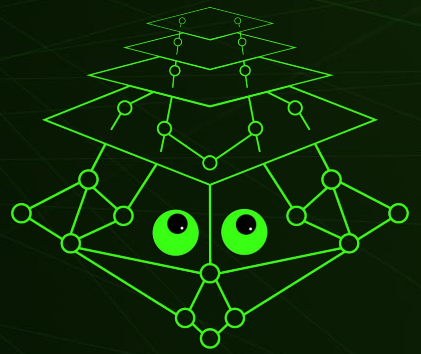
Workshop

Finding STRANGER THINGS in Code



JOERN

Suchakra Sharma
Staff Scientist, ShiftLeft Inc.

March 5, 2020
Pasadena, CA

SCaLE 18x

ShiftLeft

Let's Prep First

- *Clone Workshop Repo*
  - https://github.com/tuxology/joern-workshop
  - `apt install source-highlight graphviz unzip`
- *Download* ***joern-cli.zip*** *and extract it in the workshop directory*
  - https://github.com/ShiftLeftSecurity/joern/releases
  - `unzip joern-cli.zip`
- Download ***VLC v3.0.8*** source and extract in workshop directory
  - http://get.videolan.org/vlc/3.0.8/vlc-3.0.8.tar.xz
  - `tar -xvf vlc-3.0.8.tar.xz`

Suchakra Sharma

Staff Scientist, ShiftLeft Inc.

Github: tuxology
Twitter: @tuxology
Email: suchakra@shiftleft.io

PhD, École Polytechnique de Montréal

Loves systems, code analysis, performance analysis, hardware tracing, samosas and poutine!

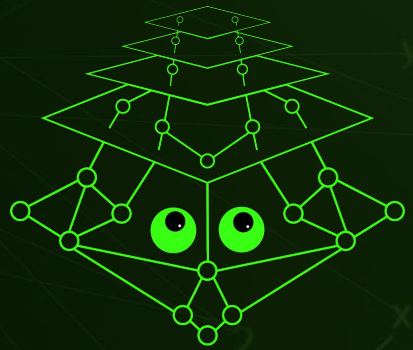
PepTalk

Why are you here?

- ***You want to,***
  - Hack and secure your applications
  - Learn how programming languages work
  - HUnt bugs and gain insights about your code
- ***Have questions like,***
  - What is static code analysis?
  - How do I do it interactively?
  - What is inside this mammoth code base?
  - What is even *code*? 😉

Pre-Workshop Poll

- ***I have used or know about***,
  - Interactive debuggers (GDB, rr)
  - SAST tools like Veracode/Coverity/FindSecBugs
  - Radare/PEDA/IDA Pro for security analysis
- ***I usually,***
  - Use Github to search through my code
  - Exclusively use an IDE/Editor to sift through my code
  - Grep through my source code looking for weird strings
  - Don't care about code

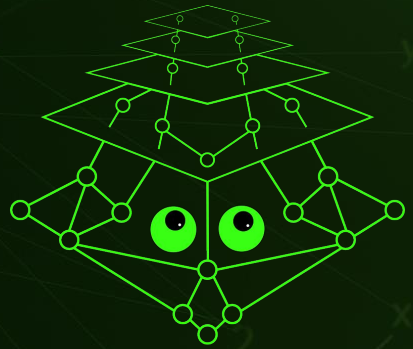


JOERN

Interactive Code Analysis

> *"Each program is its own universe, and hacking is about exploring, documenting and exploiting its rules"*
>
> *~ Fabian*

- Debugging goes hand in hand with running code
  - AddressSanitizer, ThreadSanitizer, profilers, linters
- Many tools run, and then give results but this approach flips the table - we give the tool to ask questions about the code
- It's like play-pause debugging, but for static analysis
  - IDA Pro, Radare, PEDA etc.



JOERN

Programming
Languages

What is even *code*?

```
int y = x + 50;
```

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```

Tokens

INTEGER ID(y) EQUAL ID(x)

ADD CONST(50) SEMICOLON

Lexical Analysis

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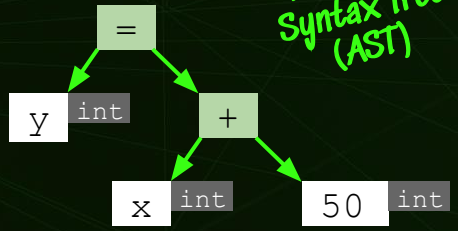

Abstract Syntax Tree (AST)

Syntactic & Semantic Analysis

What is even *code*?

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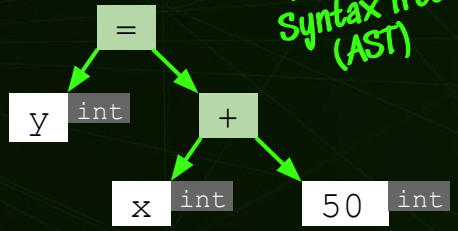
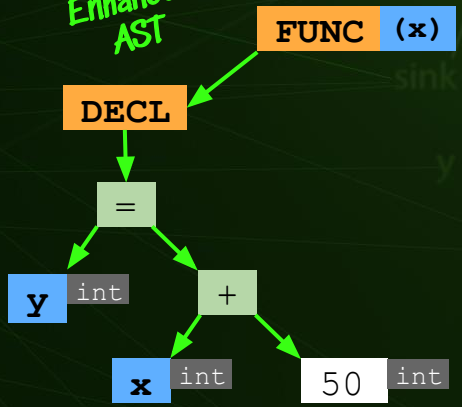


Abstract Syntax Tree (AST)

Syntactic & Semantic Analysis

Enhanced AST



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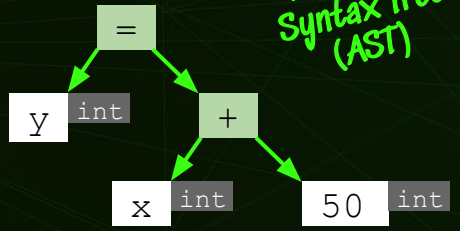
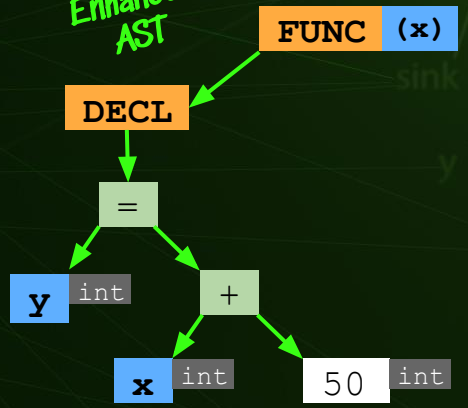


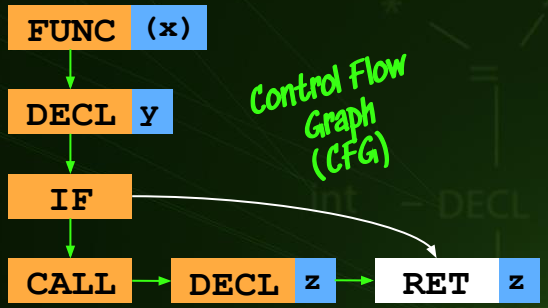
Syntactic & Semantic Analysis

Enhanced AST



Program Dependence Graph (PDG)

Control Flow Graph (CFG)



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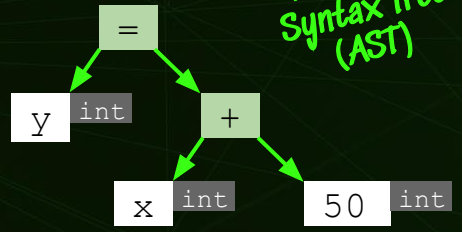

Abstract Syntax Tree (AST)

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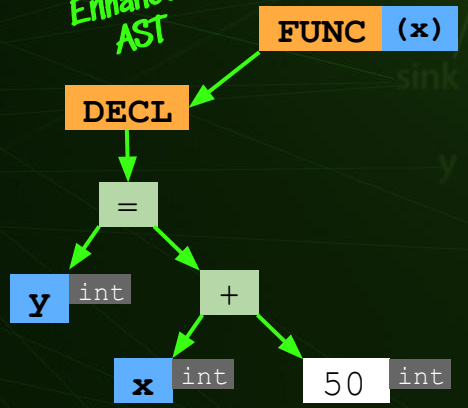

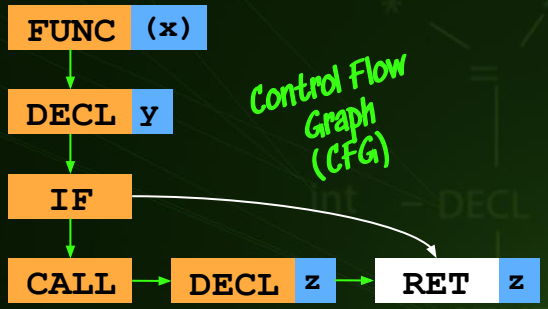

Control Flow Graph (CFG)

Program Dependence Graph (PDG)

```
10 = 50
11 = x + 10
y = 11
```

Translation

Optimizations
+
Register Alloc
+
Machine Code

Building Blocks of Code

```
import org.springframework.web.bind.annotation.RestController;

@RestController
public class PatientController {

  private static Logger log =
          LoggerFactory.getLogger(PatientController.class);

  ...

  @RequestMapping(value = "/patients", method = RequestMethod.GET)
  public Iterable<Patient> getPatient(Int id) {
      Patient pat = patientRepository.findById(id);

      if (pat != null) {
          log.info("First Patient is {}", pat.toString());
      }

      return patientRepository.findAll();
}
```

Building Blocks of Code

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        log.info("First Patient is {}", pat.toString());
    }

    return patientRepository.findAll();
  }
```

Class/Type

Package/Namespace

Member Variable

Annotation

Local Variable

Method Parameter

Method Definition

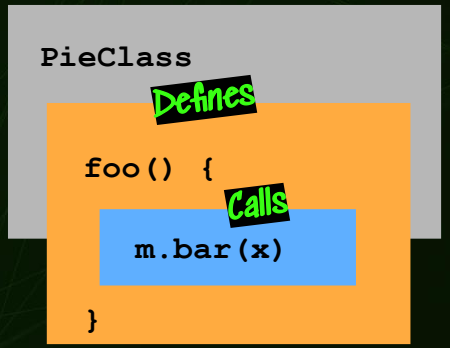
Method Block

Method Instance

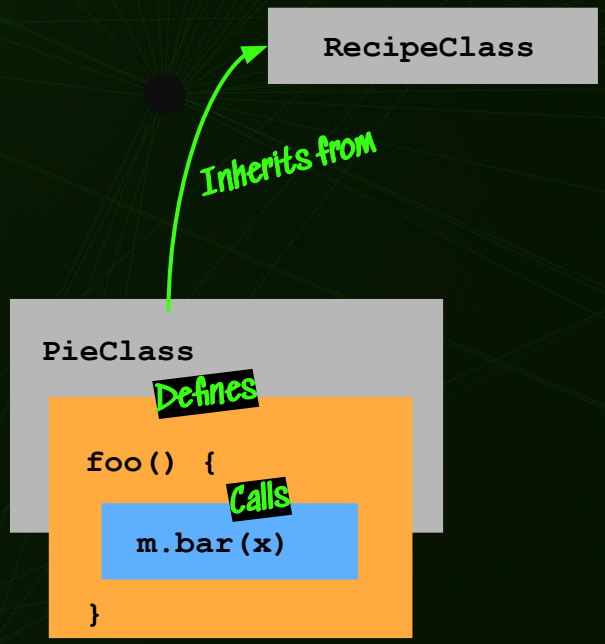
Literal

Method Return

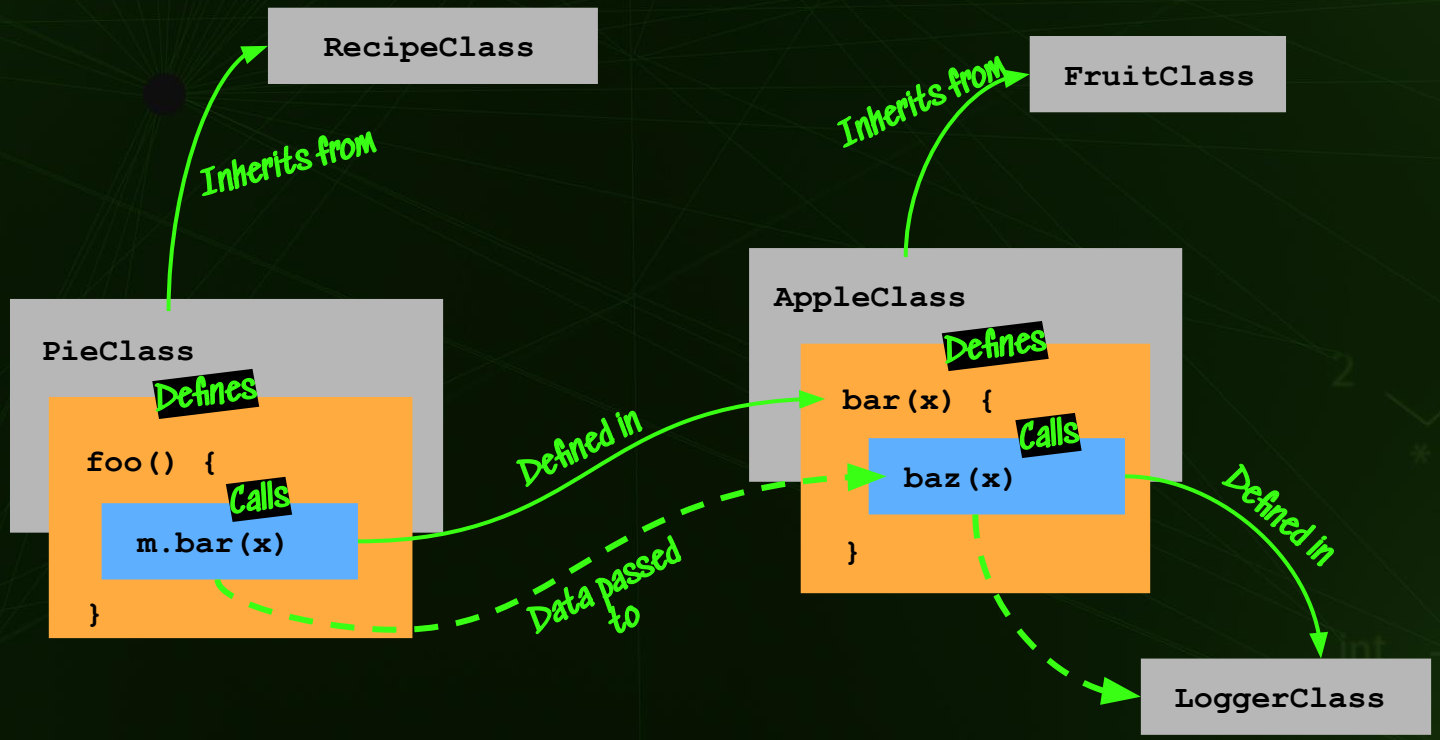
Building Blocks of Code



Building Blocks of Code



Building Blocks of Code



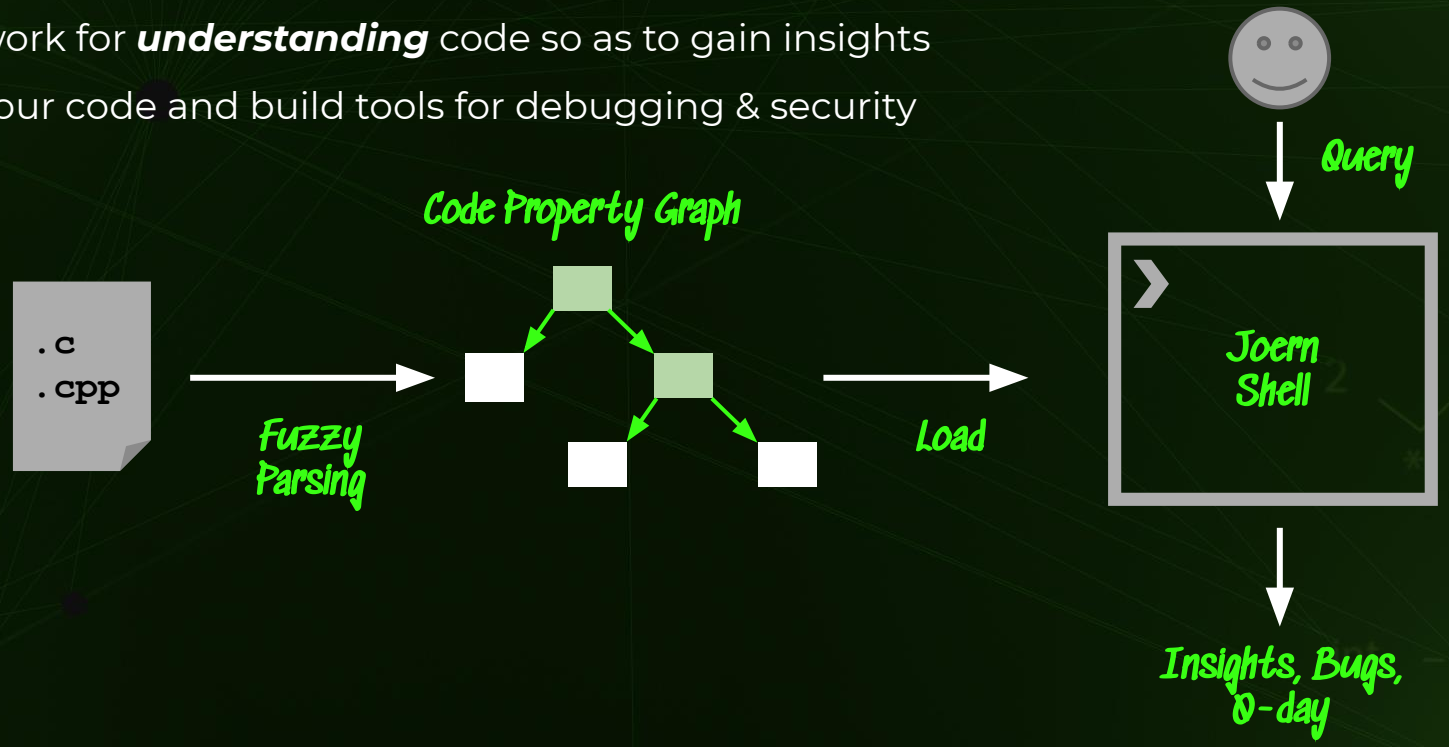
ALL THE CODE IS A GRAPH

If we think in graphs while coding, we should think in graphs while debugging

[Yo! Urn]

What is Joern?

Framework for ***understanding*** code so as to gain insights about your code and build tools for debugging & security



Module 1

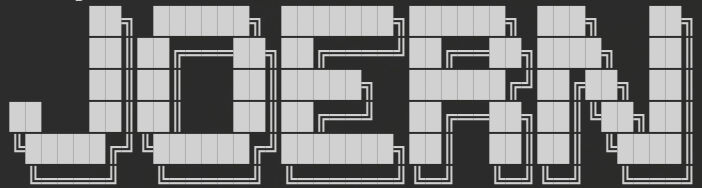
Code Surfin’

Module 1

1. Parsing and Generating a CPG (VLC v3.0.8)

suchakra@isengard: ~

```
$ wget https://github.com/ShiftLeftSecurity/joern/releases/latest/download/joern-cli.zip
$ unzip joern-cli; cd joern-cli
$ ./joern-parse ~/joern-workshop/vlc-3.0.8/
$ ./joern
```



```
Welcome to Ocular/Joern
joern> loadCpg("cpg.bin")
res0: Option[Cpg] = Some(io.shiftleft.codepropertygraph.Cpg@4f7a2262)
joern> cpg.<TAB>
```

Module 1

2. Basic Navigation - Methods

suchakra@isengard: ~

```
// List all methods that match `.*parse.*` to the shell
joern> cpg.method.name(".*parse.*").name.l

// Dump all methods that match `.*parse.*` to the shell (syntax-highlighted)
joern> cpg.method.name(".*parse.*").dump

// Create K-V pair of all methods that match `.*parse.*` and their code
joern> cpg.method.name(".*parse.*").map( m=> (m.name, m.start.dump)).l

// Dump all methods that match `.*parse.*` to file (no highlighting)
joern> cpg.method.name(".*parse.*").dumpRaw |> "/tmp/foo.c"

// View all methods that match `.*parse.*` in a pager (e.g., less)
joern> browse(cpg.method.name(".*parse.*").dump)
```

Module 1

2. Basic Navigation - Methods

suchakra@isengard: ~

```
// Dump dot representations of ASTs for all methods that
// match `parse` into file
joern> cpg.method.name("parse_public_key_packet").dot |> "/tmp/foo.dot"
```

Module 1

2. Basic Navigation - Methods

suchakra@isengard: ~

```
// Find all local variables defined in a method
joern> cpg.method.name("parse_public_key_packet").local.name.l

// Find which file and line number they are in
joern> cpg.method.name("parse_public_key_packet").location.map( x=> (x.lineNumber.get,
x.filename)).l

// Find the type of the first local variable defined in a method
joern> cpg.method.name("parse_public_key_packet").local.typ.name.l.head

// Find all outgoing calls (call-sites) in a method
joern> cpg.method.name("parse_public_key_packet").callOut.name.l

// Find which method calls a method
joern> cpg.method.name("parse_public_key_packet").caller.name.l
```

Module 1

3. Basic Navigation - Types and Filters

suchakra@isengard: ~

```
// List all local variables of type `vlc_.*`
joern> cpg.types.name("vlc_.*").localsOfType.name.l

// Find member variables of a struct
joern> cpg.types.name("vlc_log_t").map( x=> (x.name, x.start.member.name.l)).l

// Find local variables and filter them by their type
joern> cpg.local.filter(_.typ.name("vlc_log_t")).name.l

// Which method are they used in?
joern> cpg.local.filter(_.typ.name("vlc_log_t")).method.dump

// Get the filenames where these methods are
joern> cpg.local.filter(_.typ.name("vlc_log_t")).method.file.name.l
```

Module 1

4. Basic Insights - Overview

suchakra@isengard: ~

```
// Identify functions with more than 4 parameters
joern> cpg.method.where(_.parameter.size > 4).l

// Identify functions with > 4 control structures (cyclomatic complexity)
joern> cpg.method.where(_.controlStructure.size > 4).l

// Identify functions with more than 500 lines of code
joern> cpg.method.where(_.numberOfLines >= 500).l

// Identify functions with multiple return statements
joern> cpg.method.where(_.ast.isReturn.l.size > 1)
```

Module 1

4. Basic Insights - Overview

suchakra@isengard: ~

```
// Identify functions with more than 4 loops
joern> cpg.method.where(_.ast.isControlStructure.parserTypeName("(For|Do|While).*").size >
4).l

// Identify functions with nesting depth larger than 3
joern> cpg.method.where(_.depth(_.isControlStructure) > 3).name.l
```

Module 1

5. Basic Insights - Calls into libraries

suchakra@isengard: ~

```
// All names of external methods used by the program
joern> cpg.method.external.name.l.distinct.sorted

// All calls to strcpy
joern> cpg.call("str.*").code.l

// All methods that call strcpy
joern> cpg.call("str.*").method.name.l

// Looking into parameters: second argument to sprintf is NOT a literal
joern> cpg.call("sprintf").argument(2).filterNot(_.isLiteral).code.l

// Quickly see this method above
joern> cpg.call("sprintf").argument(2).filterNot(_.isLiteral).dump
```

Module 2

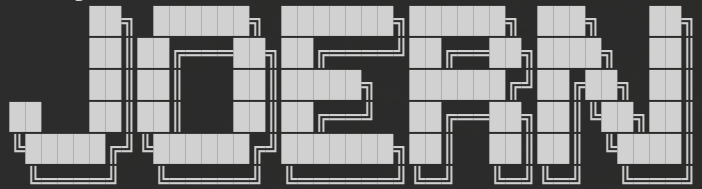
Memory Mémoire

Module 2

1. Generating CPG for `alloc_party.c`

suchakra@isengard: ~

```
joern> exit
$ ./joern-parse ~/joern-workshop/alloc_party --out alloc.bin
$ ./joern
```



```
Welcome to Ocular/Joern
joern> loadCpg("alloc.bin")
res0: Option[Cpg] = Some(io.shiftleft.codepropertygraph.Cpg@4f7a2262)
joern> cpg.<TAB>
```

Module 2

2. Memory Allocation Bugs - Zero Alloc/Overflow

suchakra@isengard: ~

```
/*
 * So we have a situation where the malloc's argument contains an arithmetic operation
 *
 * This can lead to two cases:
 *   1. Zero Allocation, if the operation makes the argument 0 (we get a NULL ptr)
 *   2. Overflow, if the computed allocation is smaller and we use memcpy() eventually
 */

void *alloc_havoc(int y) {
  int z = 10;
  void *x = malloc(y * z);
  return x;
}
```

Module 2

2. Memory Allocation Bugs - Zero Alloc/Overflow

suchakra@isengard: ~

```
// The location where malloc has an arithmetic operation
joern> cpg.call("malloc").filter(_.argument(1).arithmetics).code.l

// Identify if there is
joern> var source = cpg.method.name(".*alloc.*").parameter
joern> var sink = cpg.call("malloc").filter(_.argument(1).arithmetics).argument
joern> sink.reachableByFlows(source).p
```

Module 2

2. Memory Allocation Bugs - Double Free

suchakra@isengard: ~

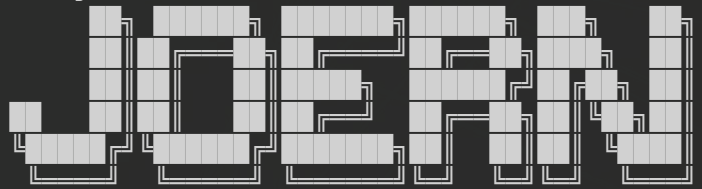
```
// Find how many data flows are there starting from the same malloc() call-site
// to parameters of all free() call-sites. If more than one, we can inspect them for double free

joern> var source = cpg.call(".*alloc.*")
joern> var sink = cpg.call("free").argument
joern> sink.reachableByFlows(source).p
```

Module 2

3. Back to the VLC CPG

suchakra@isengard: ~

```
joern> exit
$ ./joern
```




```
Welcome to Ocular/Joern
joern> loadCpg("vlc.bin")
res0: Option[Cpg] = Some(io.shiftleft.codepropertygraph.Cpg@4f7a2262)
```

Module 2

3. Memory Allocation Bugs - Buffer Overflow

suchakra@isengard: ~

```
/**
  * Find calls to malloc where the first argument contains an arithmetic expression,
  * the allocated buffer flows into memcpy as the first argument, and the third
  * argument of that memcpy is unequal to the first argument of malloc. This is
  * an adaption of the old-joern query first shown at 31C3 that found a
  * buffer overflow in VLC's MP4 demuxer (CVE-2014-9626).
  **/

  val src = cpg.call("malloc").filter(_.argument(1).arithmetics).l

  cpg.call("memcpy").whereNonEmpty { call => call.argument(1)
        .reachableBy(src.start)
        .filterNot(_.argument(1)
        .codeExact(call.argument(3).code))
  }.code.l
```

Module 3

Scripting Away to Glory

Module 3

1. Scripting - Buffer Overflow

suchakra@isengard: ~

```
/**
  * We can wrap the previous query as a script that we can use internally
  * anytime we like. Just wrap it in a method!
  **/

  joern> def buffer_overflows(cpg : io.shiftleft.codepropertygraph.Cpg ) = {
           val src = cpg.call("malloc").filter(_.argument(1).arithmetics).l

           cpg.call("memcpy").whereNonEmpty { call => call.argument(1)
                 .reachableBy(src.start)
                 .filterNot(_.argument(1)
                 .codeExact(call.argument(3).code))
           }.code.l
         }

  defined function buffer_overflows
  joern> buffer_overlows(cpg)  // run the script from within Joern Shell!
```

Module 3

p_block->i_buffer == MAX_UINT64 **causes an overflow!**

suchakra@isengard: ~

```
joern> buffer_overlows(cpg).filter(_.method.name( ".*ParseT.*")).l.start.dump
res57: List[String] = List(
  """static subpicture_t *ParseText( decoder_t *p_dec, block_t *p_block )
{
    decoder_sys_t  *p_sys = p_dec->p_sys;
    subpicture_t  *p_spu = NULL;
    if( p_block->i_flags & BLOCK_FLAG_CORRUPTED )
        return NULL;
     ...
    /* Should be resiliant against bad subtitles */
    if( p_sys->iconv_handle == (vlc_iconv_t)-1 ||  p_sys->b_autodetect_utf8 )
    {
        psz_subtitle =  malloc( p_block->i_buffer + 1 );
        if( psz_subtitle == NULL )
            return NULL;
        memcpy( psz_subtitle, p_block->p_buffer, p_block->i_buffer );   /* <=== */
        psz_subtitle[p_block->i_buffer] = '\0';
    }
```

Module 3

2. Scripting - Build Your Own Joern Scripts

suchakra@isengard: ~

```
// Save the following file as heap.sc

    def buffer_overflows(cpg : io.shiftleft.codepropertygraph.Cpg ) = {
        val src = cpg.call("malloc").filter(_.argument(1).arithmetics).l

        cpg.call("memcpy").whereNonEmpty { call => call.argument(1)
            .reachableBy(src.start)
            .filterNot(_.argument(1)
            .codeExact(call.argument(3).code))
        }.code.l
    }

// Import and execute from Joern
joern> import $file.^.heap
joern> heap.buffer_overflows(cpg)
```

Module 3

3. Scripting - DIY Tooling!

suchakra@isengard: ~

```
// Save the following file as buffer_overflow.sc

@main def execute(payload: String) = {
    loadCpg(payload);
    val src = cpg.call("malloc").filter(_.argument(1).arithmetics).l

    cpg.call("memcpy").whereNonEmpty { call => call.argument(1)
          .reachableBy(src.start)
          .filterNot(_.argument(1)
          .codeExact(call.argument(3).code))
    }.code.l
}

// Run externally as your own tool!
$ ./joern --script buffer_overflow.sc --params payload=vlc.bin
```

Acknowledgements

- Fabian Yamaguchi, inventor of CPG and Joern
  - Talk: https://fabs.codeminers.org/talk/2019-huawei/
- Joern Community
  - Markus, Niko, Michael, Chetan
- Jöern (@joernchen) - yes, there is a real person for which the project was named

Thanks Folks

Community: https://gitter.im/joern-code-analyzer/community
Website: http://joern.io

Workshop Resources: https://github.com/tuxology/joern-workshop

Twitter: @tuxology
Mail: mail@suchakra.in