-Studio (www.viva64.com).

V529 Odd semicolon ';' after 'if' operator.

Note that this is a very simple syntactic check!

You could (should?) use coding guidelines that disallow this, even though it is legal C++

Spot the security flaw!

```
static OSStatus SSLVerifySignedServerKeyExchange (SSLContext
*ctx, bool isRsa, SSLBuffer signedParams, uint8_t *signature,
UInt16 signatureLen)
{ OSStatus  err;
  ..
  if((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
    goto fail;
  if((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
    goto fail;
  goto fail; ⚡
  if((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
    goto fail;
  ...
fail:
  SSLFreeBuffer(&signedHashes);
  SSLFreeBuffer(&hashCtx);
}
```

Infamous goto bug in iOS implementation of TLS

- **Dead code analysis** would easily reveal this flaw!
- Or simply code style that insists you **always use { }** for branches

Spot the 2 defects!

```
void start_engine_control() {
    char* buf2 = malloc (2*SOME_CONSTANT);
    char* buf = malloc (SOME_CONSTANT);
    start_engine();
    memset(buf2, 0, SOME_CONSTANT);
        // initialise first half of buf2 to 0

    // main loop
    while (true) {
        get_readings(buf,buf2);
        perform_engine_control(buf,buf2);
    }
}
```

Spot the defects!

possible integer overflow
(hard to check for code analyser, but for a constant is may be doable)

```
void start_engine_control() {
    char* buf2 = malloc (2*SOME_CONSTANT);
    char* buf = malloc (SOME_CONSTANT);
    start_engine();
    memset(buf2, 0, SOME_CONSTANT);
    // initialise first half of buf2 to 0

    // main loop
    while (true) {
        get_readings(buf,buf2);
        perform_engine_control(buf,buf2);
    }
}
```

No check if mallocs succeeded!!
(easier to check syntactically)

Check you mallocs!

```
void start_engine_control() {  
    ...  
    char* buf = malloc (SOME_CONSTANT);  
    if (buf == NULL) { // now what?!?!?  
        exit(0); // or something more graceful??  
    }  
    ...  
    start_engine();  
    perform_engine_control(buf);  
}
```

Typically, the place where malloc fails is the place to think about what to do.

The alternative is not check the result of malloc here, and simply let `perform_engine_control` segfault or let this function check for null arguments, but there we have even less clue on what to do.

Spot the defect :-)



First Ariane V launch

integer overflow in conversion of 64 bit float to 16 bit int
https://www.youtube.com/watch?v=PK_yguLapgA

Limits of static analyses

Does

```
if (i < 5 ) { c = 5; }
```

```
if ((i < 0) || (i*i > 20 )){ c = 6; }
```

initialise c?

Many analyses become hard – or undecidable - at some stage

Analysis tools can then:

- report that they “**DON'T KNOW**”
- give a (possible) **false positive**
- give a (possible) **false negative**

Example source code analysis tools

- free tools for Java: CheckStyle, PMD, Findbugs,.....
- for C(++) from Microsoft: PRefix, PRefast, FxCop
- outdated, but free tools focusing on security
 - ITS4 and Flawfinder (C, C++), RATS (also Perl, PHP)
- commercial
 - Coverity (C/C++), Klocwork (C/C++, Java), VeraCode (Java, C#, C/C++, JavaScript...), PVS-Studio (C++, C#, Java), PolySpace (C/C++, Ada), SparkAda (Ada)
- for web-applications
 - Fortify, Microsoft CAT.NET, IBM AppScan, VeraCode, RIPS..
- for many languages: Semmle (bought by github)

easy & fun
to download
and try out!

*Such tools can be useful, but... **a fool with a tool is still a fool***

PREfast & SAL

PREfast & SAL

- Developed by Microsoft as part of major push to improve quality assurance
- **PREfast** is a lightweight static analysis tool for C(++)
 - only finds bugs within a single procedure
- **SAL** (Standard Annotation Language) is a language for annotating C(++) code and libraries
 - SAL annotations improve the results of PREfast
 - more checks
 - more precise checks
- PREfast is included in some variants of Visual Studio

PREfast checks

- **library function usage**
 - deprecated functions
 - eg gets()
 - correct use of functions
 - eg does format string match parameter types?
- **coding errors**
 - eg using = instead of == in an if-statement
- **memory errors**
 - assuming that malloc returns non-zero
 - going out of array bounds

PREfast example

```
_Check_return_ void *malloc(size_t s);
```

_Check_return_ means that caller *must* check the return value of `malloc`

PREfast annotations for buffers

```
void memset( char *p,  
            int v,  
            size_t len);
```

```
void memcpy( char *dest,  
            char *src,  
            size_t count);
```

SAL annotations for buffer parameters

- `_In_` The function **reads** from the buffer. The caller provides the buffer and initializes it.
- `_Inout_` The function both **reads** from and **writes** to buffer. The caller provides the buffer and initializes it.
- `_Out_` The function **only writes** to the buffer. The caller must provide the buffer, and the function will initialize it..

PREfast can use these annotations to check that (uninitialised) variables are not read before they are written

SAL annotations for buffer sizes

specified with suffix of `_In_` `_Out_` `_Inout_` `_Ret_`

- `cap_(size)` the *writable* size in elements
- `bytecap_(size)` the *writable* size in bytes
- `count_(size)` `bytecount_(size)`
the *readable* size in elements

`count` and `bytecount` should be only be used for inputs, ie. parameter declared as `_In_`

PREfast can use these annotations to check for buffer overruns

SAL annotations for nullness of parameters

Possible (non)nullness is specified with prefix

- `opt_`
parameter may be null, and procedure will check for this
- no prefix means pointer may not be null

PREfast can use these annotations to spot potential null dereferences at compile-time

- So references are treated as **non-null by default**

PREfast example

```
void* memset( _Out_cap_(len) char *p,  
              int v,  
              size_t len);
```

_Out_cap_(len) specifies that

- `memset` will only write the memory at `p`
- It will write `len` bytes

PREfast example

```
void memcpy( _Out_cap_(count) char* dest,  
             _In_count_(count) char* src,  
             size_t count);
```

So memcpy will read src the and write to dest

Example annotation & analysis

```
void work() {  
    int elements[200];  
    wrap(elements, 200);  
}  
int *wrap(int *buf, int len) {  
    int *buf2 = buf;  
    int len2 = len;  
    zero(buf2, len2);  
    return buf;  
}  
void zero( int *buf,  
          int len){  
    int i;  
    for(i = 0; i <= len; i++) buf[i] = 0;  
}
```

Example annotation & analysis

```
void work() {  
  int elements[200];  
  wrap(elements, 200);  
}
```

PREfast builds **constraints**, based on annotations and on the program logic (eg. guards of if/while statements) and checks **contracts**

```
_Ret_cap_(len) int *wrap(  
  _Out_cap_(len) int *buf,  
  int len) {
```

```
  int *buf2 = buf;  
  int len2 = len;  
  zero(buf2, len2);  
  return buf;  
}
```

1. **constraint**

len = length(buf)

2. Check **contract (precondition)** of zero

3. Check **contract (postcondition)** of wrap

4. **constraints**

len = length(buf)

i ≤ len

```
void zero( _Out_cap_(len) int *buf,  
  int len){
```

5. Check

0 ≤ i < length(buf)

```
  int i;
```

```
  for(i = 0; i ≤ len; i++) buf[i] = 0;
```

```
}
```



SAL pre- and postconditions

```
#include </prefast/SourceAnnotations.h>
[SA_Post( MustCheck=SA_Yes )] double* CalcSquareRoot
    ([SA_Pre( Null=SA_No )] double* source,
     unsigned int size)
```

Here `[SA_Post (MustCheck=SA_Yes)]`
requires caller to check the return value of `CalcSquareRoot`
(this is an alternative syntax for `_Check_return_`)

and `[SA_Pre (Null=SA_No)]`
requires caller to pass non-null parameter `source`

Tainting annotations in pre/postconditions

You can specify pre- and postconditions to express if inputs or outputs of a methods maybe **tainted**

Here tainted means this is untrusted user input, which may be malicious

SAL specifications for tainting:

- `[SA_Pre(Tainted=SA_Yes)]`

This argument is tainted and cannot be trusted without validation

- `[SA_Pre(Tainted=SA_No)]`

This argument is not tainted and can be trusted

- `[SA_Post(Tainted=SA_No)]`

As above, but as postcondition for the result

Warning: changing SAL syntax

- SAL syntax keeps changing

For the exercise, stick to the syntax described in these slides & on the webpage for the exercise.

- PREfast behaviour can be a bit surprising when you use **count** instead of **cap** or when you use **bytecap** instead of **cap**

Benefits of annotations

- **Annotations express design intent**
for human reader & for tools
- **Adding annotations you can find more errors**
- **Annotations improve precision**
ie reducing false negatives and false positives
because tool does not have to guess design intent
- **Annotations improve scalability**
annotations isolate functions so they can be analysed one at a time:
 - it allows **intra-procedural (local) analysis**
 - instead of **inter-procedural (global) analysis**

Drawback of annotations

- The effort of having to write them...
 - who's going to annotate the millions of lines of (existing) code?
- Practical issue of motivating programmers to do this
- Microsoft's approach
 - requiring annotation on checking in new code
 - rejecting any code that has `char*` without `_count()`
 - incremental approach, in two ways:
 1. beginning with few core annotations
 2. checking them at every compile, not adding them in the end
 - build tools to infer annotations, eg SALInfer
 - unfortunately, not available outside Microsoft

Static analysis in the workplace

- **Static analysis is not for free:**
 - **Commercial tools cost money**
 - **Even free open source tools cost time & effort to learn to use**

Criteria for success

- **Acceptable level of false positives**
 - acceptable level of false negatives also interesting, but less important
- **Not too many warnings**
 - this turns off potential users
- **Good error reporting**
 - context & trace of error
- **Bugs should be easy to fix**
- **You should be able to teach the tool**
 - to suppress false positives
 - add design intent via assertions

Limitations of static analysis

Big challenges for static analysis are

1. **The heap (aka dynamic memory)** poses a major challenge for static analysis
 - The heap is a very dynamic structure evolving at runtime; what is a good abstraction at compile-time?
2. **Concurrency**

Many static analysis will disregard the heap completely & ignore the possibility for concurrency

- Note that all the examples in these slides did
- This is then a source of false positives and/or false negatives

Some coding standards for safety-critical code, eg **MISRA-C**, disallow use of the heap (aka dynamic memory)