RSAConference2021
May 17 – 20 | Virtual Experience

SESSION ID: **LAB2-R08**

Finding Stranger Things in Code

STATIC ANALYSIS USING JOERN

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ShiftLeft Inc.

Workshop Prep

- Clone Workshop Repo
  - `git clone https://github.com/joernio/workshops`
  - `cd workshops/2021-RSA`
  - `apt install source-highlight graphviz unzip`
- Download **Joern** and install
  - `wget https://github.com/joernio/joern/releases/latest/download/joern-install.sh`
  - `chmod +x ./joern-install.sh`
  - `sudo ./joern-install.sh`
- Download **VLC v3.0.12** source and extract in a convenient directory
  - `wget http://get.videolan.org/vlc/3.0.12/vlc-3.0.12.tar.xz`
  - `tar -xvf vlc-3.0.12.tar.xz`

Workshop Prep

- Machine Requirements
  - At least 5-7GB free RAM (close as many browser tabs as possible, pkill slack etc)
  - At least 4 CPUs (preferably modern)
  - OpenJDK 1.8+
- Important Links
  - Joern Docs: https://docs.joern.io
  - Queries: https://queries.joern.io
  - Joern Community: https://discord.gg/SrUX84xMFR Join **#rsa-lab2-r08**

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PhD, Computer Engineering - loves systems, code analysis, performance analysis, hardware tracing, samosas and poutine!

Why are you here?

- **You may have the following question in your mind**
  - How do computer programs and programming languages work?
  - I know some bad coding practices. How can I “mass detect” them in large codebases?
  - How do static analysis tools work? Can I create my own tools?
  - So many of these tools. Can I get like a CLI shell to hunt bugs?
  - *How hard is it to find a Zero Day?*

What you will learn

- Gain ability to find vulnerabilities in large code-bases (such as VLC)
- Interactive code analysis and code exploration
- Convert your manual code auditing steps to automated analyses
- Get insights about how external libraries are being used by your own code
- Stop reliance on “vendor SAST” and roll your sleeves to find real bugs
- Some proficiency in Scala

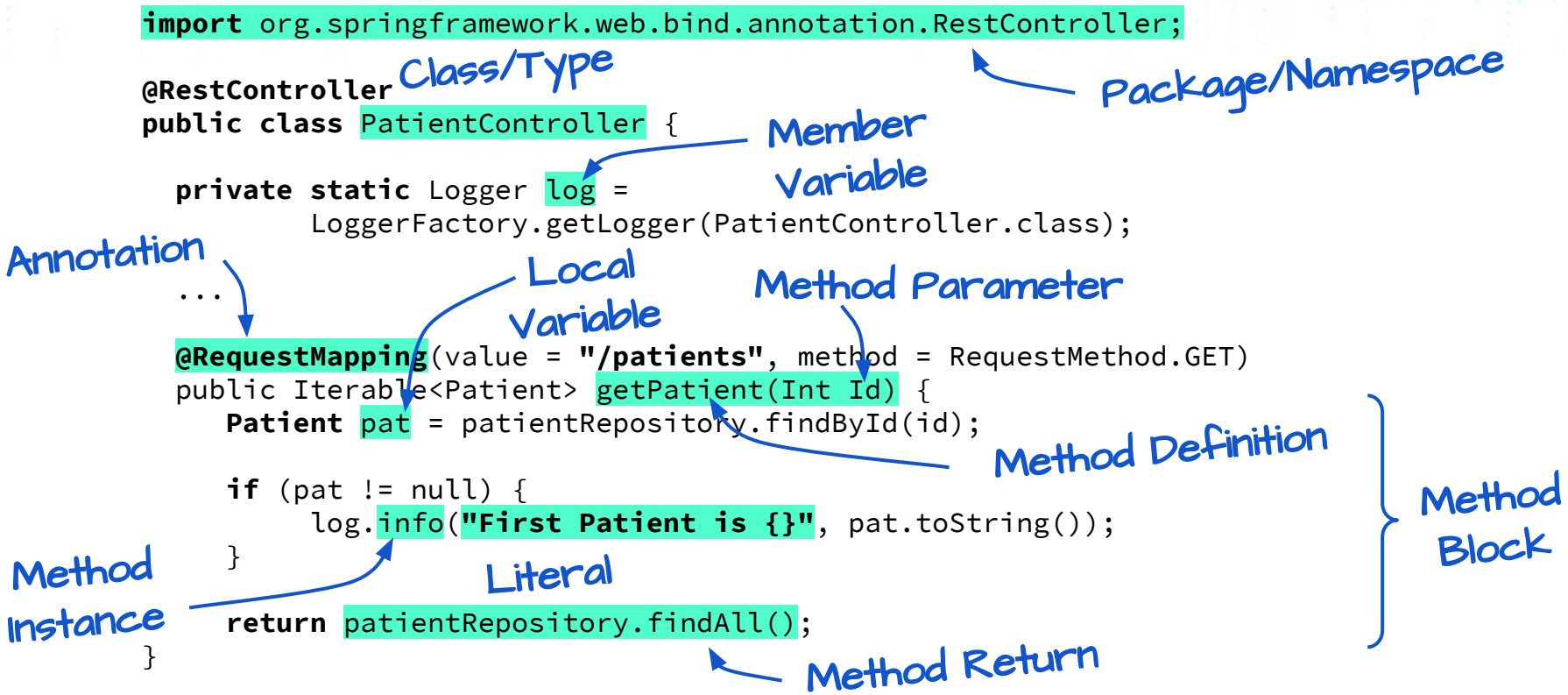
Static Analysis Primitives

What is even code?

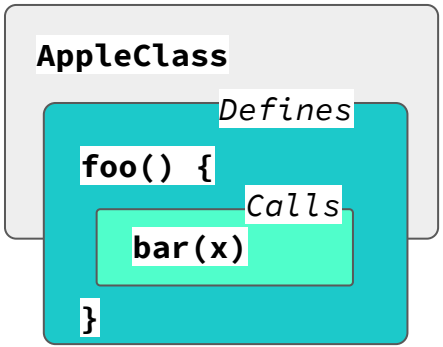
Building Blocks of Code

```
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() {
     Patient pat = patientRepository.findOne(1l);

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

     return patientRepository.findAll();
}
```

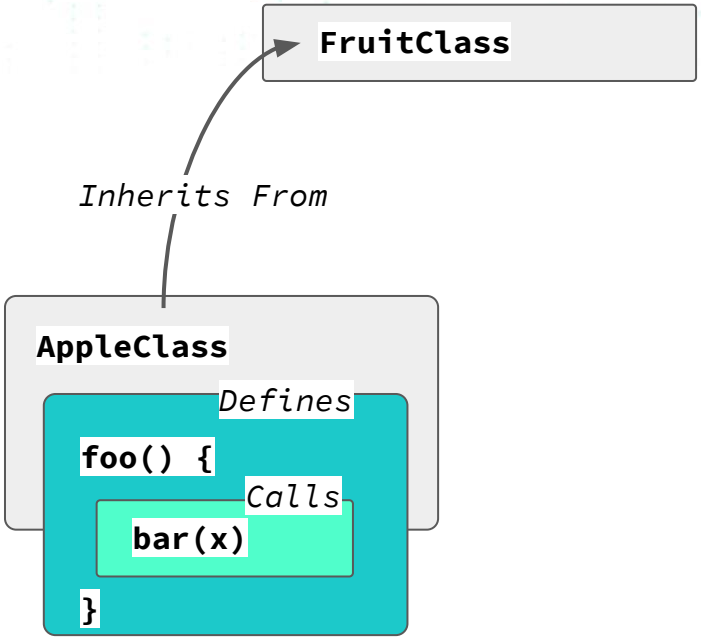
Building Blocks of Code



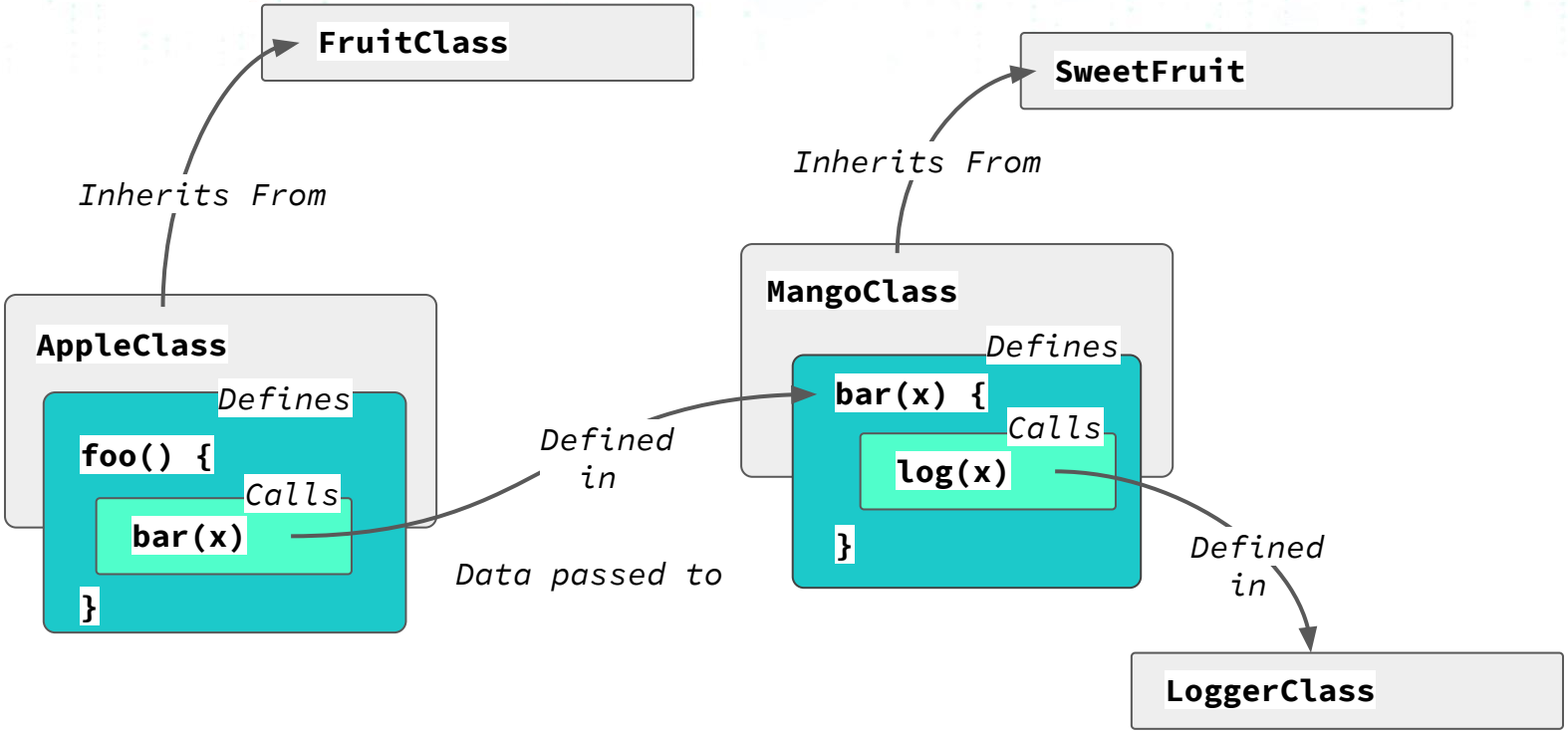
Building Blocks of Code



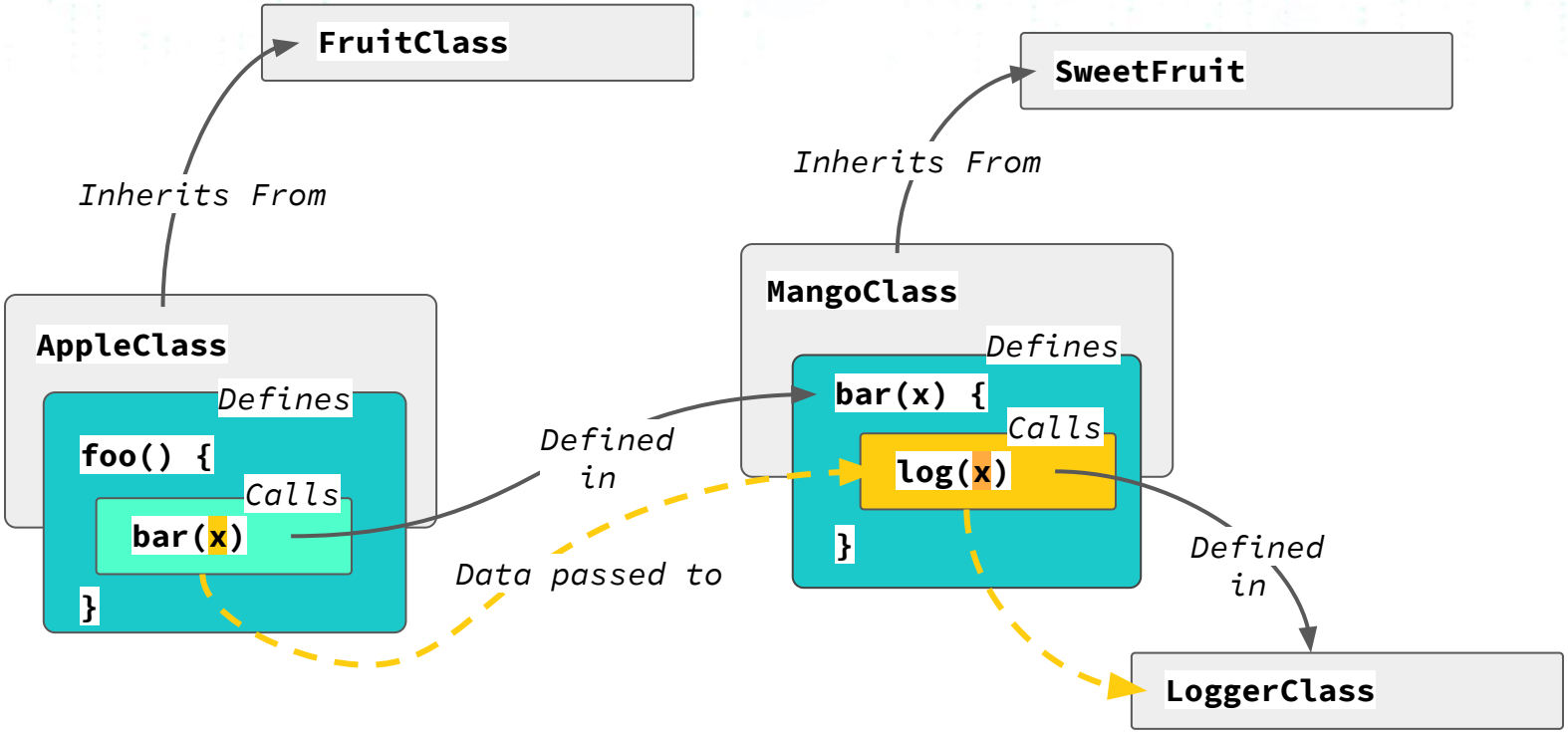
Building Blocks of Code



Building Blocks of Code



Building Blocks of Code



ALL THE CODE IS A GRAPH

We think in graphs while coding - we should think in graphs while debugging

Workshop Plan

- **FAMILIARIZATION**
- **MODULE 1**
  - **Basic Code Navigation** - Searching functions, types, call-sites
  - **Basic Insights** - Finding rule violations
- **WORKING BREAK 1**
- **MODULE 2**
  - **Hunting Bugs** - Finding memory allocation related bugs
- **WORKING BREAK 2**
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  - **VLC Vulnerability discovery exercise**
- **SHOW AND TELL**

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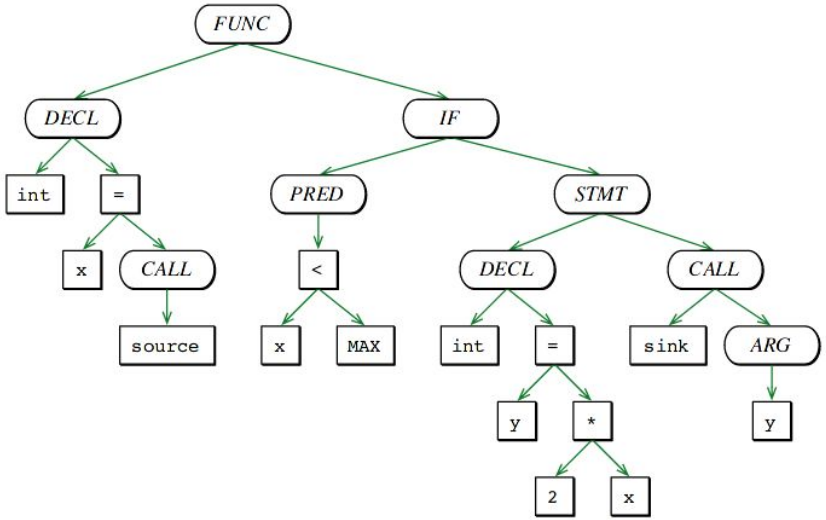
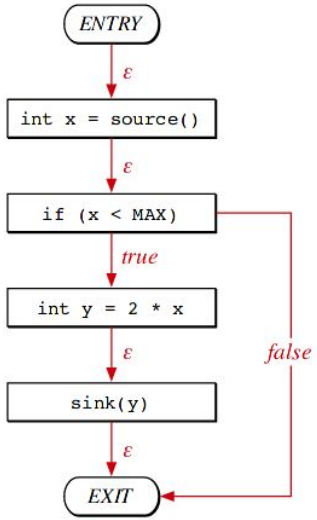
Graph Data Structures For Code

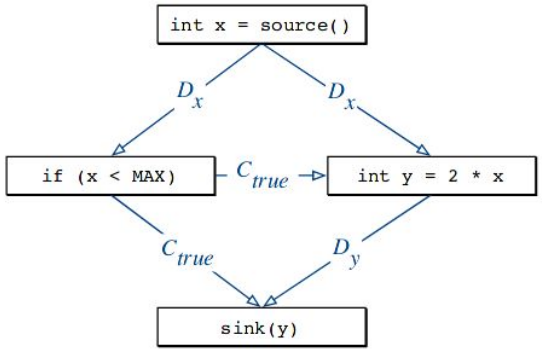
```
void foo()
{
    int x = source();
    if (x < MAX)
    {
        int y = 2 * x;
        sink(y);
    }
}
```



(a) Abstract syntax tree (AST)



(b) Control flow graph (CFG)

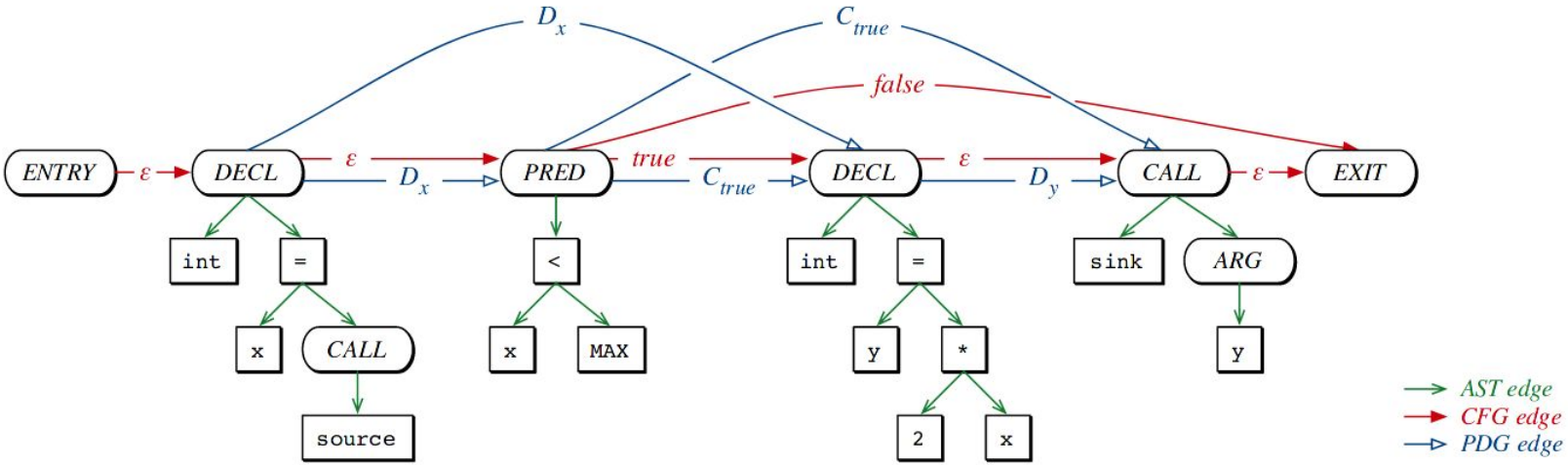


(c) Program dependence graph (PDG)

```
void foo()
{
    int x = source();
    if (x < MAX)
    {
        int y = 2 * x;
        sink(y);
    }
}
```

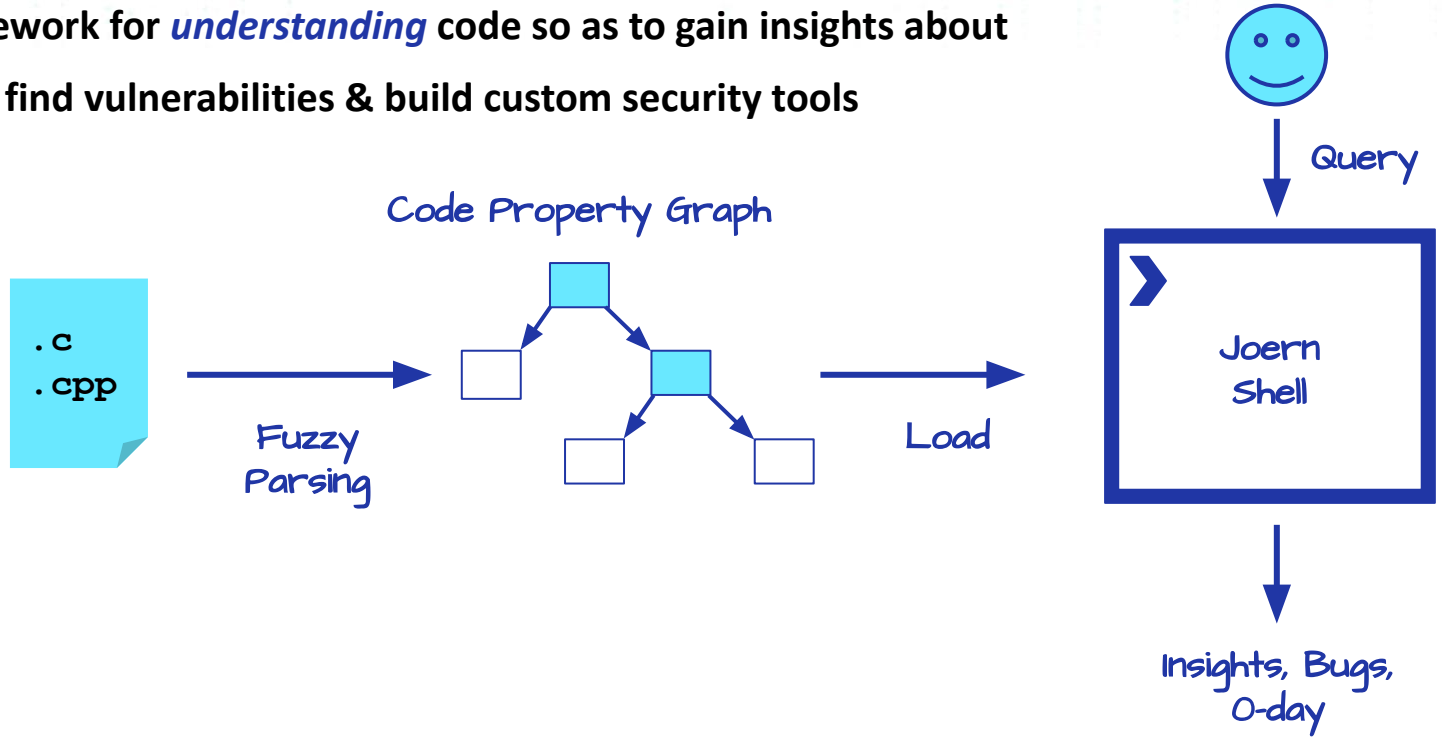
Code Property Graph (CPG)

***Modeling and Discovering Vulnerabilities with Code Property Graphs**, Yamaguchi et al. (IEEE Symp. Sec and Priv., 2014)*



Exploring CPG with Joern

- Framework for *understanding* code so as to gain insights about code, find vulnerabilities & build custom security tools

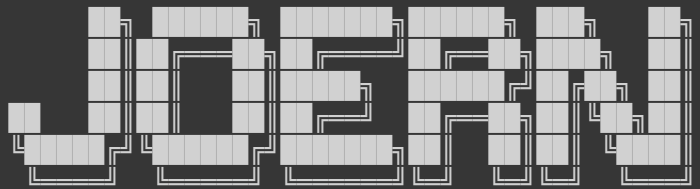


Quickstart

suchakra@isengard: ~

suchakra@isengard: ~

```
$ wget http://www.acme.com/software/thttpd/thttpd-2.29.tar.gz
$ tar -xvf thttpd-2.29.tar.gz
$ joern
```



```
Type `help` or `browse(help)` to begin
joern> importCode("/tmp/thttpd-2.29")
res0: Cpg = io.shiftleft.codepropertygraph.Cpg@4f7a2262)
joern> cpg.method.name("handle.*").name.l
...
joern> cpg.method.name("strcpy").caller.name.l
res18: List[String] = List(
  "get_filename"
```

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MODULE 1

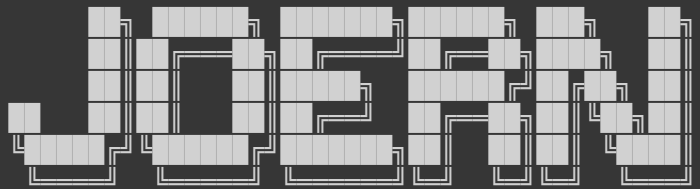
Code Navigation and Insights

Import VLC Code

suchakra@isengard: ~

suchakra@isengard: ~

```
$ joern
```



```
Type `help` or `browse(help)` to begin
joern> importCode"/tmp/vlc-3.0.12")
res0: Cpg = io.shiftleft.codepropertygraph.Cpg@4f7a2262)
joern> run.ossdataflow
joern> save
```

Basic Navigation - Methods

suchakra@isengard: ~

suchakra@isengard: ~

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

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

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

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

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

Basic Navigation - Methods

suchakra@isengard: ~

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```
// 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").call.name.l

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

Basic Navigation - Repeating Graph Traversals

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```
// Find the sequence of callers going UP from a given method
joern> cpg.method.name("parse_public_key_packet").repeat(_.caller)(_.emit).name.l

// Find the callees of a method going DOWN until you hit a given method(CAN BE EXPENSIVE)
joern>
cpg.method.name("download_key").repeat(_.callee)(_.emit.until(_.isCallTo"parse_public_key_packet"))).na
me.l
```

Basic Navigation - Types, Variables and Filtering

suchakra@isengard: ~

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```
// List all local variables of type `vlc_.*`
joern> cpg.types.name("vlc_.*").localOfType.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.where(_.typ.name("vlc_log_t")).name.l

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

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

Basic Insights - Code Complexity

suchakra@isengard: ~

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

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

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

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

Basic Insights - Code Complexity

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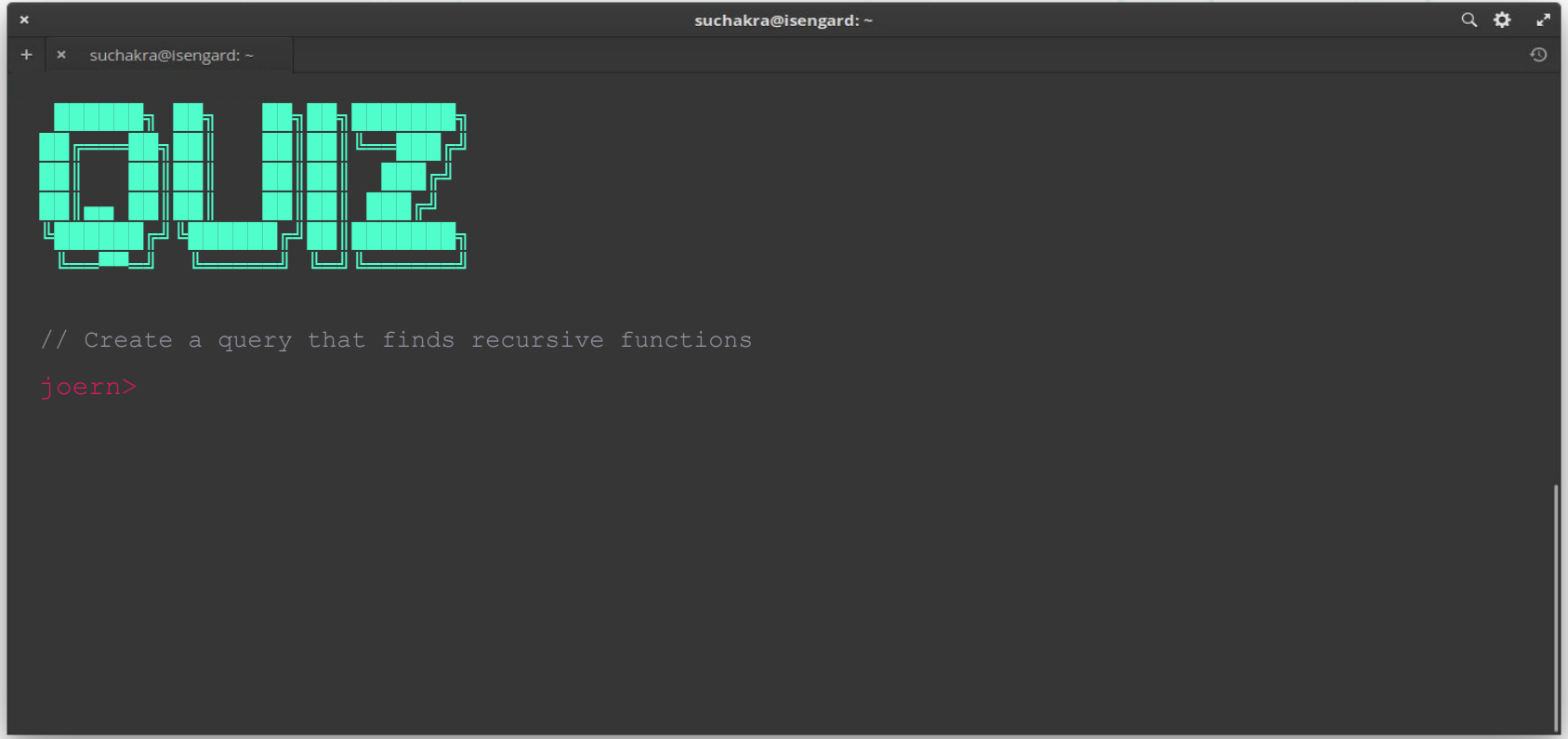
```
// Identify functions with more than 4 loops
joern> cpg.method.filter(_.controlStructure.controlStructureType("FOR|DO|WHILE").size > 4).name.l

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

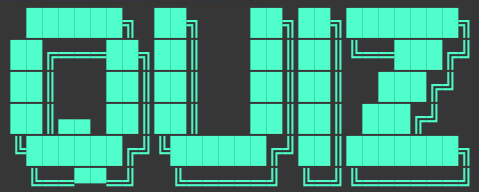
QUIZ


suchakra@isengard: ~
suchakra@isengard: ~
QUIZ
// Create a query that finds recursive functions
joern>

QUIZ

suchakra@isengard: ~

suchakra@isengard: ~




```
// Create a query that finds recursive functions
joern> cpg.method.filter(x => x.call.name.l.contains(x.name)).name.l
res88: List[String] = List(
  "dirfd",
  "tdestroy_recurse",
  "vlc_dictionary_insert_impl_",
  ...
)
```

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MODULE 2

Hunting Bugs

Memory Allocation Bugs - Zero Alloc/Overflow

suchakra@isengard: ~

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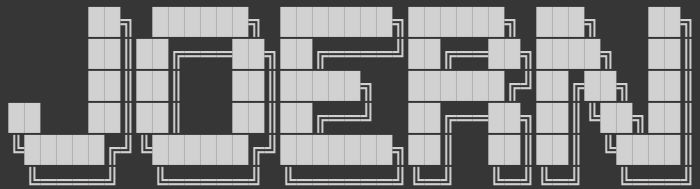
```
/*
 * So we have a situation where the malloc's argument contains an arithmetic operation
 *
 * This can lead to two cases:
 *   1. Zero Allocation, if the operation makes the argument 0 (we get a NULL ptr)
 *   2. Overflow, if the computed allocation is smaller and we use memcpy() eventually
 */

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

Import alloc_party **Code**

suchakra@isengard: ~

suchakra@isengard: ~

```
$ joern
```



```
Type `help` or `browse(help)` to begin
joern> importCode"/tmp/alloc_party")
res0: Cpg = io.shiftleft.codepropertygraph.Cpg@4f7a2262)
joern> run.ossdataflow
joern> save
```

Memory Allocation Bugs - Zero Alloc/Overflow

suchakra@isengard: ~

suchakra@isengard: ~

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

// Identify if there is a call from some method to any of these weird mallocs
joern> def source = cpg.method.name(".*alloc.*").parameter
joern> def sink = cpg.call("malloc").where(_.argument(1).isCallTo(Operators.multiplication)).argument
joern> sink.reachableByFlows(source).p
```

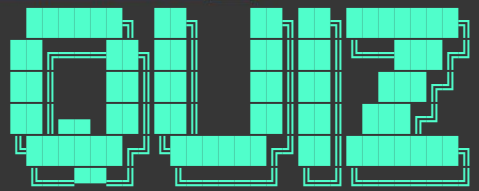
QUIZ


suchakra@isengard: ~
suchakra@isengard: ~
QUIZ
// Write a query to find a double free the sample code (Hint: Dataflow from allocation to freedom)
joern>

QUIZ

suchakra@isengard: ~

suchakra@isengard: ~




```
// Write a query to find a double free the sample code (Hint: Dataflow from allocation to freedom)
joern> def source = cpg.call(".*alloc.*")
joern> def sink = cpg.call("free").argument
joern> sink.reachableByFlows(source).p
```

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MODULE 3

Finding Vulnerabilities in VLC

Buffer Overflow Hunting in VLC - First Try!

suchakra@isengard: ~

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```
// Find the memcpy() calls where return value of calls from malloc having addition
operations reaches the first argument of the memcpy

def src = cpg.call("malloc").where(_.argument(1).isCallTo(Operators.addition)).l

cpg.call("memcpy").where { call =>
      call.argument(1)
      .reachableBy(src)
}.code.l
```

Buffer Overflow Hunting in VLC - Dataflows [OPTIONAL]

suchakra@isengard: ~

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```
// Find dataflows from all these interesting sources and sinks

joern> def source = cpg.call("malloc").where(_.argument(1).isCallTo(Operators.addition))
defined function source

joern> def sink = cpg.call("memcpy").argument
defined function sink

joern> sink.reachableByFlows(source).p
```

DRY Functions

suchakra@isengard: ~

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```
// Wrap possible buffer overflow query in a function

joern> def buffer_overflows(cpg :  io.shiftleft.codepropertygraph.Cpg ) = {
           def src =
cpg.call("malloc").where(_.argument(1).isCallTo(Operators.addition)).l
           cpg.call("memcpy").where { call =>
                call.argument(1)
                .reachableBy(src)
           }.code.l
       }

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

Scripting with Joern - DIY Tools

suchakra@isengard: ~

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```
// save the following text as  mytools.sc in /home/$USER/bin/joern

        def buffer_overflows(cpg :  io.shiftleft.codepropertygraph.Cpg ) = {
            def src =
cpg.call("malloc").where(_.argument(1).isCallTo(Operators.addition)).l
            cpg.call("memcpy").where { call =>
                 call.argument(1)
                 .reachableBy(src)
            }.code.l
        }

joern> import $file.mytools(cpg)  // import your script
joern> mytools.buffer_overflows(cpg)  // run the script from within Joern Shell!
```

Scripting with Joern - DIY Tools

suchakra@isengard: ~

suchakra@isengard: ~

```
// save the following text as  buffer_overflows.sc in /home/$USER/bin/joern
// You can replace the open(graph) with other command like importCode() to work on
// fresh code. You could generate JSONs also, create reports etc..

        @main def execute(graph:  String) = {
            open(graph)
            println("Finding possible buffer overflows" )
             def src =
cpg.call("malloc").where(_.argument(1).isCallTo(Operators.addition)).l
            cpg.call( "memcpy").where { call =>
                 call.argument(1)
                 .reachableBy(src)
            }.code.l
        }

// Run externally as your own tool!
$ joern --script buffer_overflow.sc --params graph=vlc-3.0.12
```

ACTIVITY

1. Find Possible Buffer Overflows in VLC
   There is at least one “close but no cigar” and one real case. May be tough
2. Anything else that is interesting ¯_(ツ)_/¯
   Open-ended tinkering with VLC. Lets see what you get!

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SHOW AND TELL

p_block->i_buffer == MAX_UINT64 causes overflow!!

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```
joern> buffer_overflows(cpg).filter(_.method.name(".*ParseText.*")).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';
    }
```

FIN

https://joern.io