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 – think of `grep` or `CTRL-F`

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

2. type checking

3. more advanced analyses take into account semantics

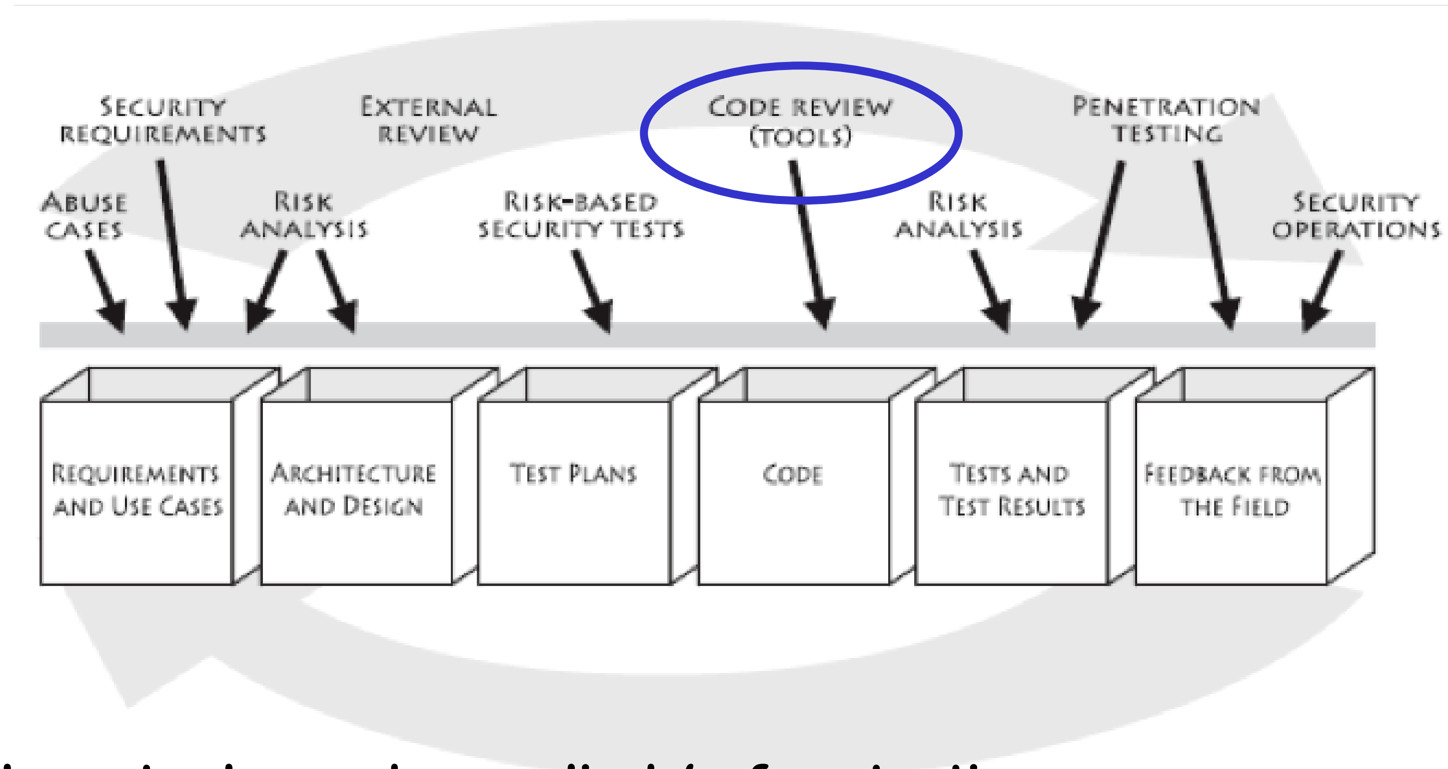
   – using: dataflow analysis, control flow analysis, abstract interpretation, symbolic evaluation, constraint solving, program verification, model checking...

The more lightweight tools are called source code scanners.

Tools that focus on security also called SAST (Static Application Security Testing)

Static analysis/source code 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 week 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:

- **rate of false positives**
  - **tool complains about non-error**
- **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 and violations of conventions, eg
  - Java method starting with capital letter
  - C# method name starting with lower case letter
  - constants not written with all capital letters
  - ...

- 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 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/SSL

Dead code analysis would easily reveal this flaw!

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);
 }
}
```

t(handles[SemaphoreIndex], 1); que

Spot the 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);
 }
}
```

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

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.

Limits of static analyses

Does

```
if (i < 5 ) { c = 5; }
if ((i < 0) || (i*i > 20 )){ c = 6; }
```

initialise c?

Many analyses become hard - if not undecidable - at some stage

Analysis tools can then...

- report that they "DON'T KNOW"
- give a (possibly) false positive
- give a (possibly) false negative

The PREfast tool can do some arithmetic

Example source code analysis tools

- for Java: CheckStyle, PMD, Findbugs,....
- for C(++): PVS-Studio
- for C(++) from Microsoft: PREfix, PREfast, FxCop
- somewhat outdated, but free tools focusing on security

  ITS4 and Flawfinder (C, C++), RATS (also Perl, PHP)
- commercial

  Coverity (C,C++), Klocwork (C(++), Java), PolySpace (C(++) , Ada), VeraCode (Java, .NET, C, C++, javascript...)
- for web-applications

  commercial: Fortify, Microsoft CAT.NET, VeraCode...

  open source: RIPS, OWASP Orizon, ...

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 is 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 (unitialised) variables are not read before they are written

SAL annotations for buffer sizes

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

- `cap_(size)` the *writeable* size in elements
- `bytecap_(size)` the *writeable* 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 deferences 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( char _Out_cap_(count) *dest,
             char _In_count_(count) *src,
             size_t count);
```

So `memcopy` 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);
}
_Ret_cap_(len)  int *wrap(
            _Out_cap_(len) int *buf,
                           int len) {
  int *buf2 = buf;
  int len2 = len;
  zero(buf2, len2);
  return buf;
}
void zero( _Out_cap_(len) int *buf,
                           int len){
  int i;
  for(i = 0; i <= len; i++)  buf[i] = 0;
}
```

Tool builds constraints (based on annotations and on the program logic (eg guards of if/while statements)

and checks contracts

1. Build constraint
   len = length(buf)
2. Check contract for call to zero
3. Check contract for return
4. Build constraints
   len = length(buf)
   i ≤ len
5. Check
   0<=i < length(buf)

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 – the current version is 2.0**

For the individual 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 reduce number of 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
    - 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 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
  - All 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

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**

In some coding standards for safety-critical code, eg MISRA-C, using the heap (aka dynamic memory) it is *not allowed at all*