Software Security

Static Analysis with PREfast & SAL

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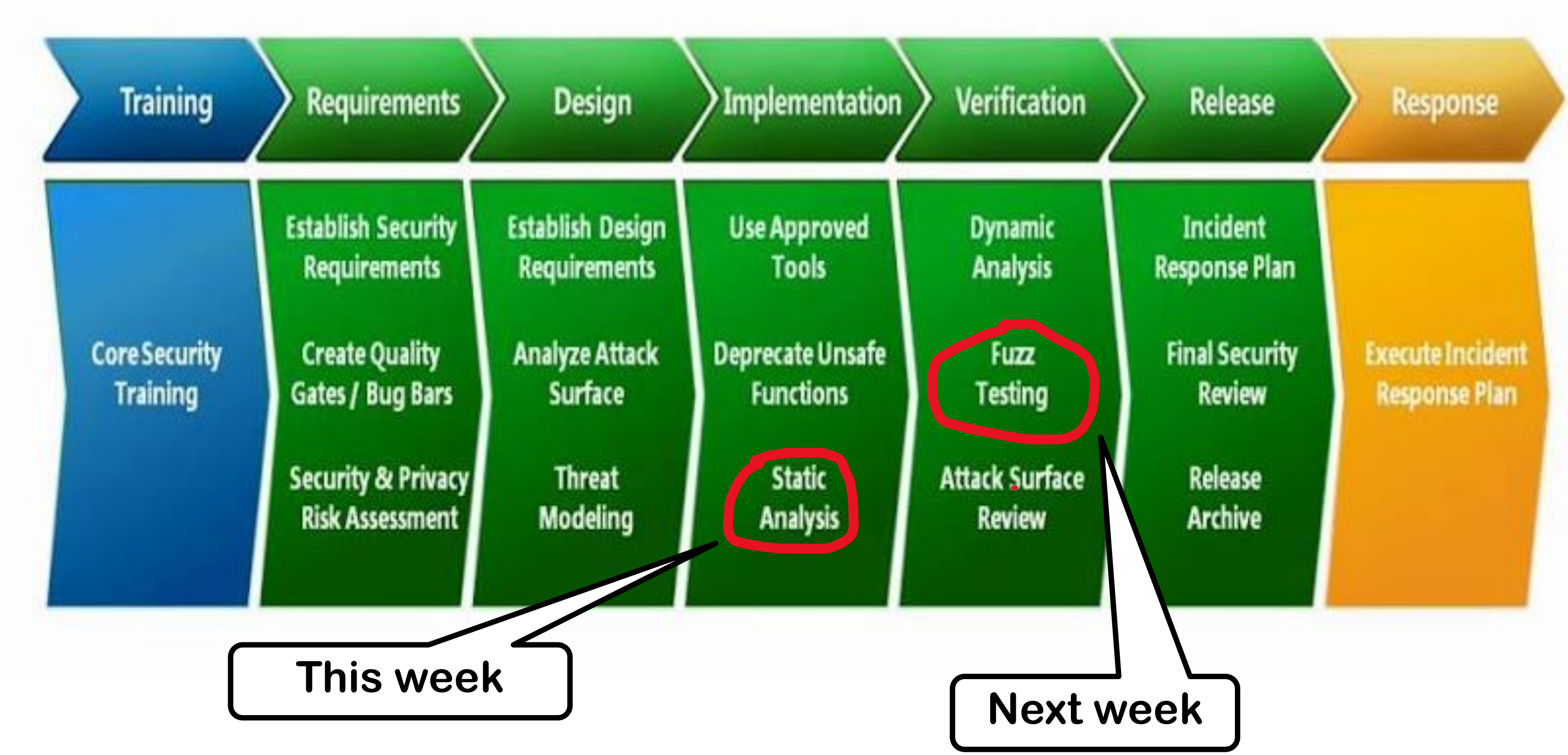
Finding & fixing memory corruption



Static analysis aka source code analysis aka SAST

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. warning if an `int` is added to a `bool`

3. **more advanced analyses taking semantics into account**

   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)

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

False positives & false negatives

Important quality measures for any 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 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.

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, SpotBugs (formerly 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++) , PolySpace (C/C++, Ada), SparkAda (Ada), Klocwork, PVS-Studio, Fortify, RIPS (PHP) , IBM AppScan, VeraCode, CheckMarx, SonarQube, Semmle (bought by github)

easy & fun to download and try out!

Some tools focus on C/C++, others on web applications

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 in noughties
- 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( _Out_cap_(count) char* dest,
             _In_count_(count) char* 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;
}
```

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

and checks contracts

1. constraint
   len = length(buf)
2. Check contract (precondition) of zero
3. Check contract (postcondition) of wrap

4. 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

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

- i.e. untrusted, potentially malicious user input,

- `[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 has changed a few times 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 <u>intra</u>-procedural (local) analysis

    instead of <u>inter</u>-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**

Should security analysists use these tools or should the developers?

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 a false positive, once and for all
  - 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)