Workshop

# DIY Static Code Analyzer

*Building your own security tools with*

Joern

**Suchakra Sharma**
Staff Scientist, ShiftLeft Inc.
**Vickie Li**
Developer Evangelist, ShiftLeft Inc.

nsec

May 21, 2021
Montreal, QC

## Let’s Prep First

- Clone Workshop Repo
    - `git clone https://github.com/joernio/workshops`
    - `cd workshops/2021-NSEC`
    - `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`

## Let’s Prep First

- 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 **#query-corner**

**Suchakra Sharma**
Staff Scientist, ShiftLeft Inc.

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*PhD, Polytechnique Montréal*
*Loves systems, code analysis, performance analysis, hardware tracing, samosas and poutine!*

## Vickie Li

Developer Evangelist, ShiftLeft Inc.

Github: vickie-sl
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Email: vickie@shiftleft.io

# **Pep**Talk

## Why are you here?

### You may have the following questions

- 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 custom static analysis tools and deploy them in CI/CD?
- *I am just here to have fun. Please don't mind me!*

### You may have used or know about,

- Interactive debuggers (GDB, rr etc), SAST tools, Github, IDE to search your code

## What you will learn today

- 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

you will be this person by EoD

## 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, Valgrind, GDB, profilers, linters
- Many tools run, and then give results but Joern approach flips the table - we give the tool to ask questions about the code
- It's like play-pause debugging, but for static analysis

## **Programming Language**
Fundamentals

## What is even *code*?

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

## What is even *code*?

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

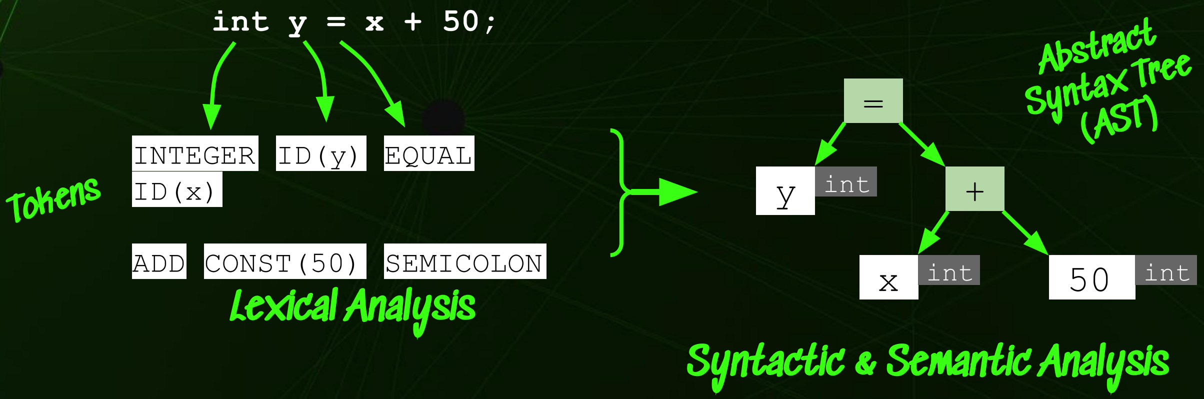
Tokens

`INTEGER` `ID(y)` `EQUAL` `ID(x)`

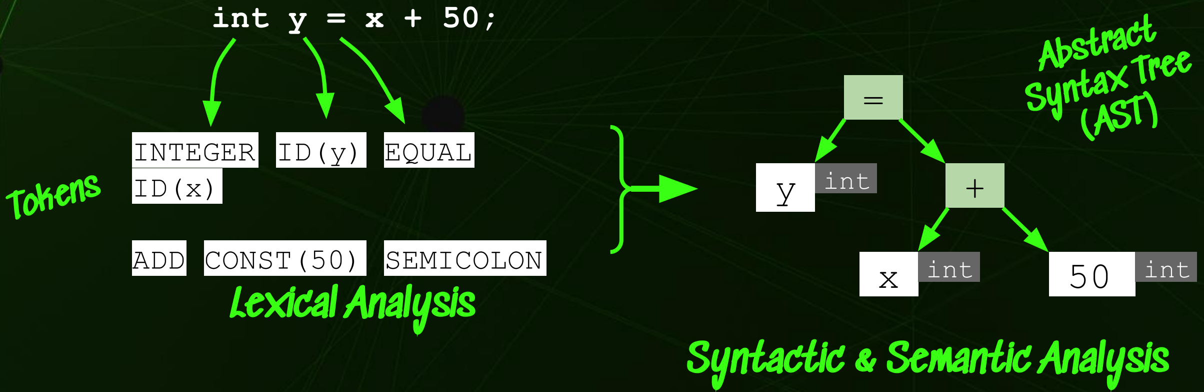
`ADD` `CONST(50)` `SEMICOLON`

Lexical Analysis

## What is even *code*?

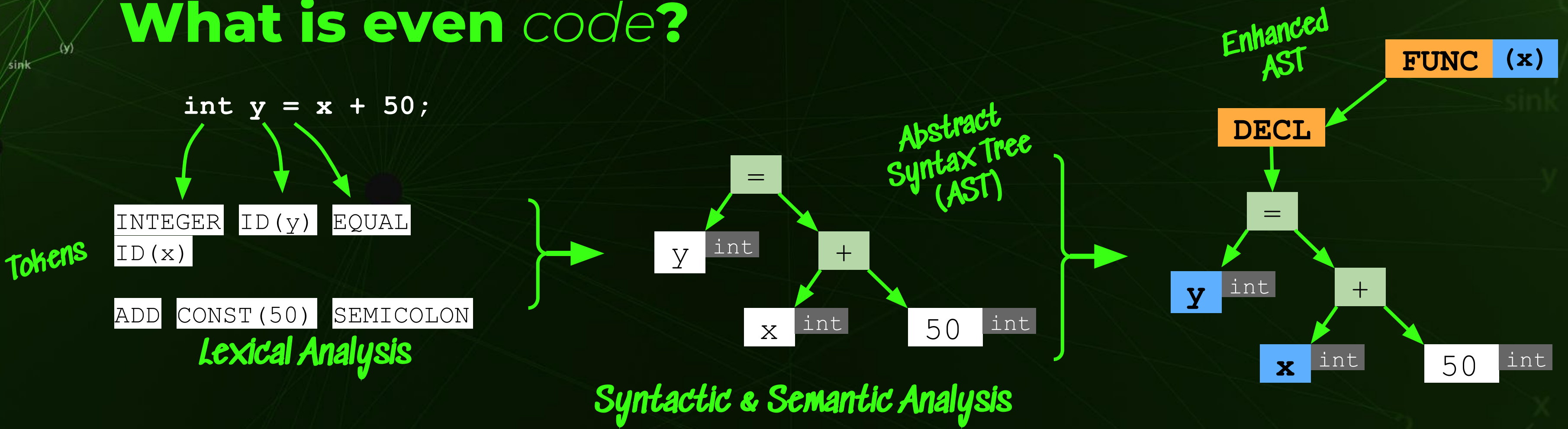


## What is even *code*?

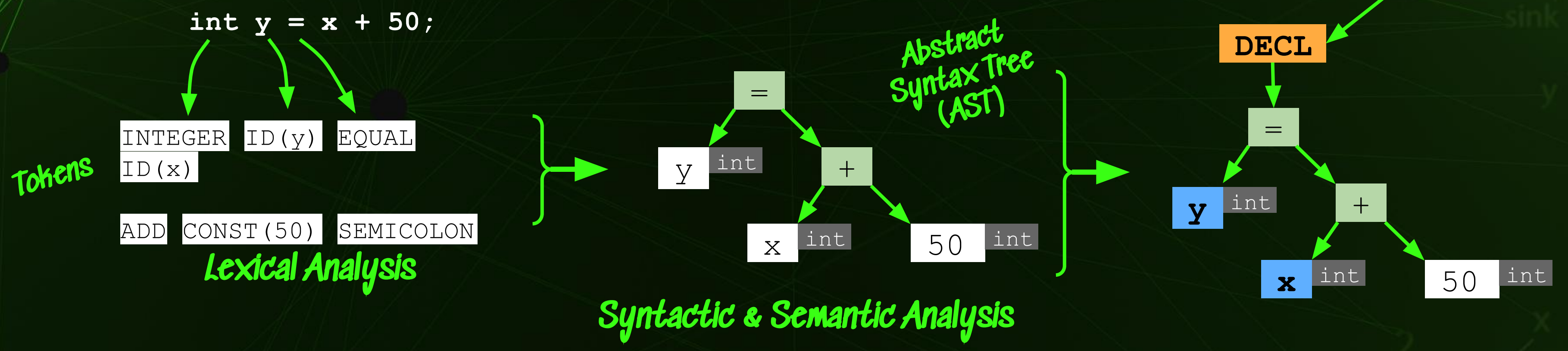


```
func(x) {
  int y = x + 50;
}
```

# What is even *code*?

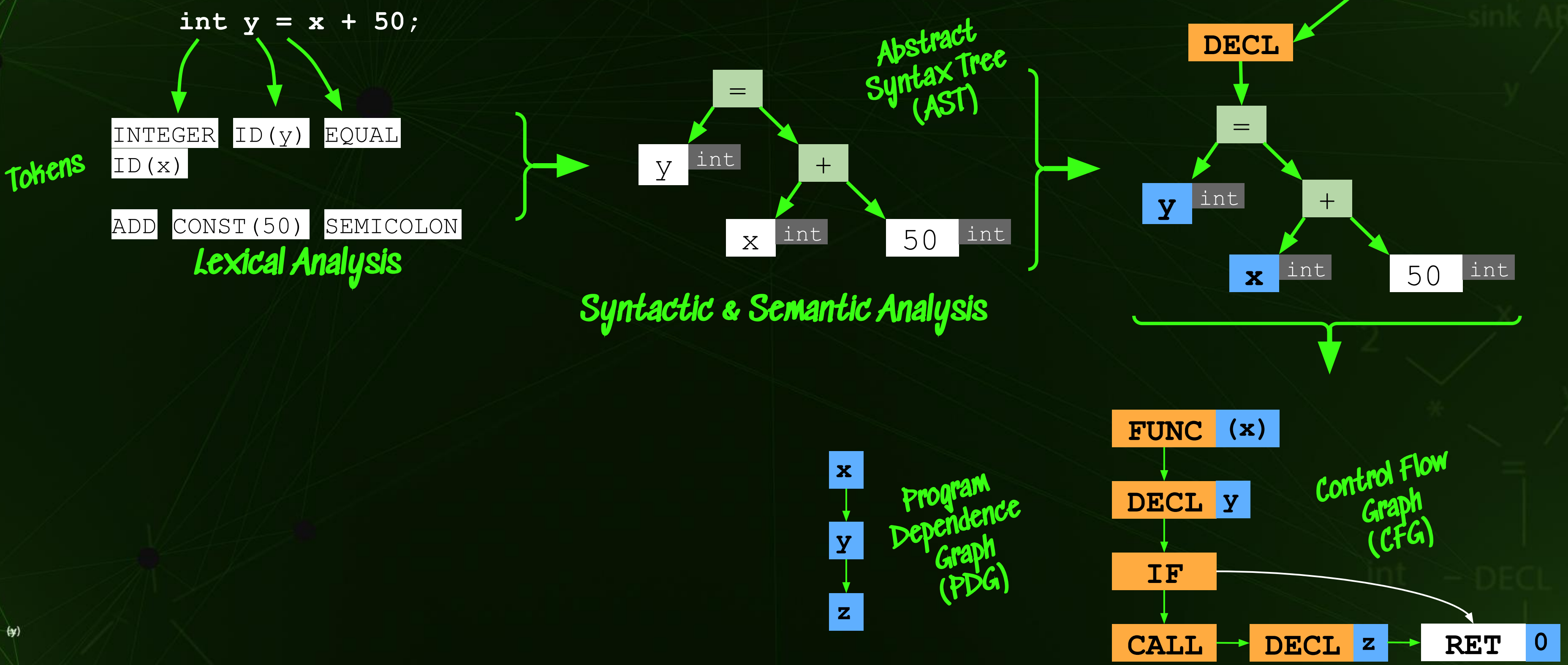


# What is even *code*?



```
func(x) {
  int y = x + 50;
  if (y > 10) {
    wololo()
    z = y
  } else {
    return 0
  }
}
```

# What is even *code*?



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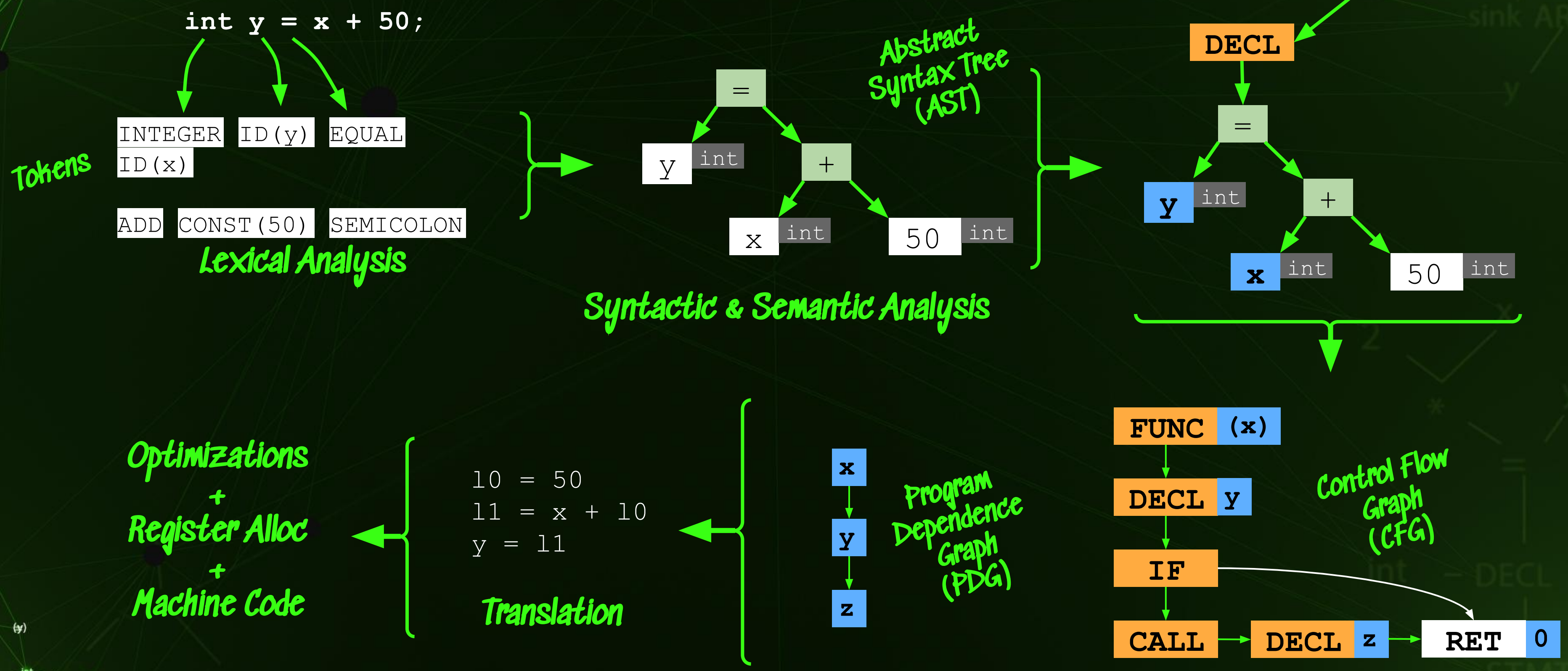

## Building Blocks of Code

```
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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@RestController
public class PatientController {

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

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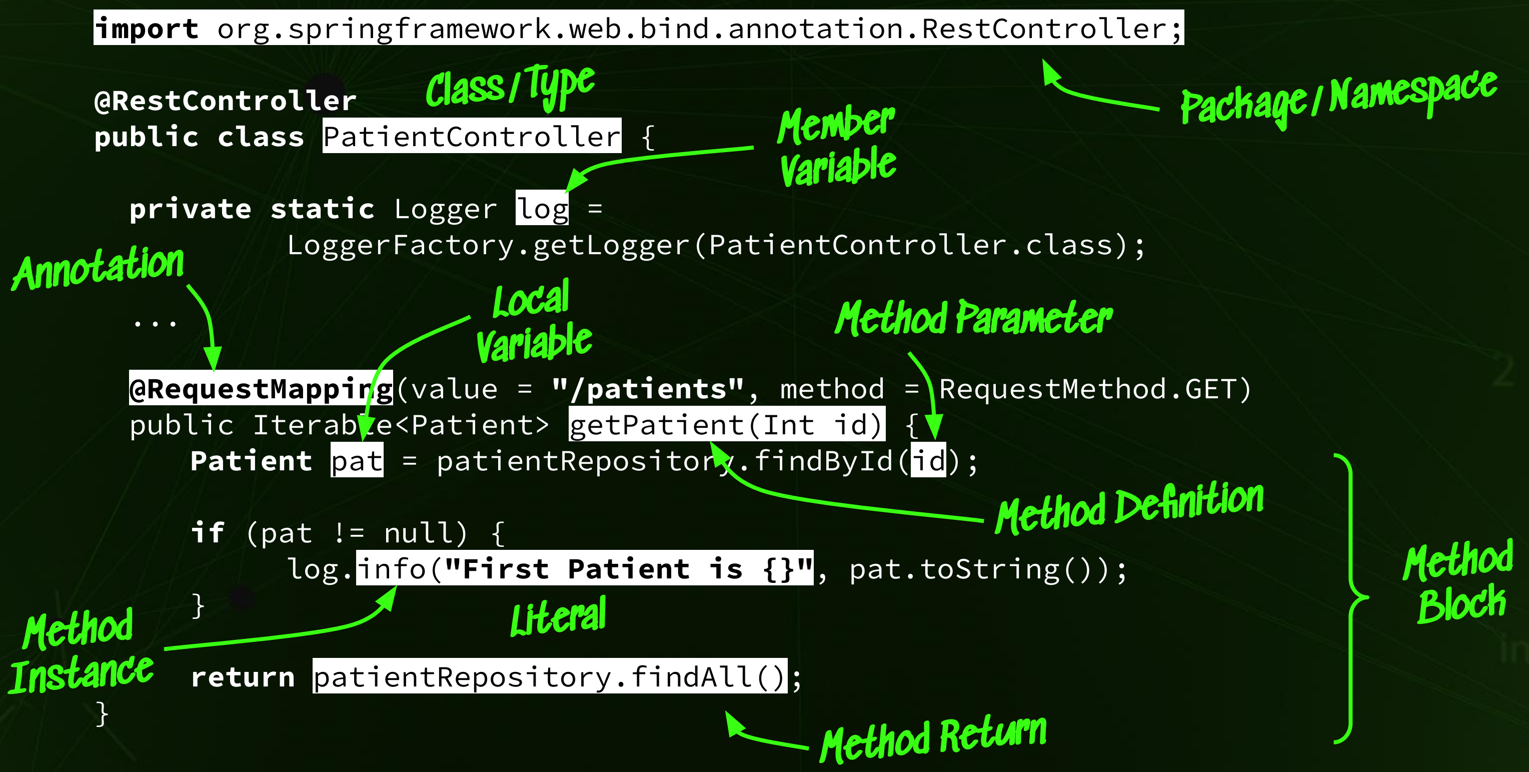
# Building Blocks of Code



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

@RestController
public class PatientController {

  private static Logger log =
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  @RequestMapping(value = "/patients", method = RequestMethod.GET)
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     Patient pat = patientRepository.findById(id);

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

     return patientRepository.findAll();
  }
```
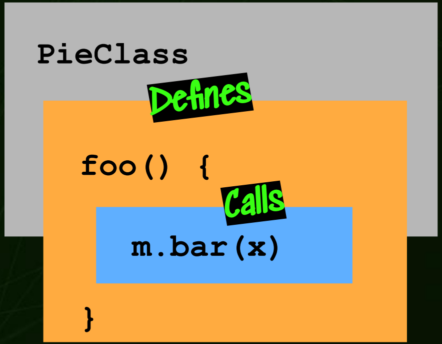
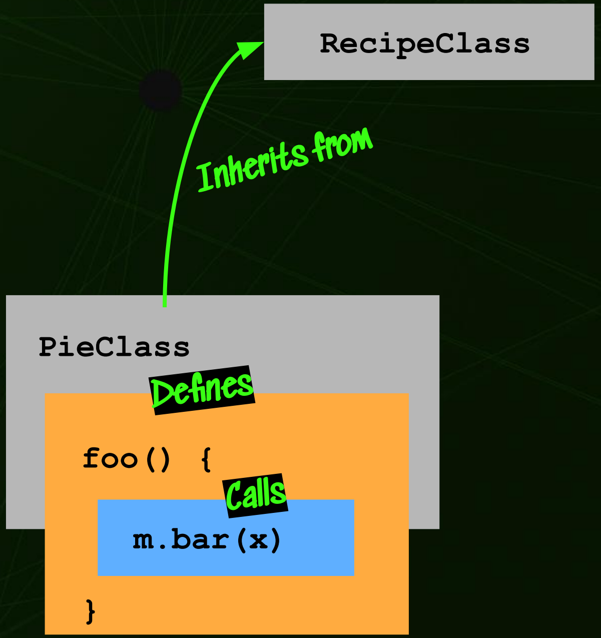

## **Building Blocks of** Code

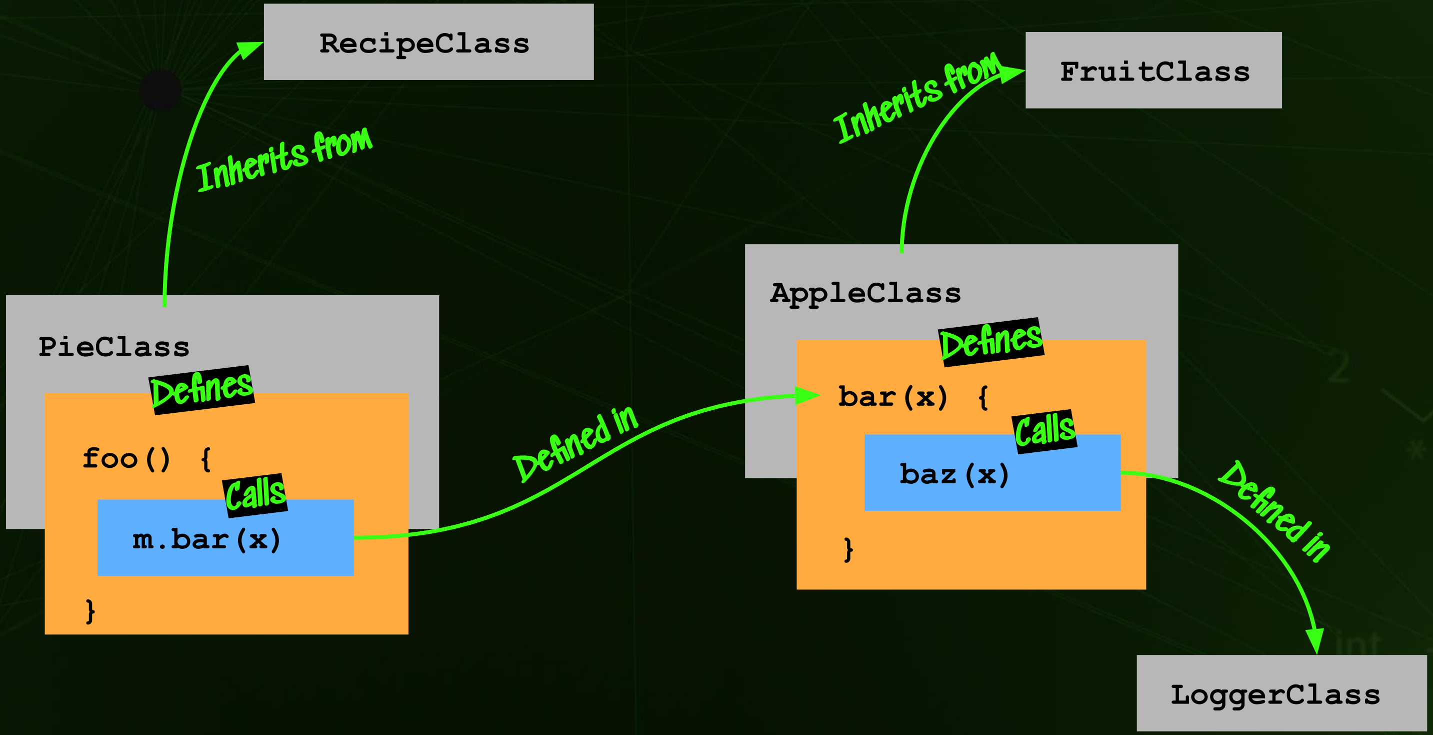


# Building Blocks of Code

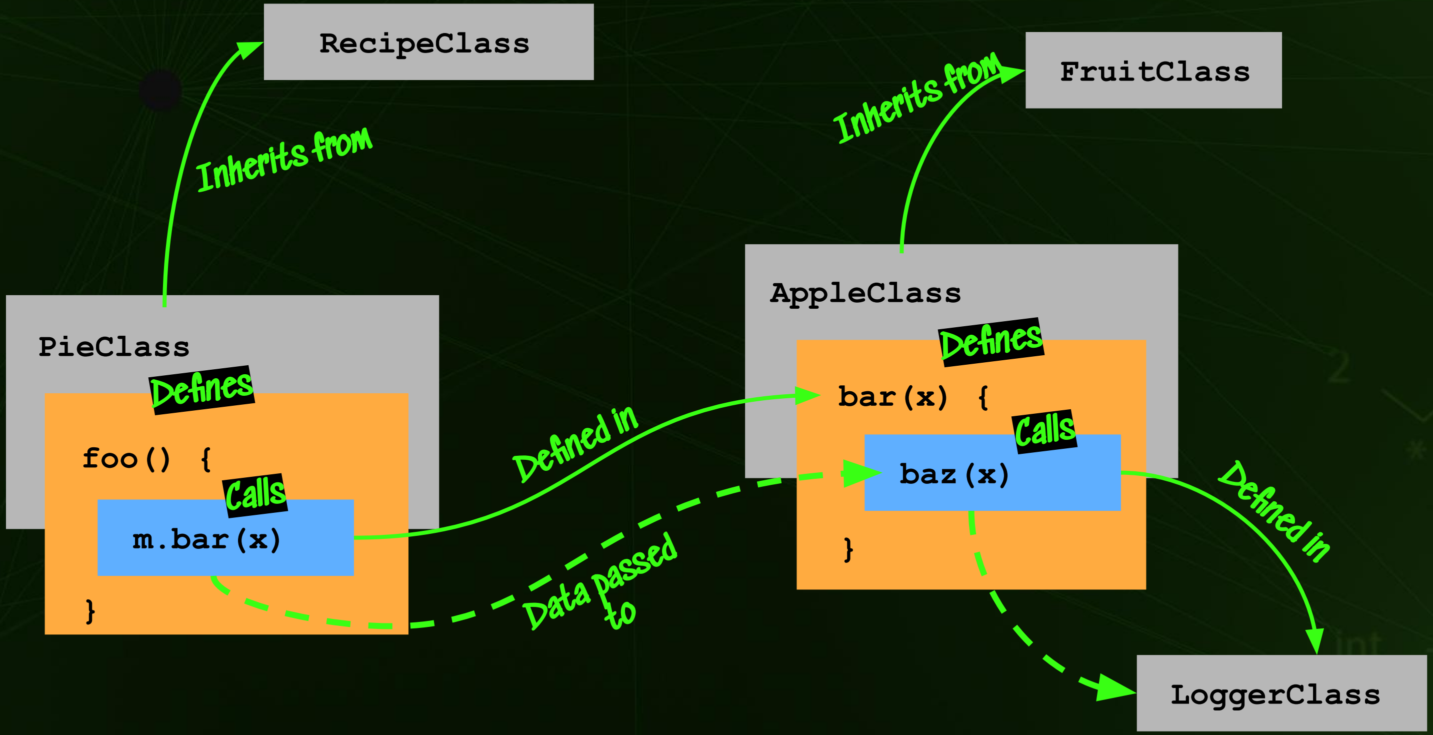


```
foo() {
  m.bar(x)
}
```

## Building Blocks of Code



## Building Blocks of Code



## ALL THE CODE IS A GRAPH

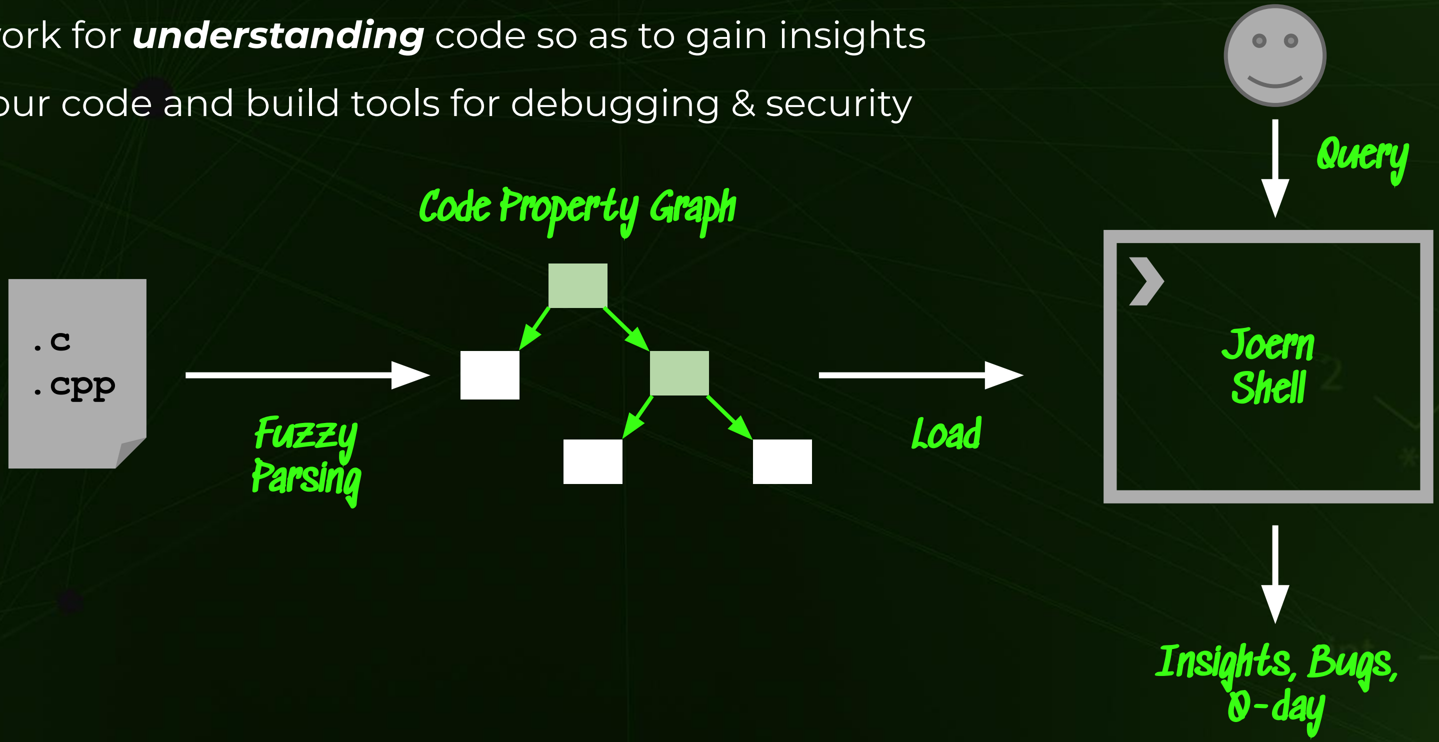
*If we think in graphs while coding, we should think in graphs while debugging*

# JOERN

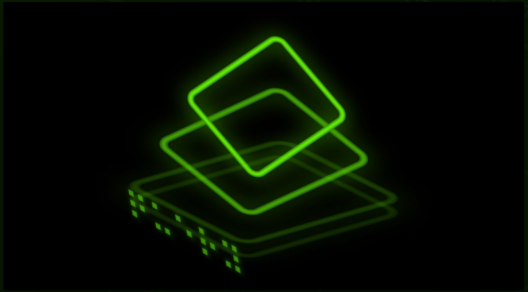
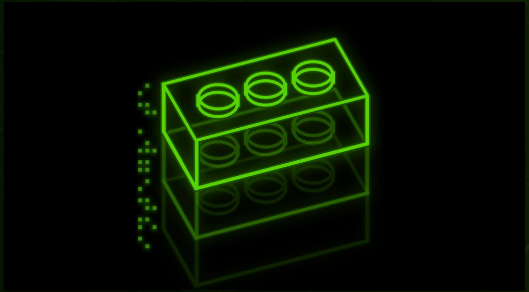
[Yo! Urn]

## What is Joern?

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



## What is Joern?

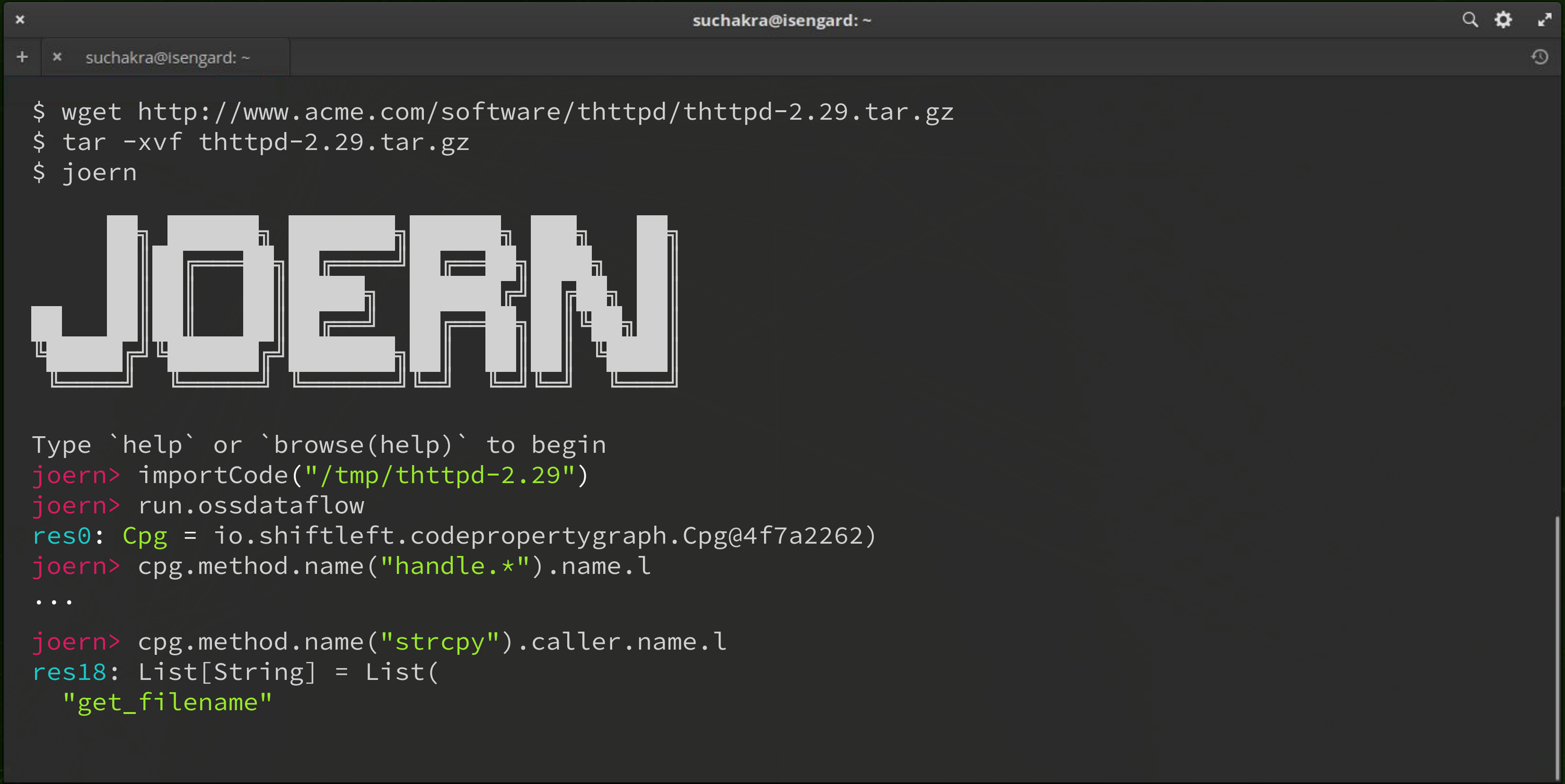
| Query | Automate | Integrate |
|---|---|---|
|  | |  |
| Ask questions on an interactive shell, iterate quickly → | Convert those questions to a recipe. Run across large codebases → | Take the recipe and integrate in your security pipeline or tools |

## Module 1

Code Navigation & Insights

Module 1

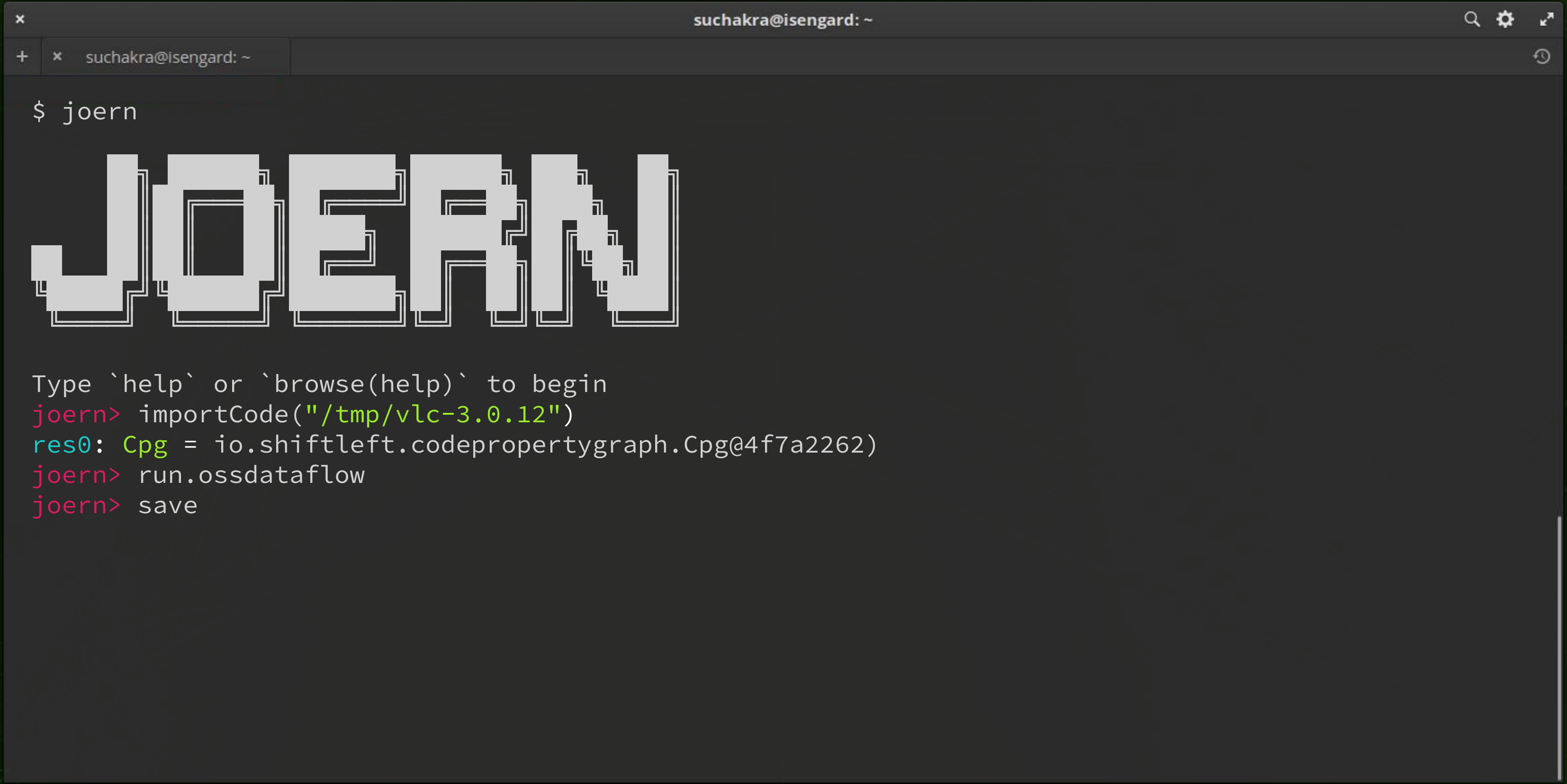
## 1. Quickstart



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

JOERN

Type `help` or `browse(help)` to begin
joern> importCode("/tmp/thttpd-2.29")
joern> run.ossdataflow
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"
```

Module 1

## 1. Parsing and Generating a CPG (VLC v3.0.12)

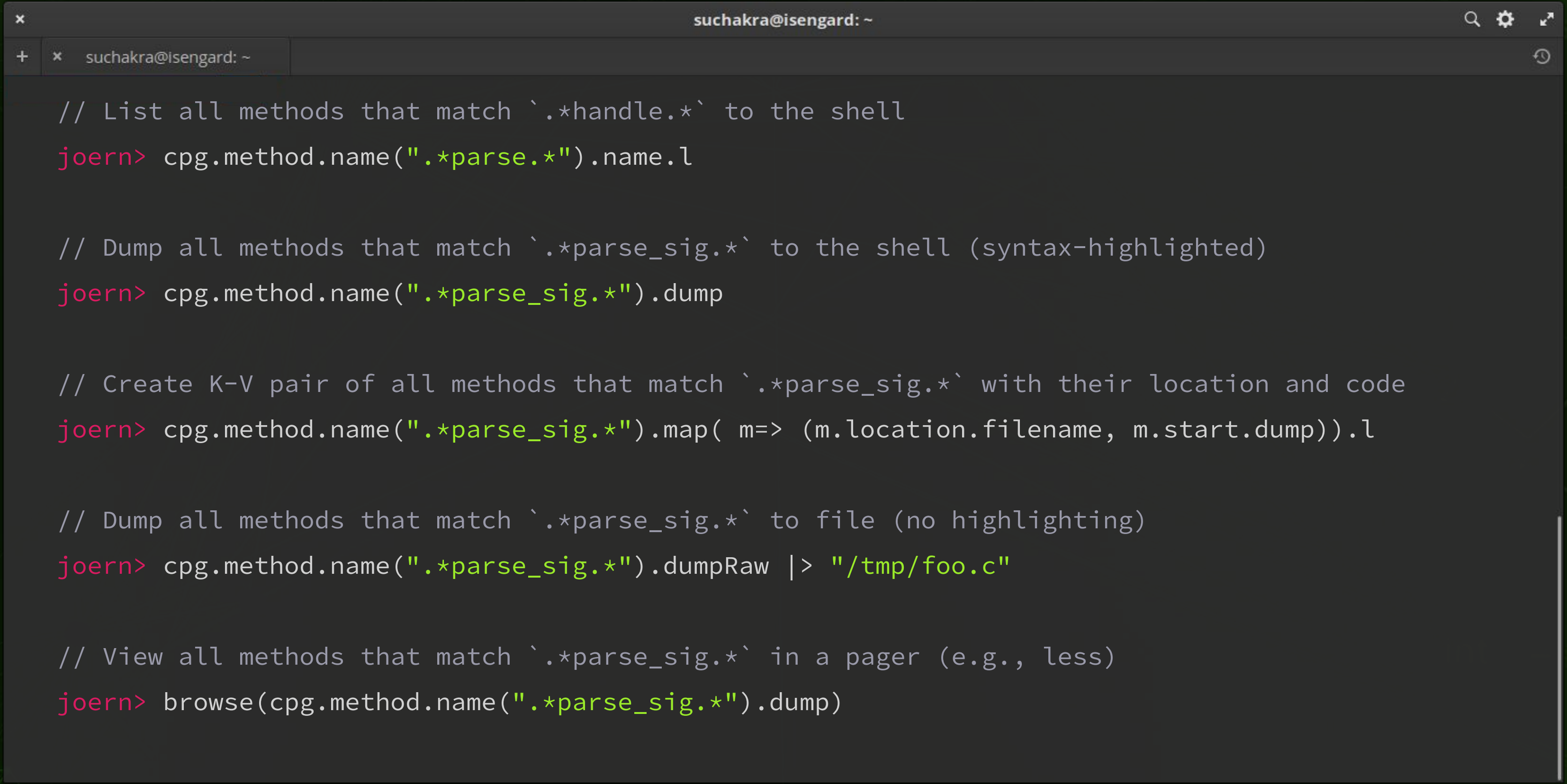


```
$ joern
```

```
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
```

Module 1

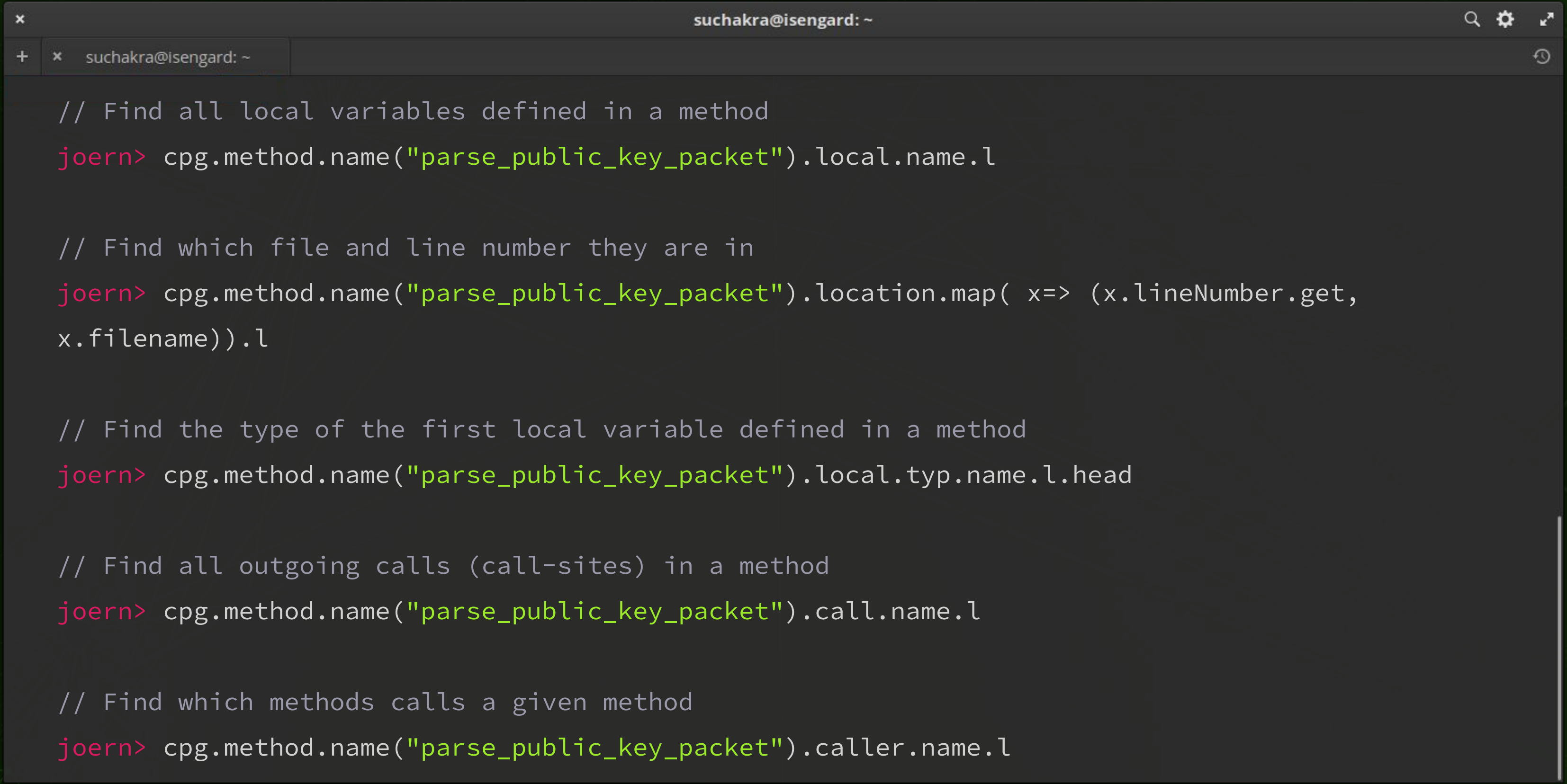
## 2. Basic Navigation - Methods



```
// 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)
```

Module 1

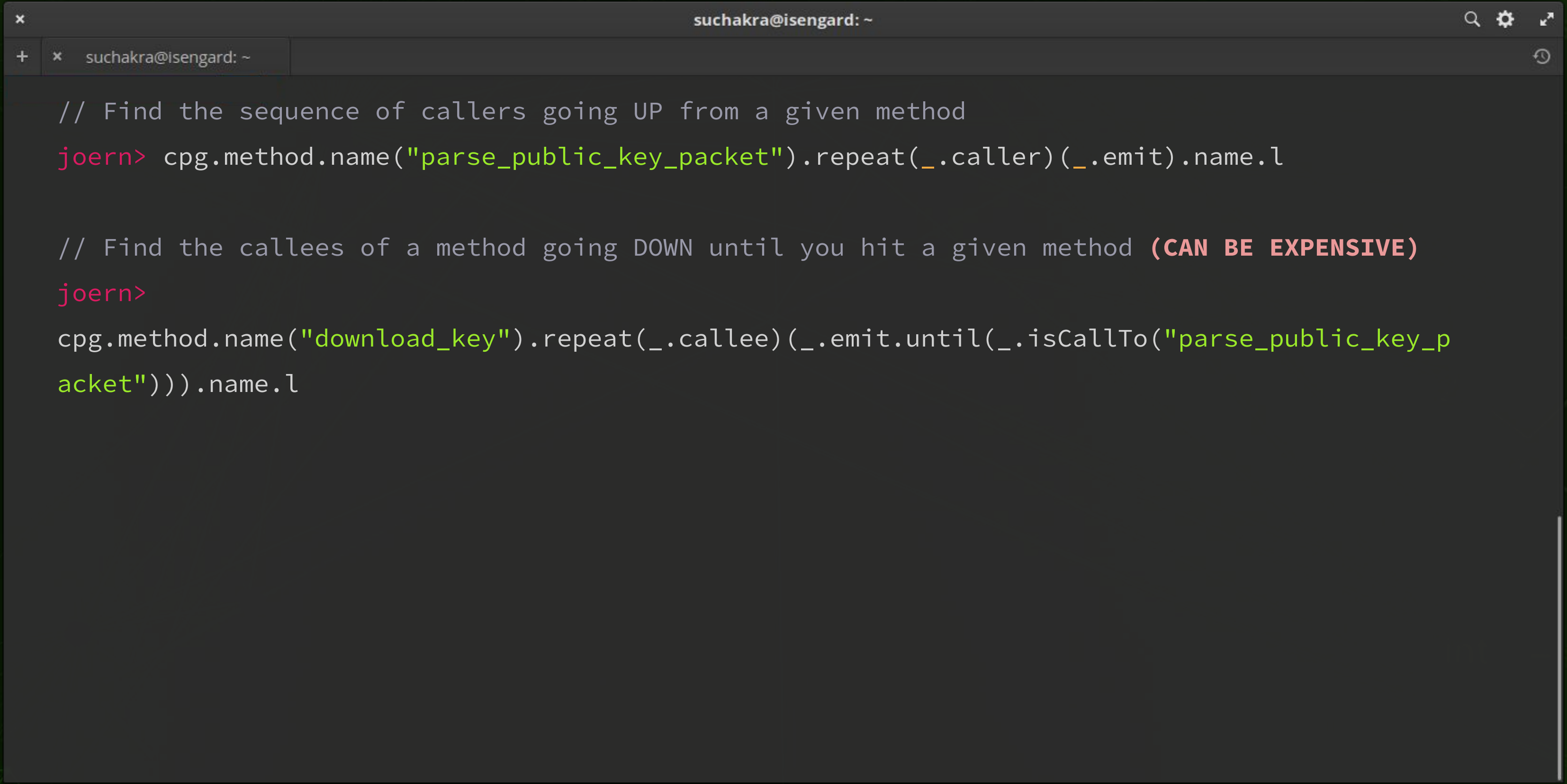
## 2. Basic Navigation - Methods



```
// 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
```

Module 1

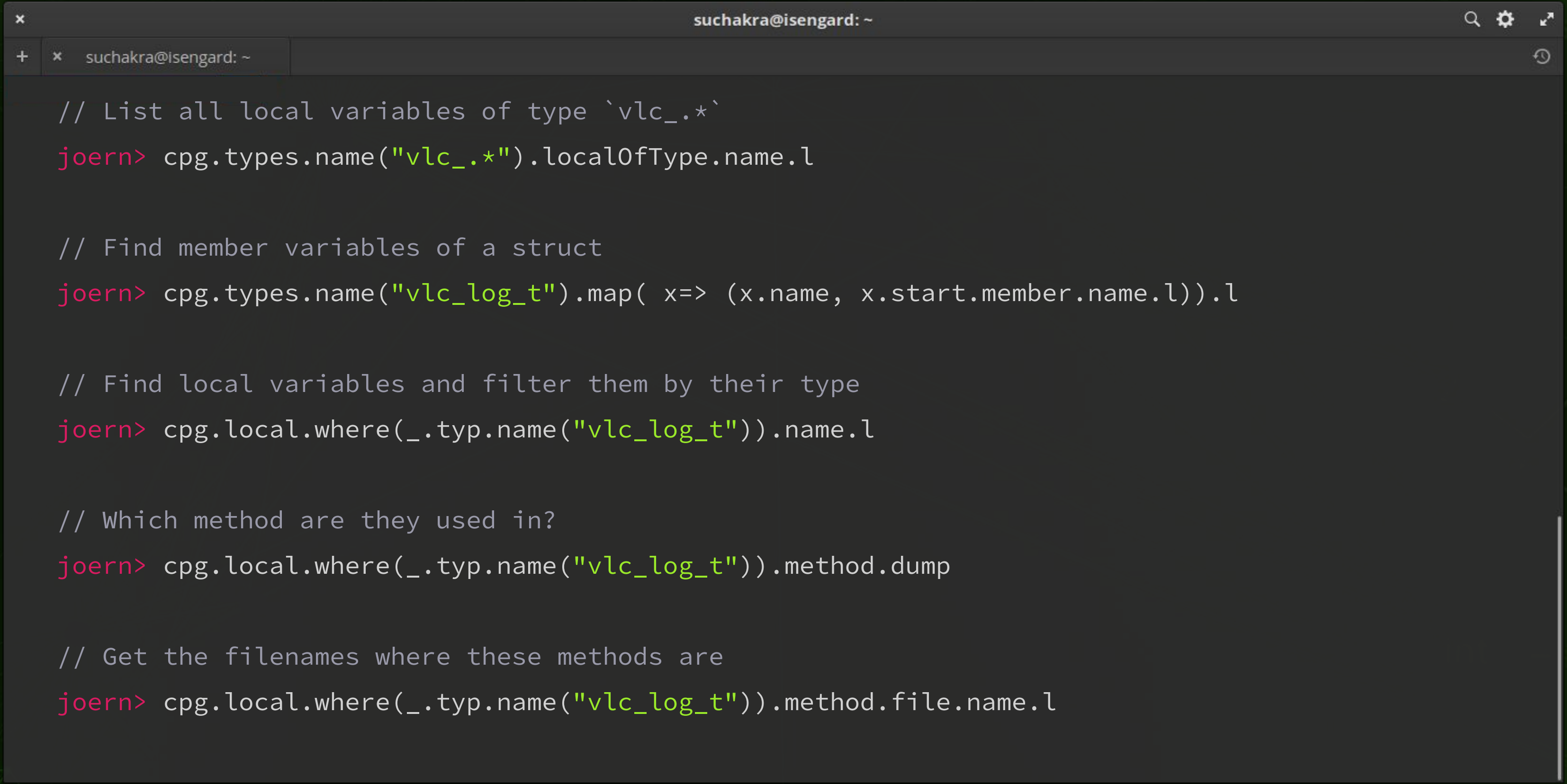
## 2. Basic Navigation - Repeating Graph Traversals



```
// 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_p
acket"))).name.l
```

Module 1

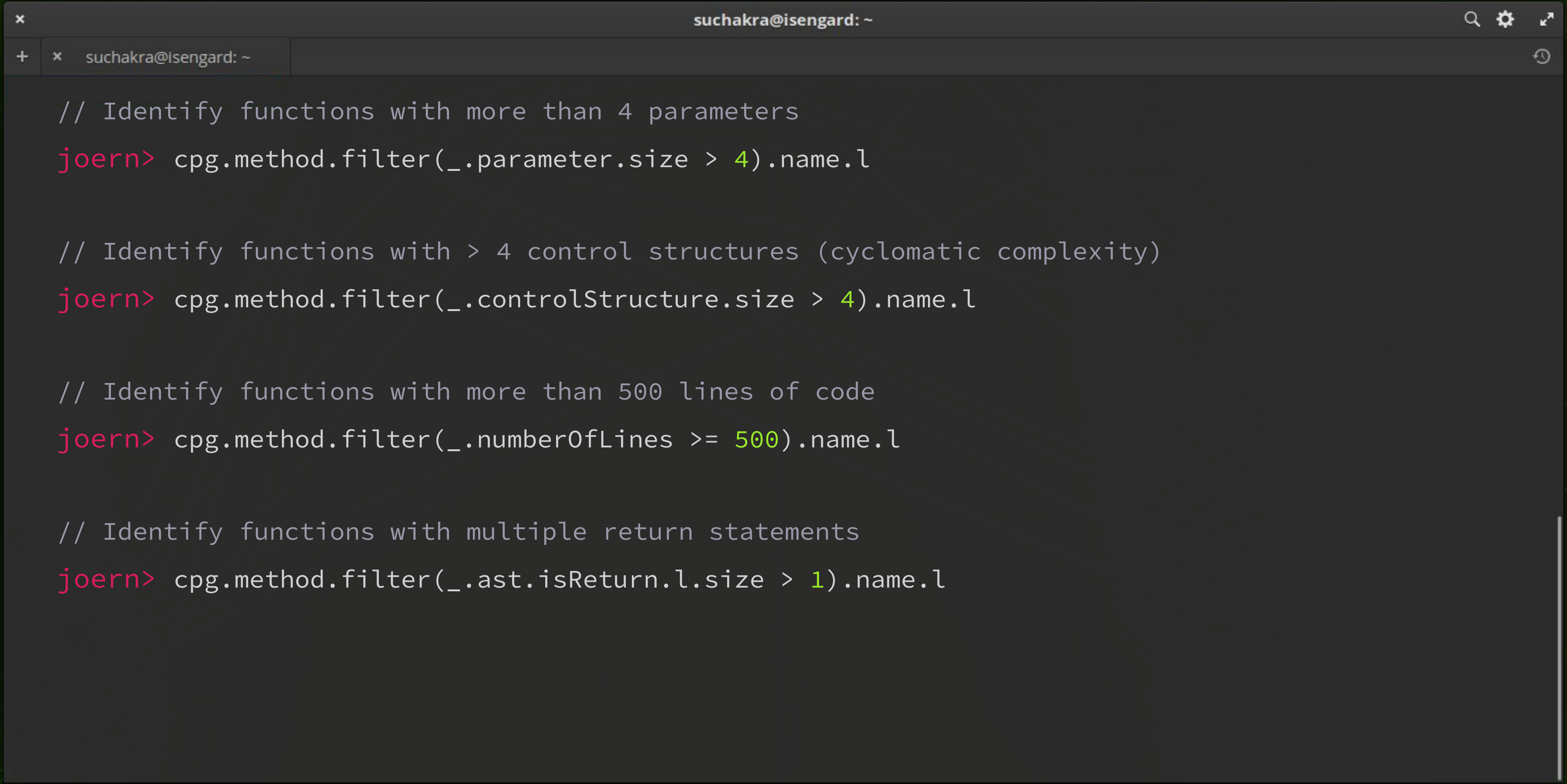
## 3. Basic Navigation - Types, Variables and Filtering



```
// 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
```

Module 1

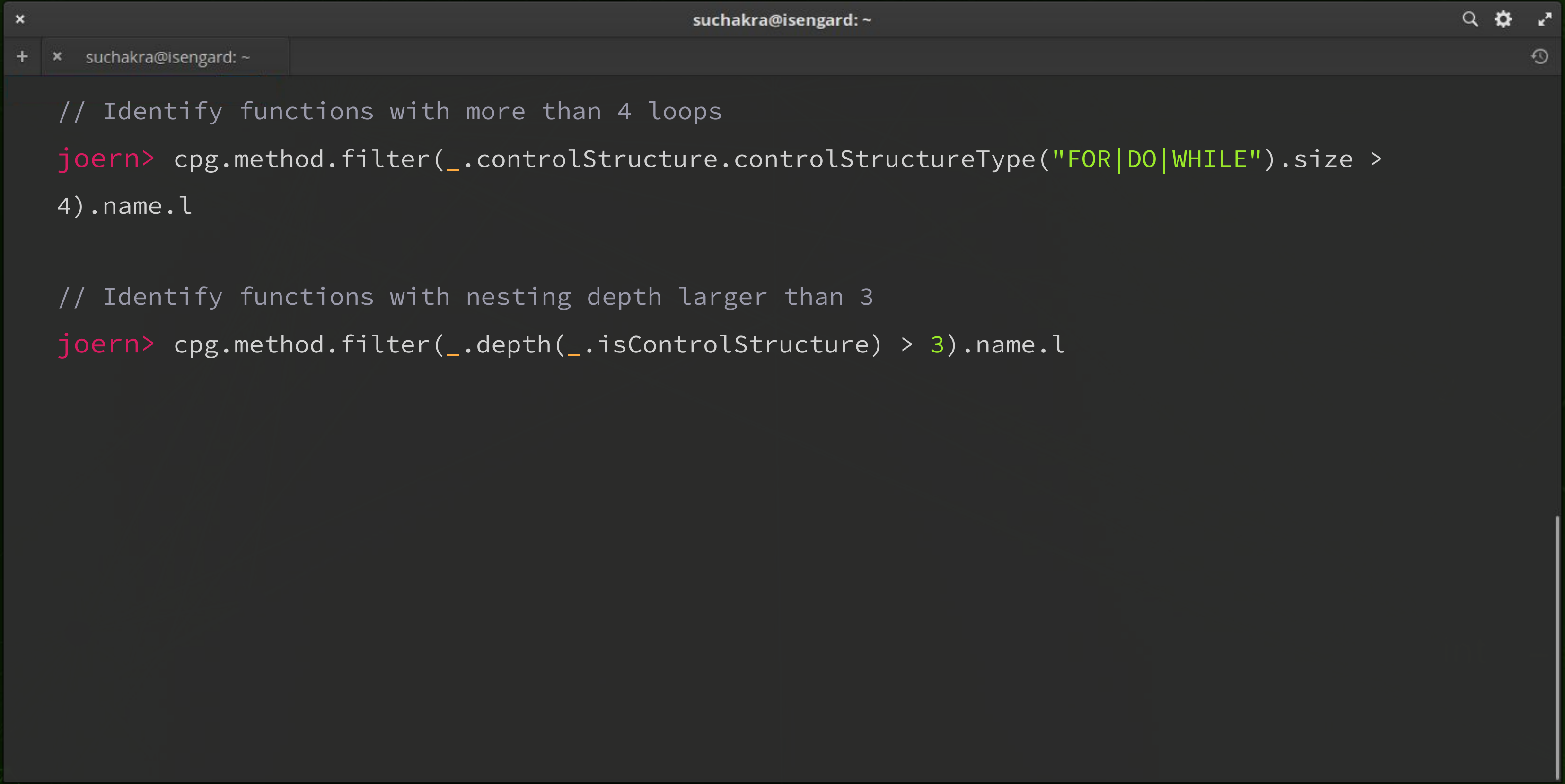
## 4. Basic Insights - Code Complexity



```
// 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
```

Module 1

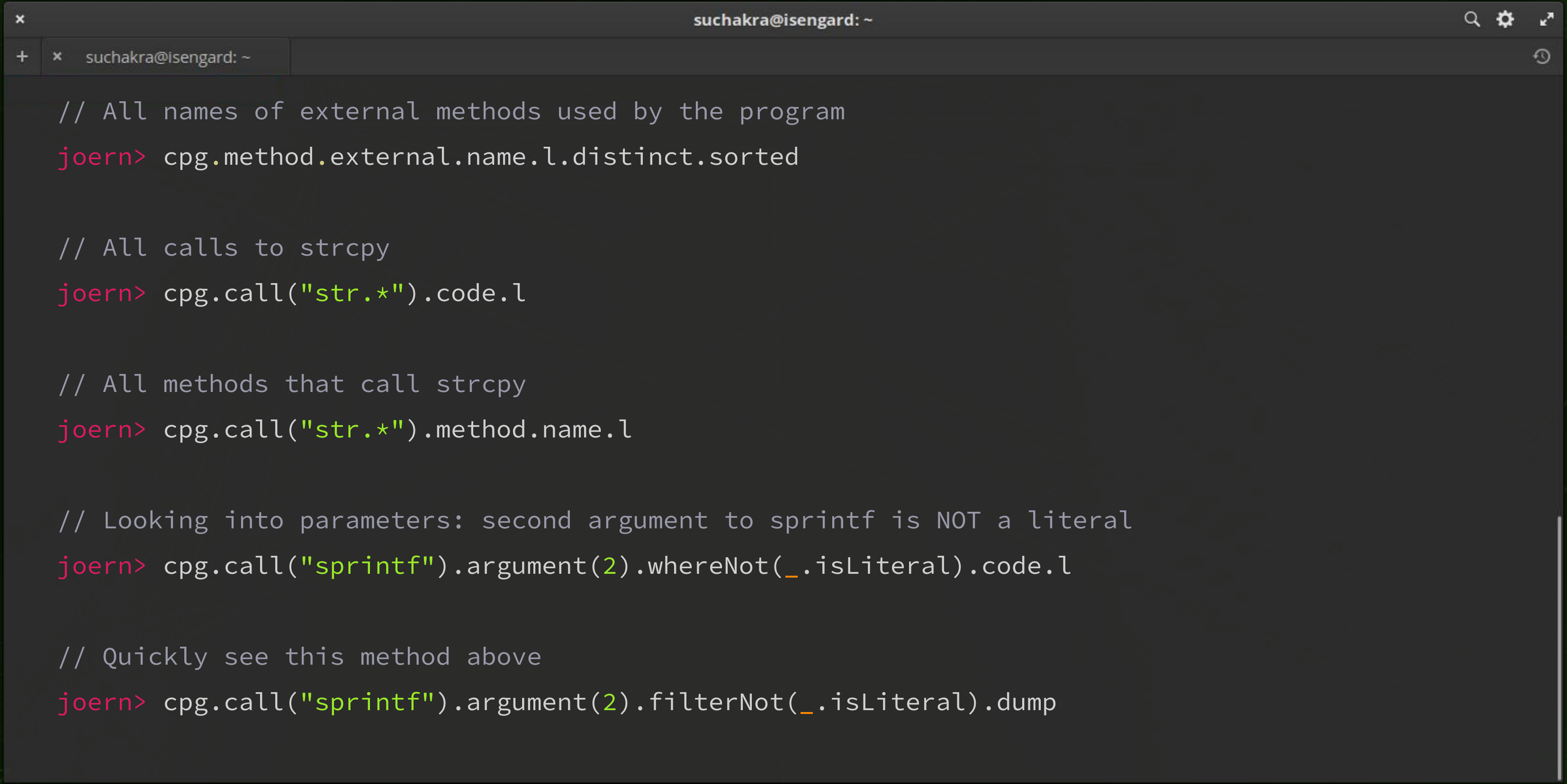
## 4. Basic Insights - Code Complexity



```
// 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
```

Module 1

## 5. Basic Insights - Calls into Libraries

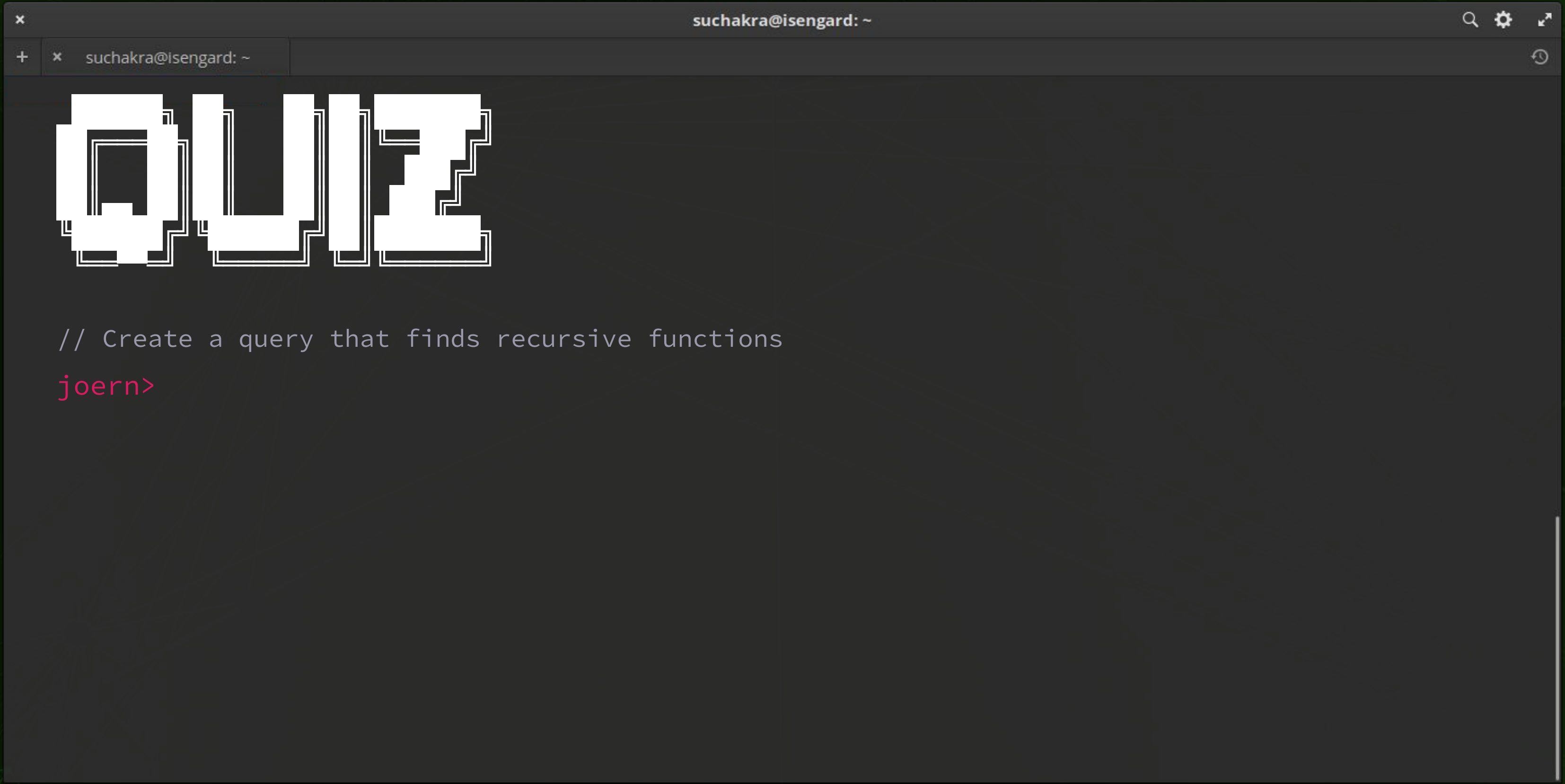


suchakra@isengard: ~

```
// 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).whereNot(_.isLiteral).code.l

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

Module 1

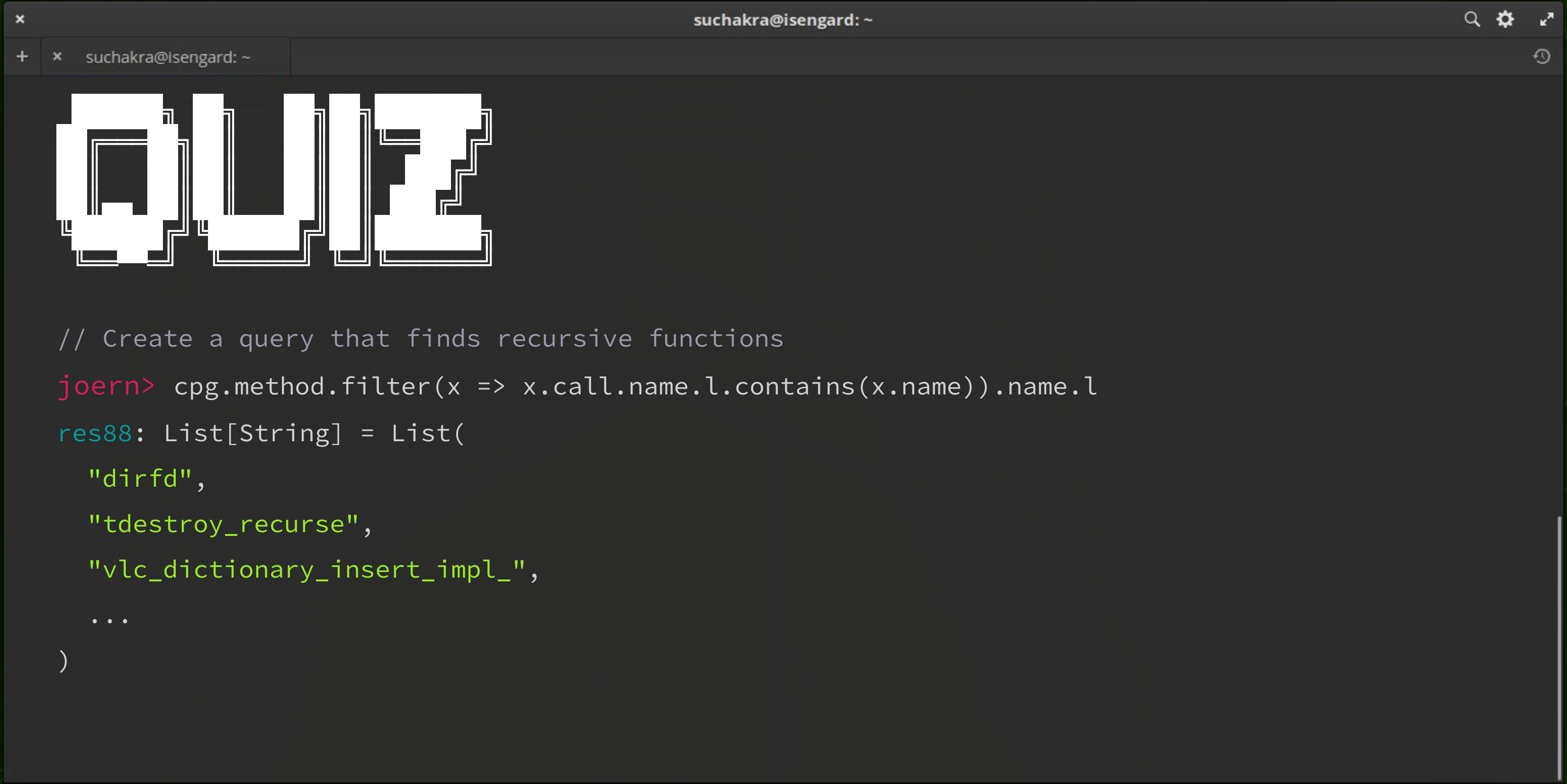
## QUIZ



```
// Create a query that finds recursive functions
joern>
```

Module 1

## QUIZ



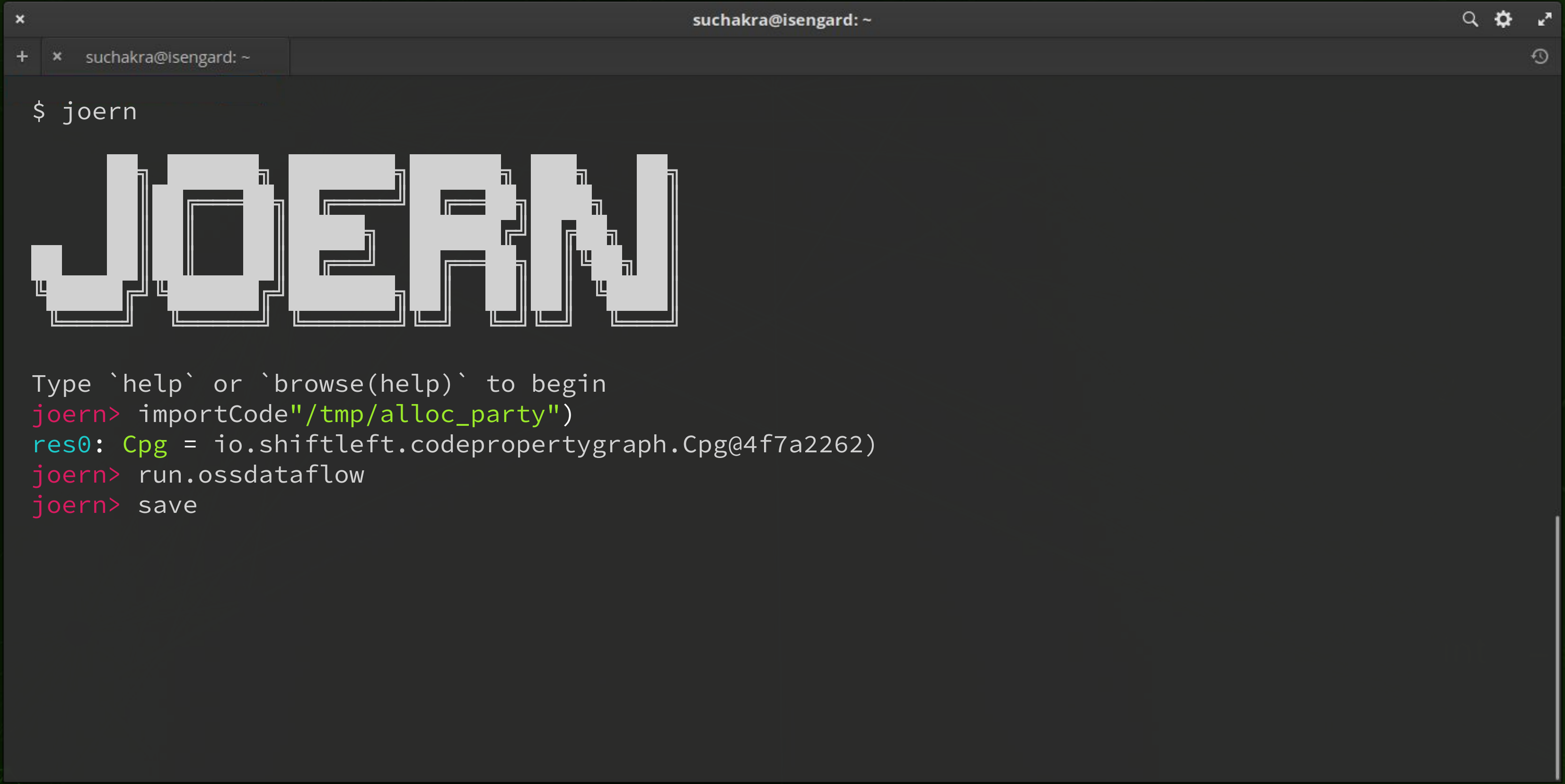
```
// Create a query that finds recursive functions
joern> cpg.method.filter(x => x.call.name.l.contains(x.name)).name.l
res88: List[String] = List(
  "dirfd",
  "tdestroy_recurse",
  "vlc_dictionary_insert_impl_",
  ...
)
```

## Module 2

Hunting Memory Bugs

Module 2

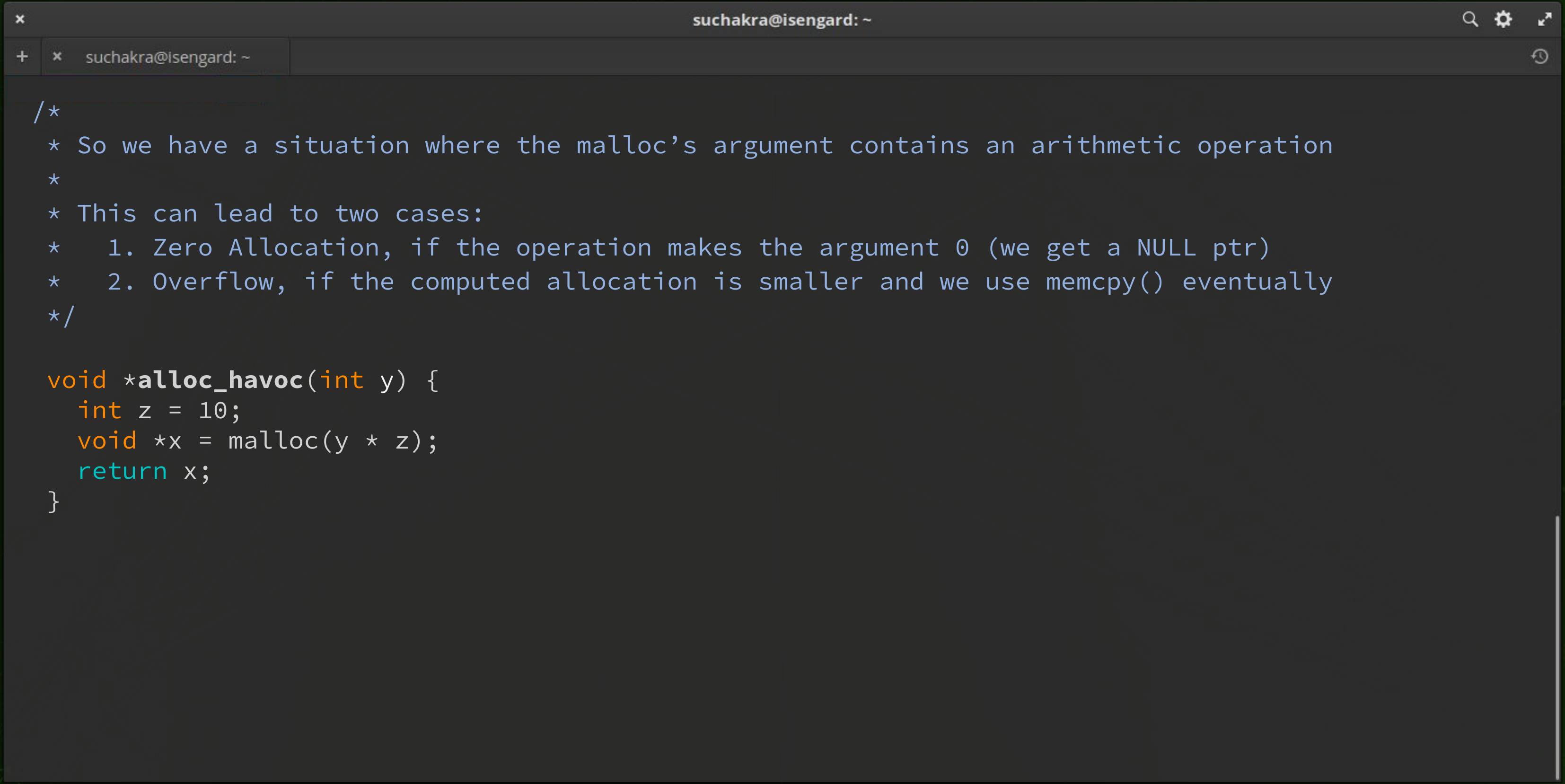
## 1. Generating CPG for `alloc_party.c`



```
$ joern

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
```

Module 2

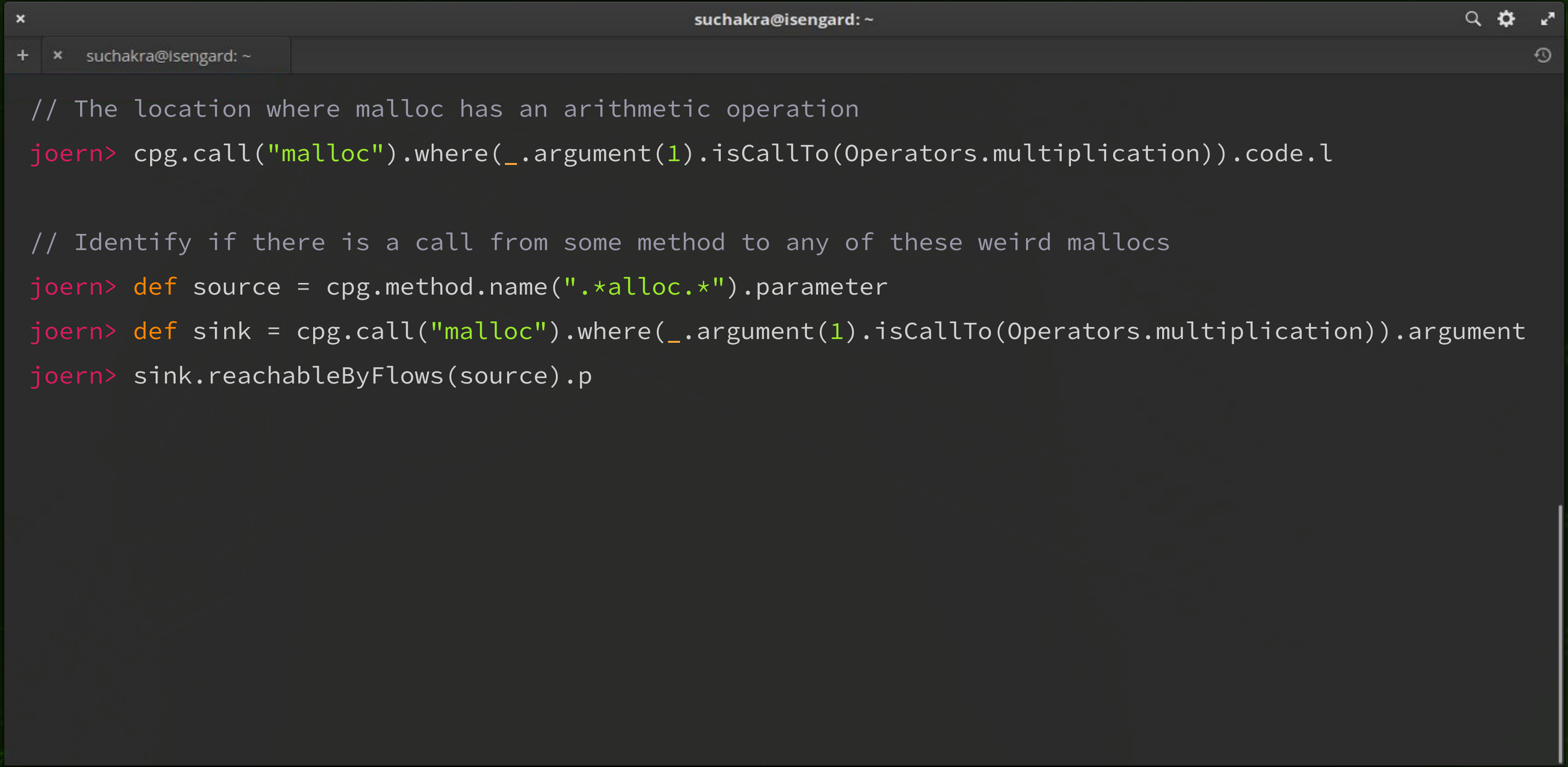
## 2. Memory Allocation Bugs - Zero Alloc/Overflow


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

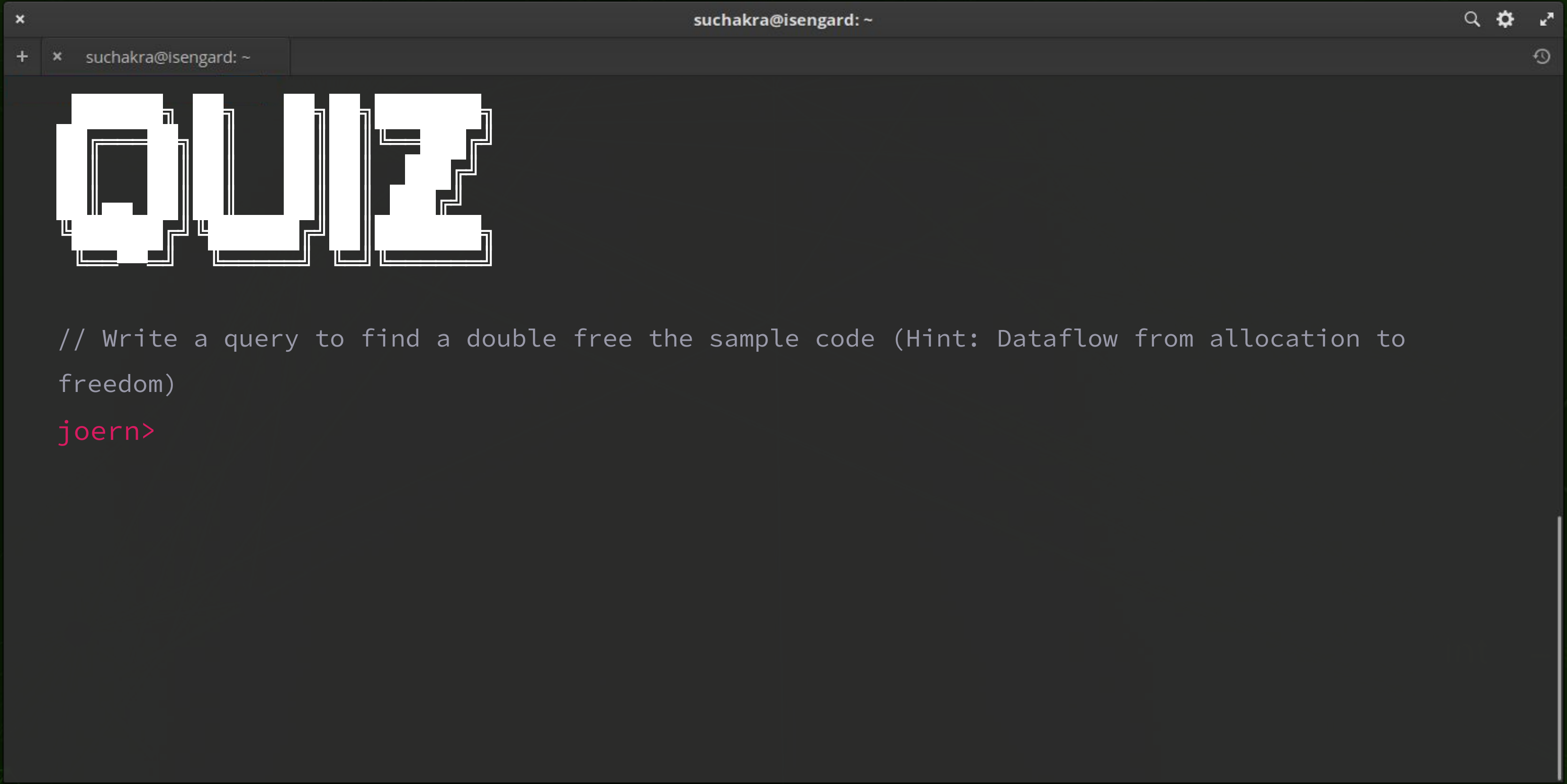
## 2. Memory Allocation Bugs - Zero Alloc/Overflow



```
// 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
```

Module 2

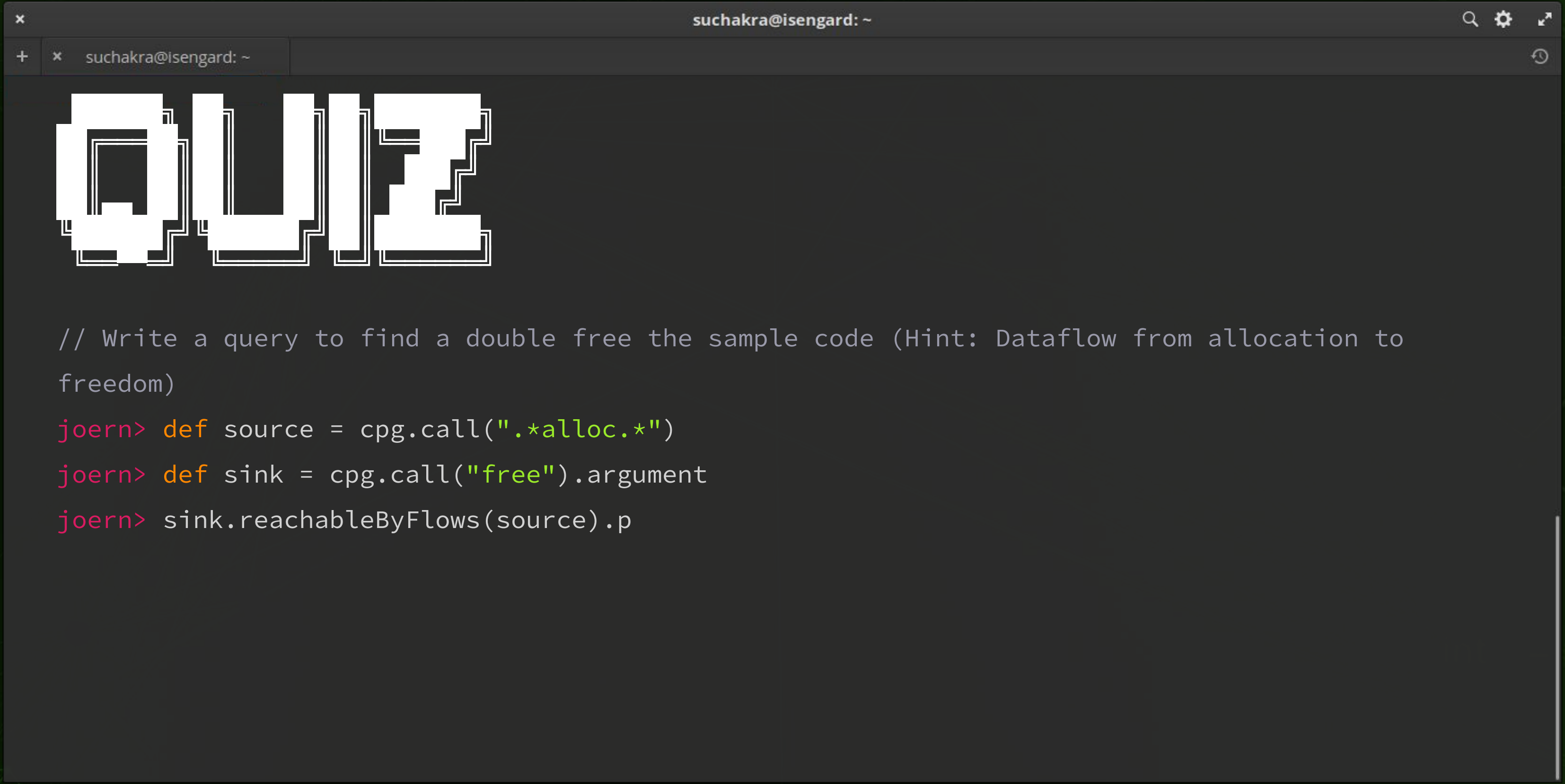
## QUIZ



```
// Write a query to find a double free the sample code (Hint: Dataflow from allocation to
freedom)
joern>
```

Module 2

## QUIZ



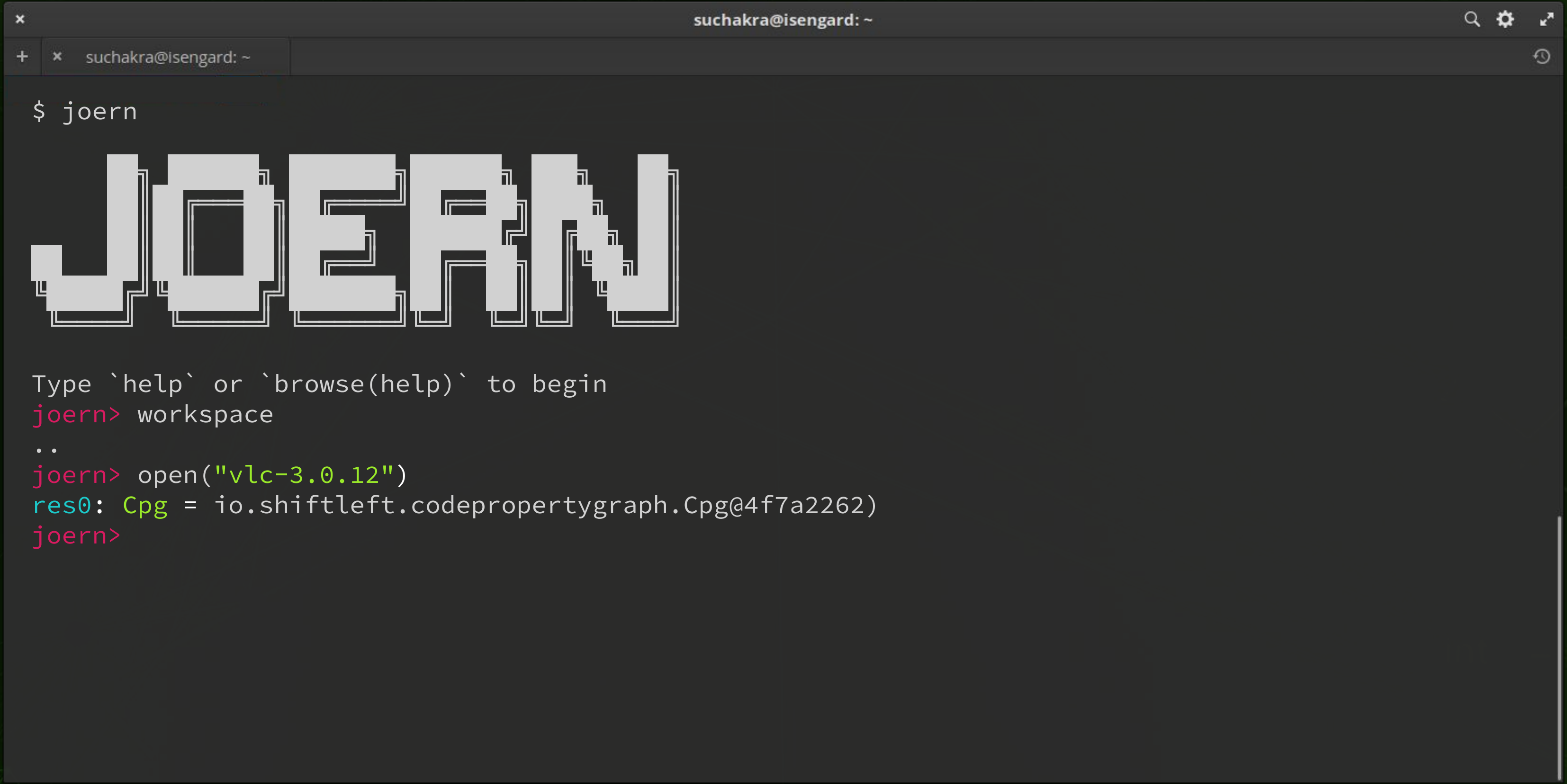
```
// Write a query to find a double free the sample code (Hint: Dataflow from allocation to
freedom)
joern> def source = cpg.call(".*alloc.*")
joern> def sink = cpg.call("free").argument
joern> sink.reachableByFlows(source).p
```

## Module 3

Finding Vulnerabilities in VLC

Module 3

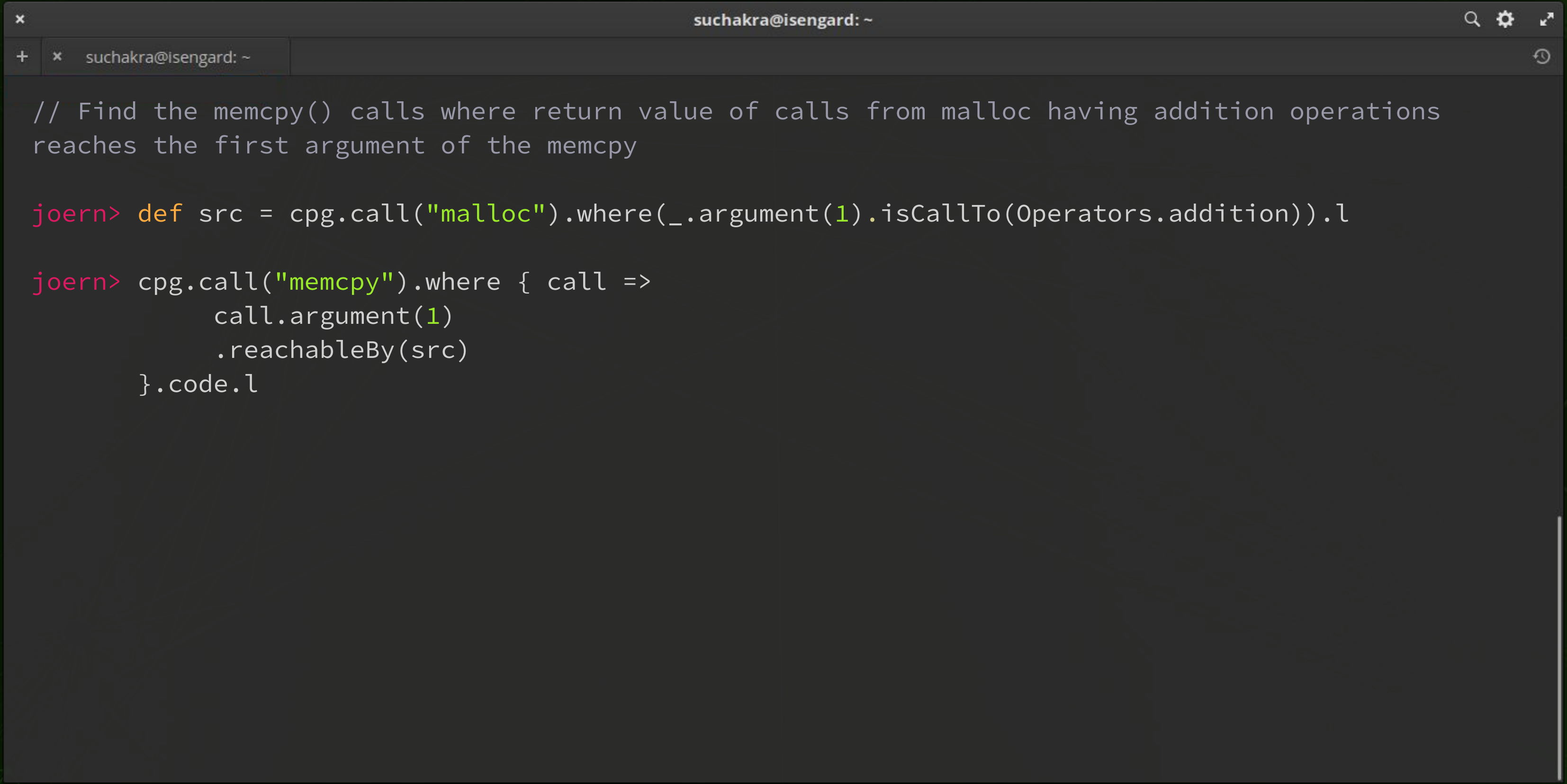
## 3. Back to the VLC CPG


suchakra@isengard: ~

```
$ joern

Type `help` or `browse(help)` to begin
joern> workspace
..
joern> open("vlc-3.0.12")
res0: Cpg = io.shiftleft.codepropertygraph.Cpg@4f7a2262)
joern>
```

Module 3

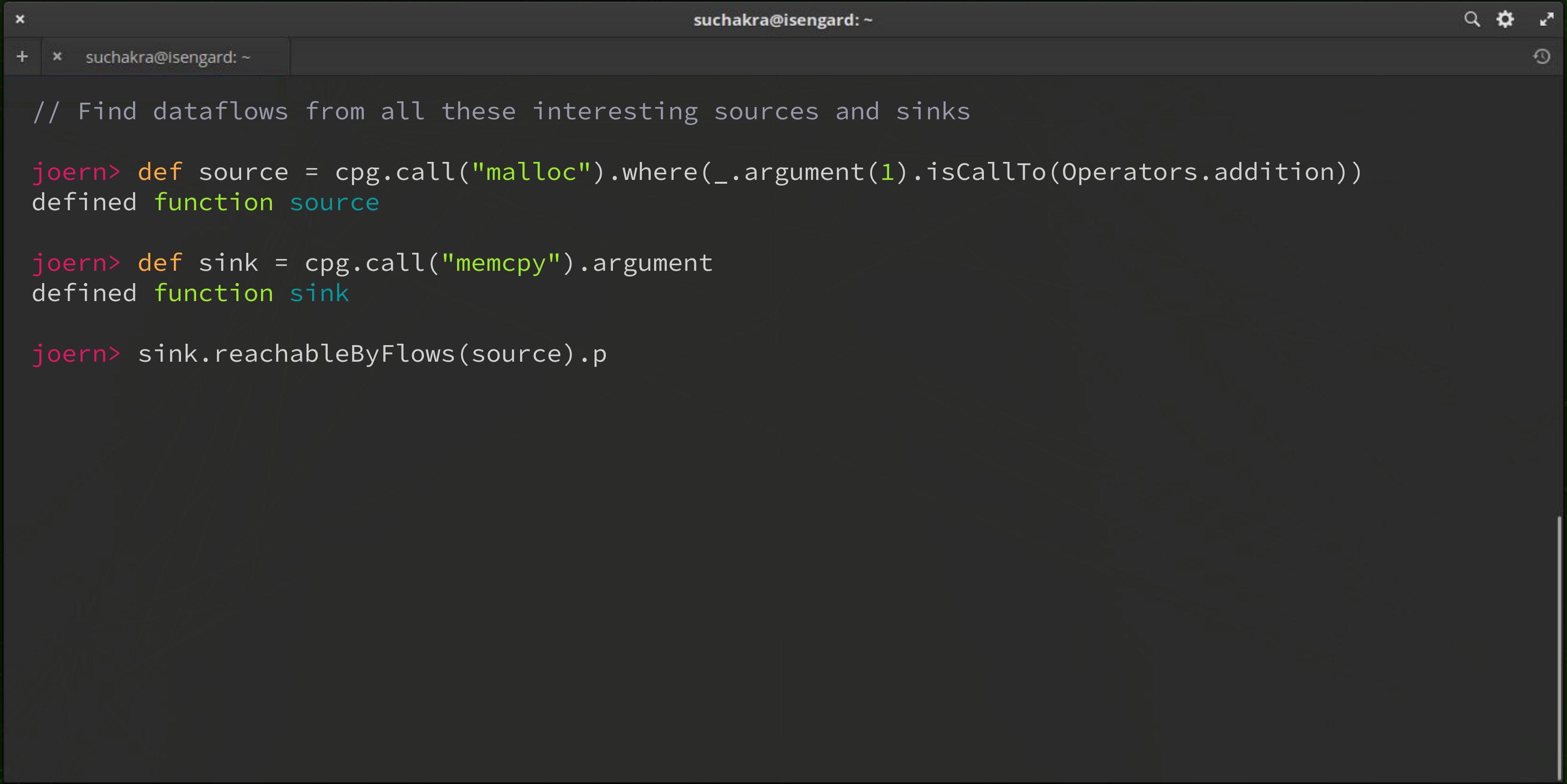
## 3. Buffer Overflow Hunting in VLC - First Try



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

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

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

Module 3

## 3. Buffer Overflow Hunting in VLC - Dataflow


suchakra@isengard: ~

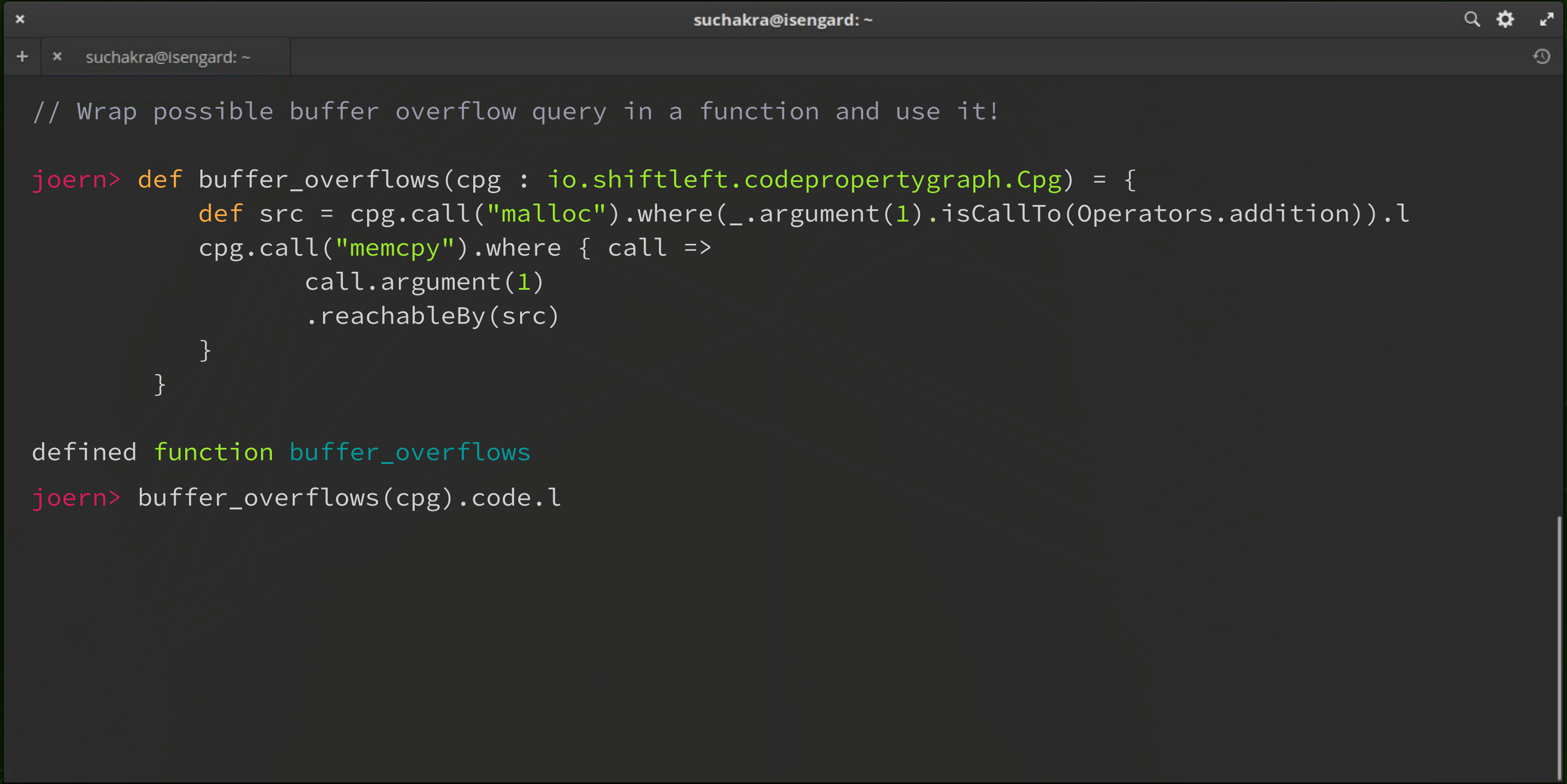
```
// Find dataflows from all these interesting sources and sinks

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
```

## Module 4

Joern Scripting

Module 4

# 1. Scripting - DRY Function

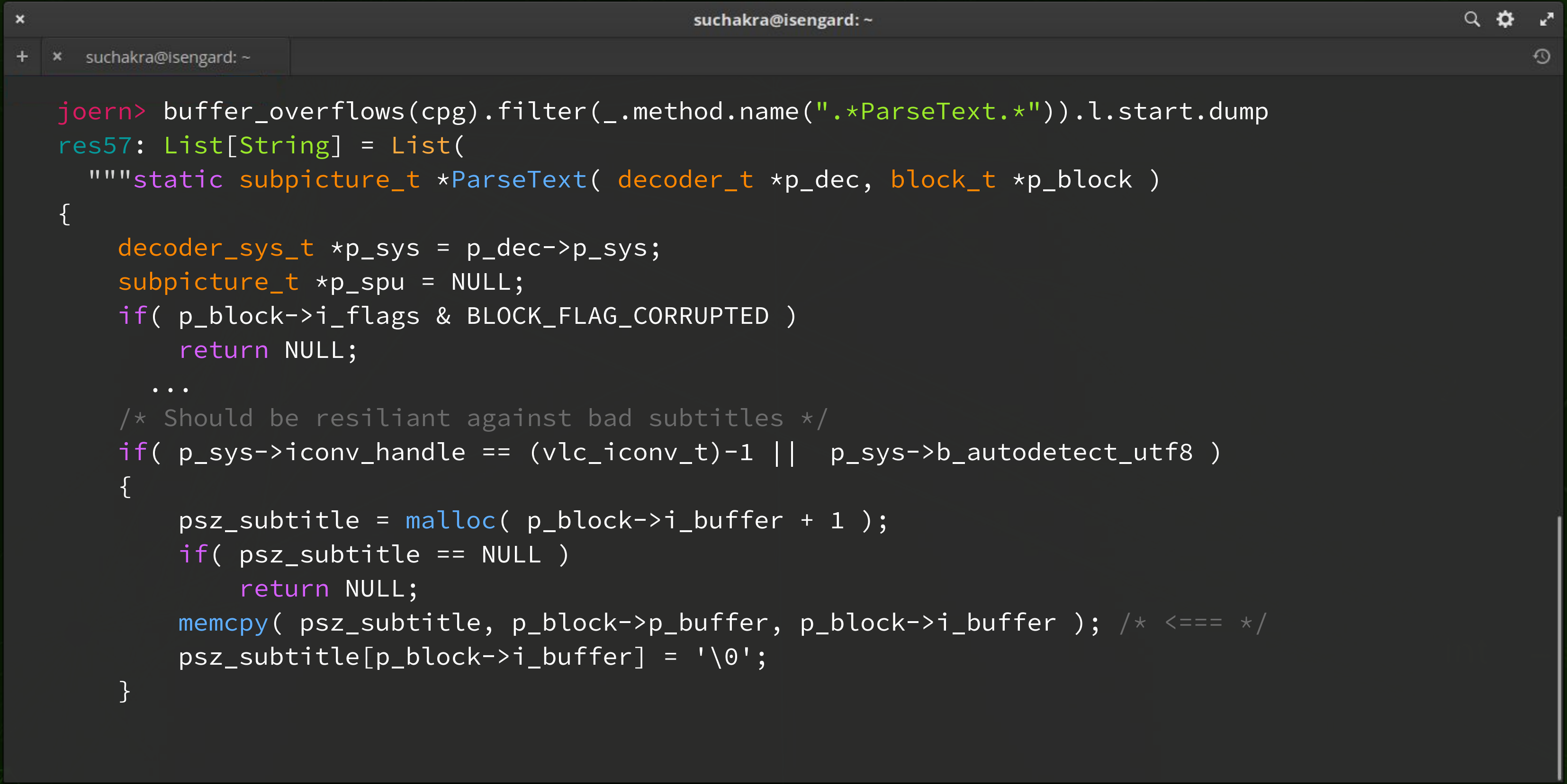


```
// Wrap possible buffer overflow query in a function and use it!

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)
            }
        }

defined function buffer_overflows

joern> buffer_overflows(cpg).code.l
```

Let’s test on VLC..

Module 4

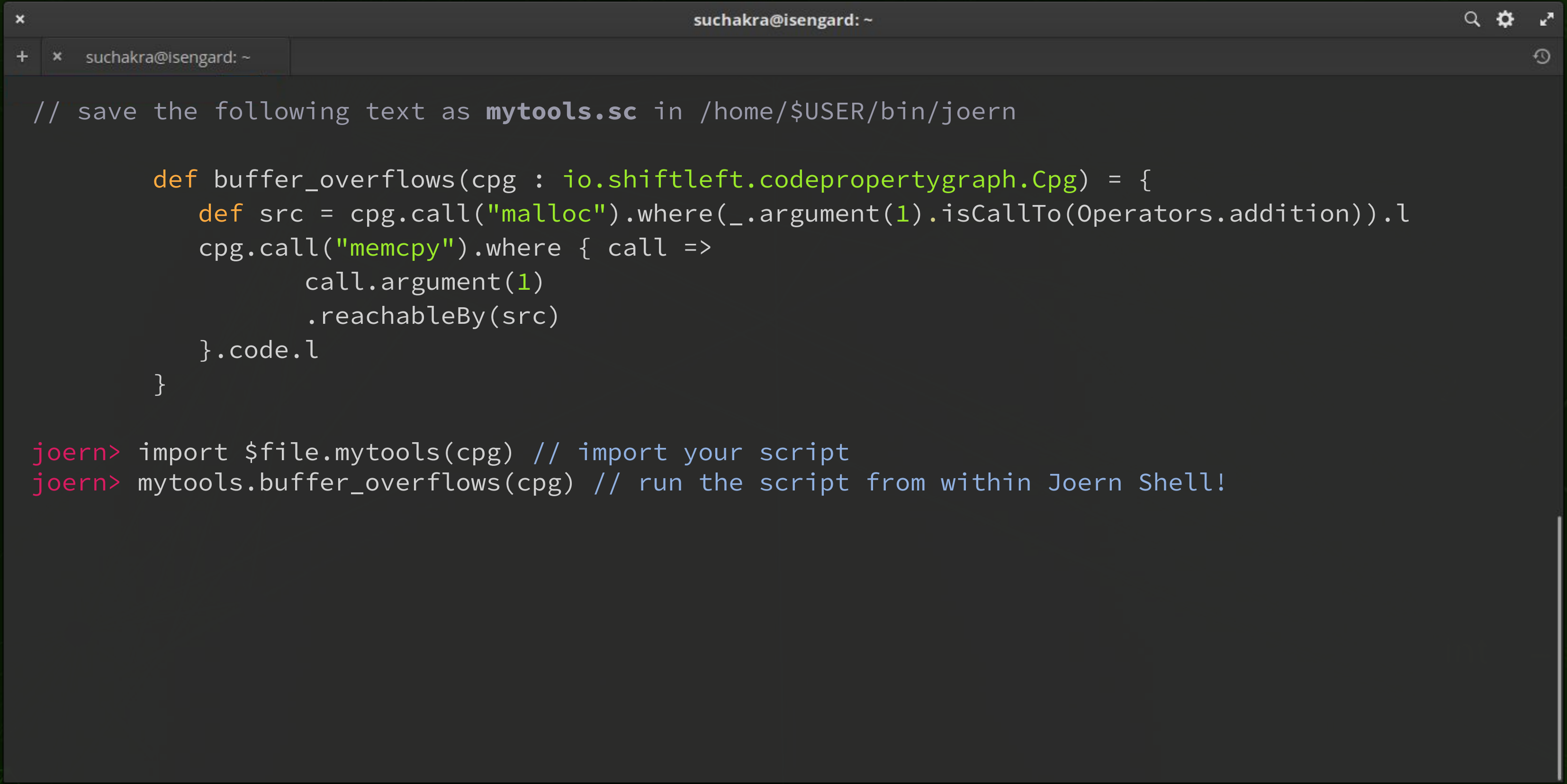
## p_block->i_buffer == MAX_UINT64 **causes an overflow!**



```
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';
    }
```

Module 4

## 1. Scripting - Creating Internal Tools

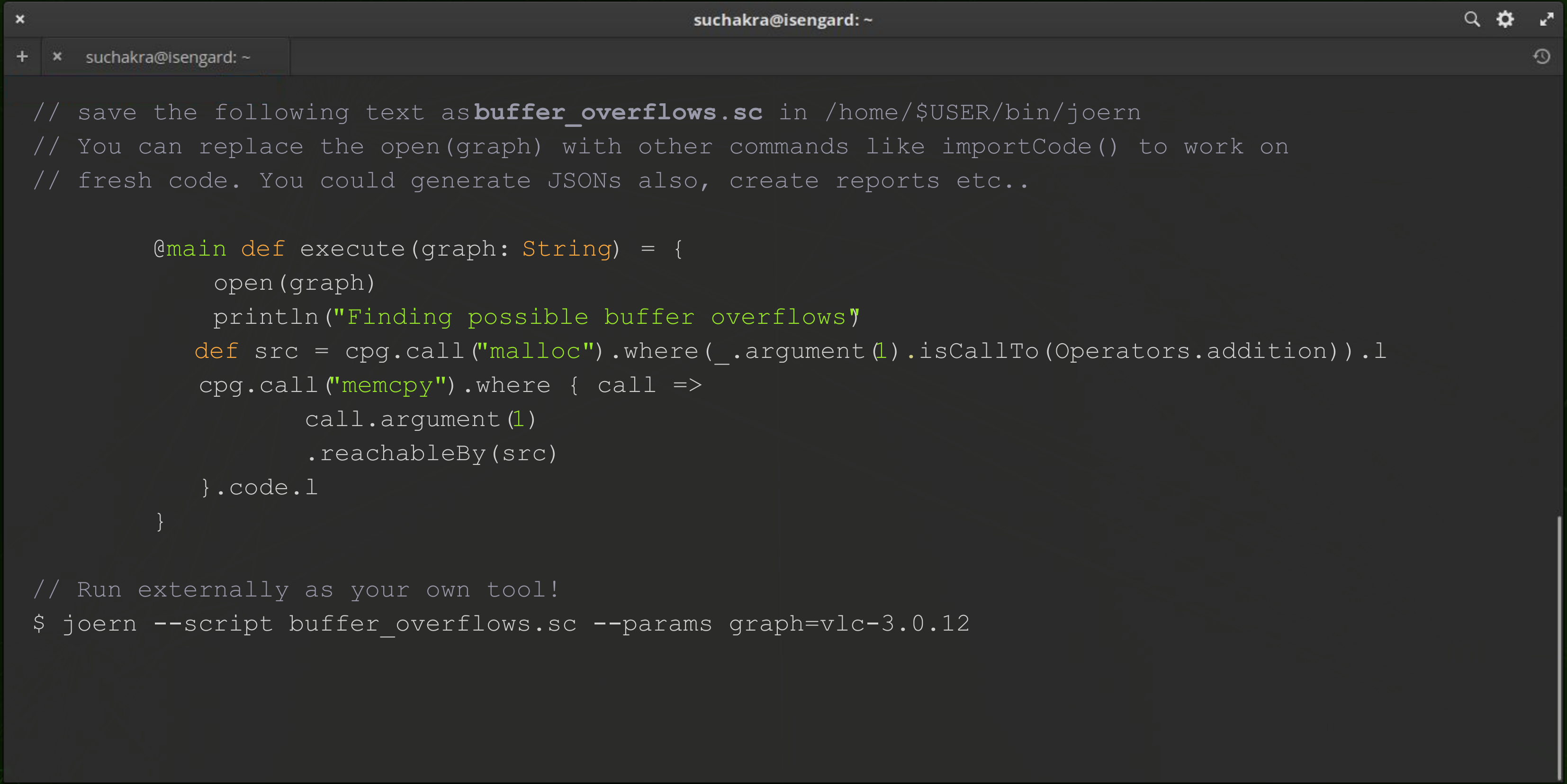


suchakra@isengard: ~

```
// 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!
```

Module 4

## 1. Scripting - Creating External Standalone Tools

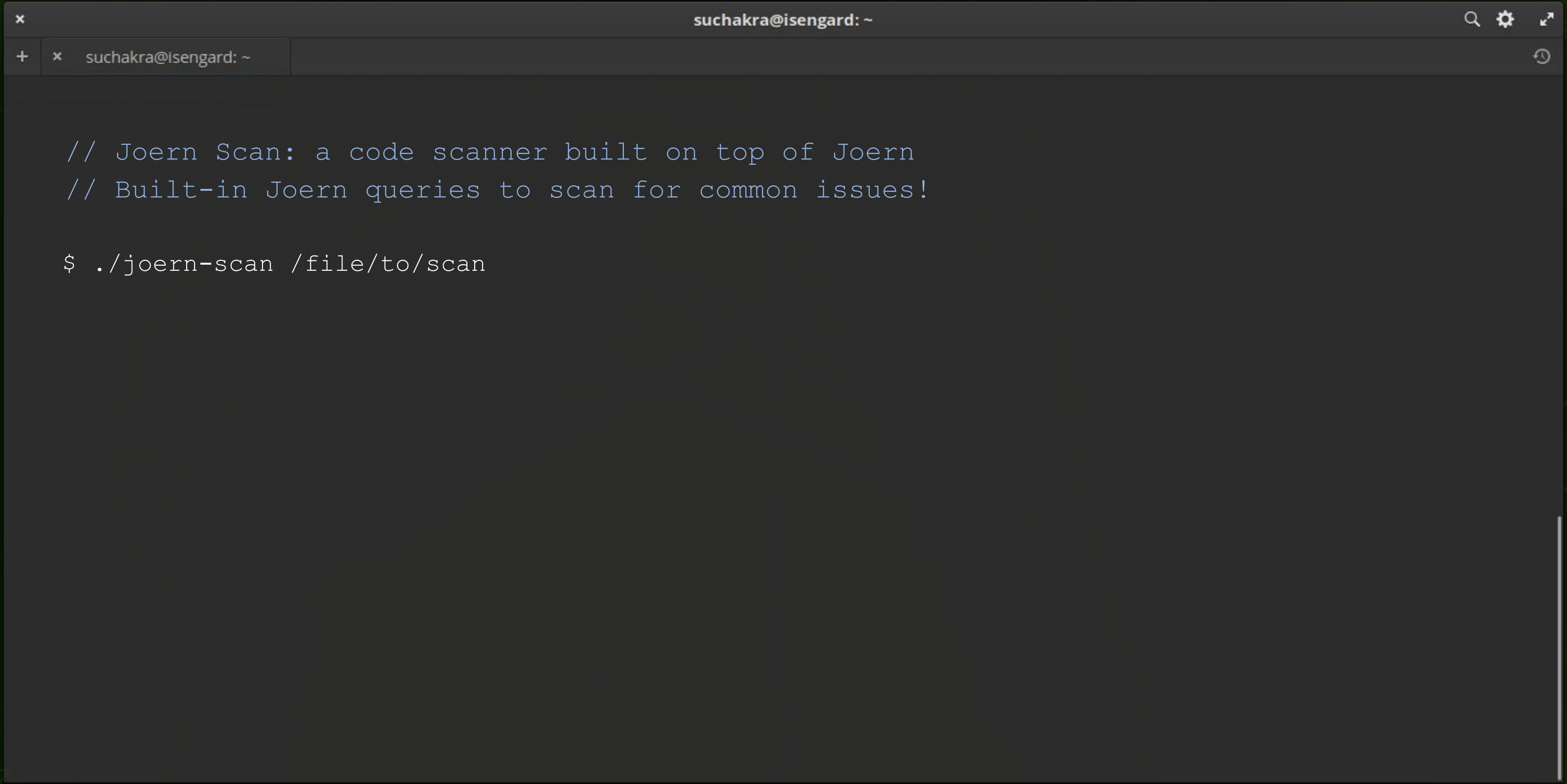


```
// save the following text as buffer_overflows.sc in /home/$USER/bin/joern
// You can replace the open(graph) with other commands like importCode() to work on
// fresh code. You could generate JSONs also, create reports etc..

        @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_overflows.sc --params graph=vlc-3.0.12
```

# Module 5

## Building Custom Scanners

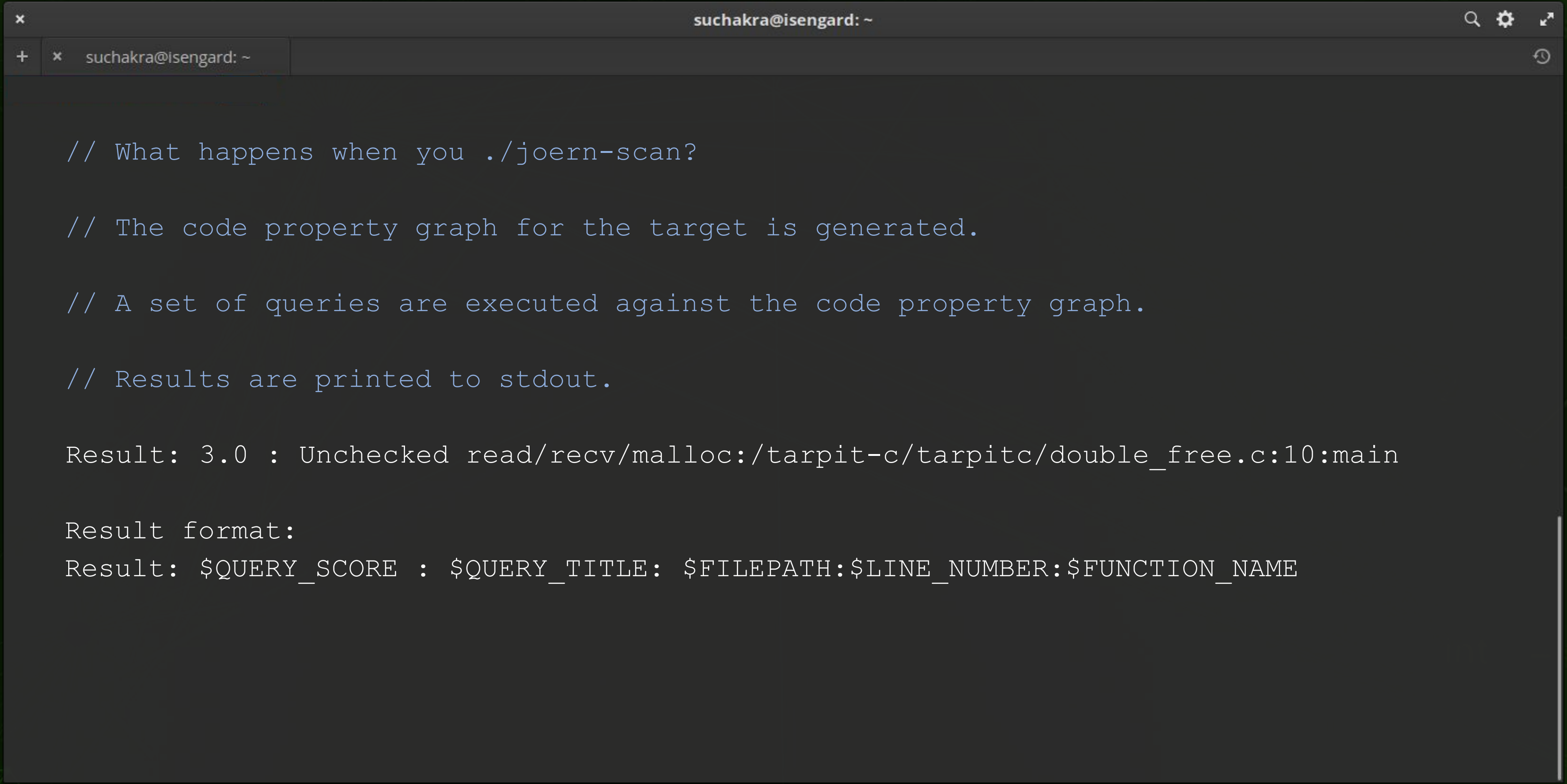
## 1. Custom Scanning - Joern Scan



```
// Joern Scan: a code scanner built on top of Joern
// Built-in Joern queries to scan for common issues!

$ ./joern-scan /file/to/scan
```

Module 5

## 2. Custom Scanning - Under The Hood

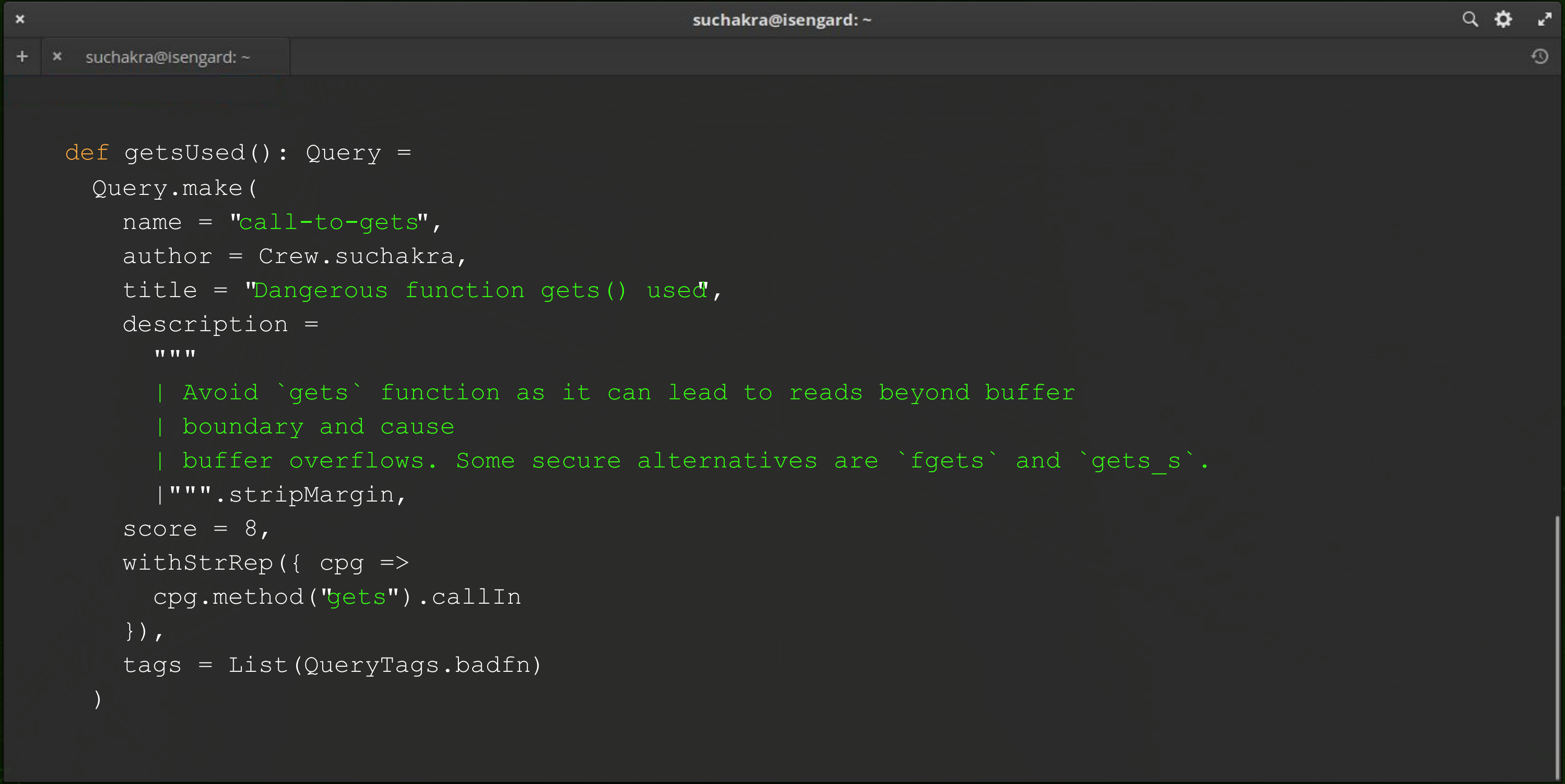


suchakra@isengard: ~

```
// What happens when you ./joern-scan?

// The code property graph for the target is generated.

// A set of queries are executed against the code property graph.

// Results are printed to stdout.

Result: 3.0 : Unchecked read/recv/malloc:/tarpit-c/tarpitc/double_free.c:10:main

Result format:
Result: $QUERY_SCORE : $QUERY_TITLE: $FILEPATH:$LINE_NUMBER:$FUNCTION_NAME
```

Module 5

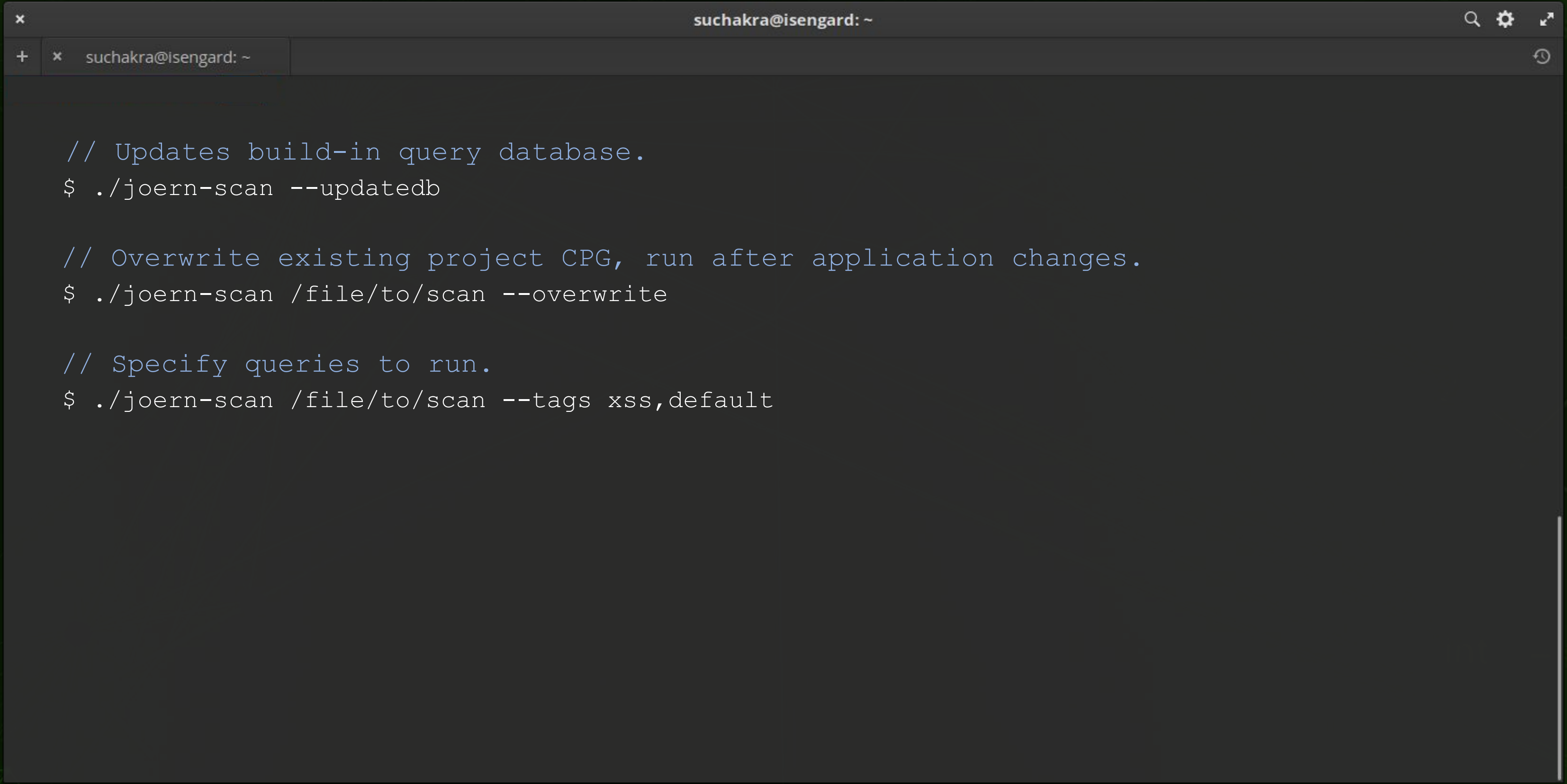
## 3. Custom Scanning - Joern Scan Queries



```
def getsUsed(): Query =
  Query.make(
    name = "call-to-gets",
    author = Crew.suchakra,
    title = "Dangerous function gets() used",
    description =
      """
      | Avoid `gets` function as it can lead to reads beyond buffer
      | boundary and cause
      | buffer overflows. Some secure alternatives are `fgets` and `gets_s`.
      |""".stripMargin,
    score = 8,
    withStrRep({ cpg =>
      cpg.method("gets").callIn
    }),
    tags = List(QueryTags.badfn)
  )
```

Module 5

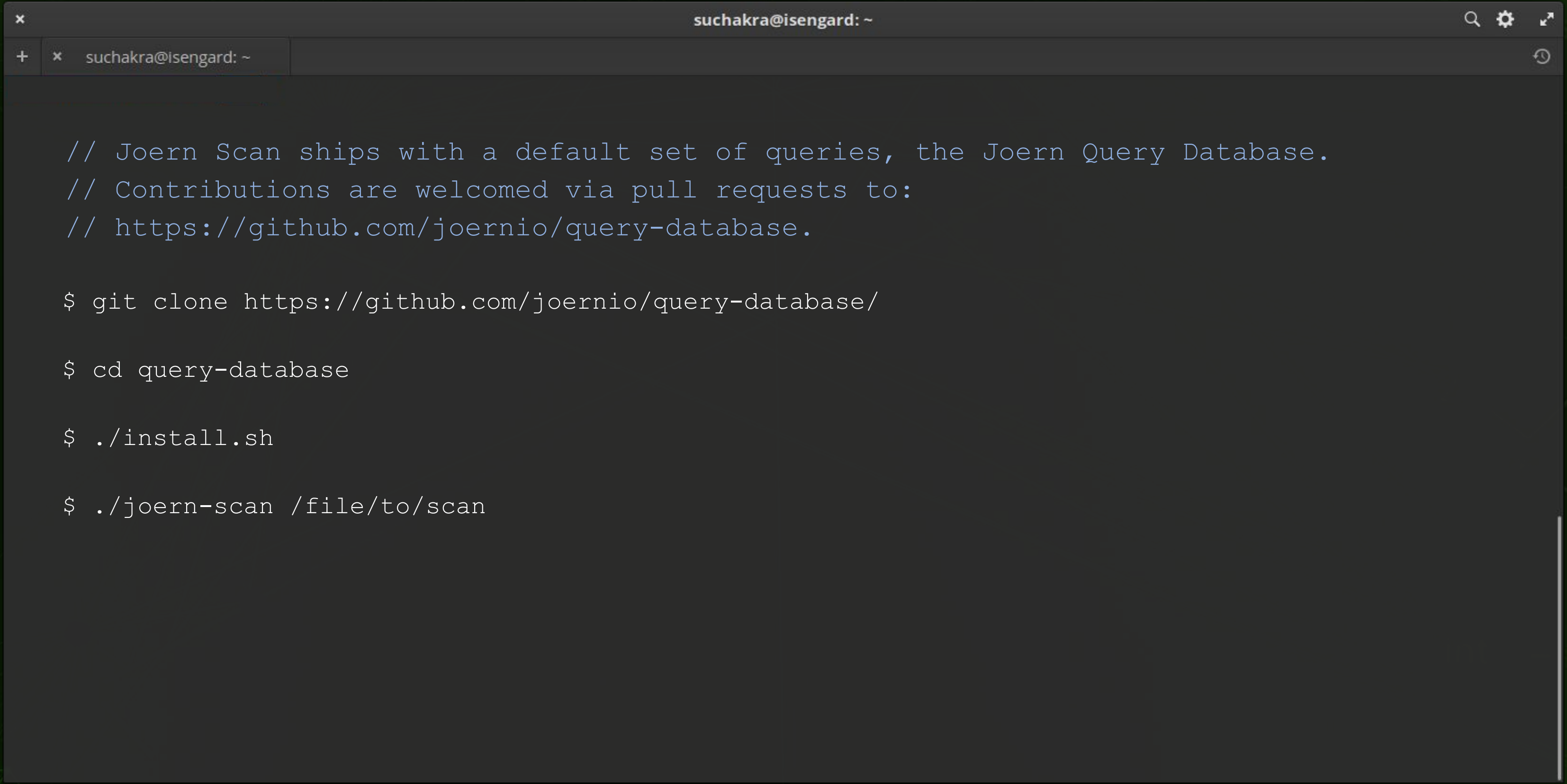
## **4. Custom Scanning** - Joern Scan Options



```
// Updates build-in query database.
$ ./joern-scan --updatedb

// Overwrite existing project CPG, run after application changes.
$ ./joern-scan /file/to/scan --overwrite

// Specify queries to run.
$ ./joern-scan /file/to/scan --tags xss,default
```

Module 5

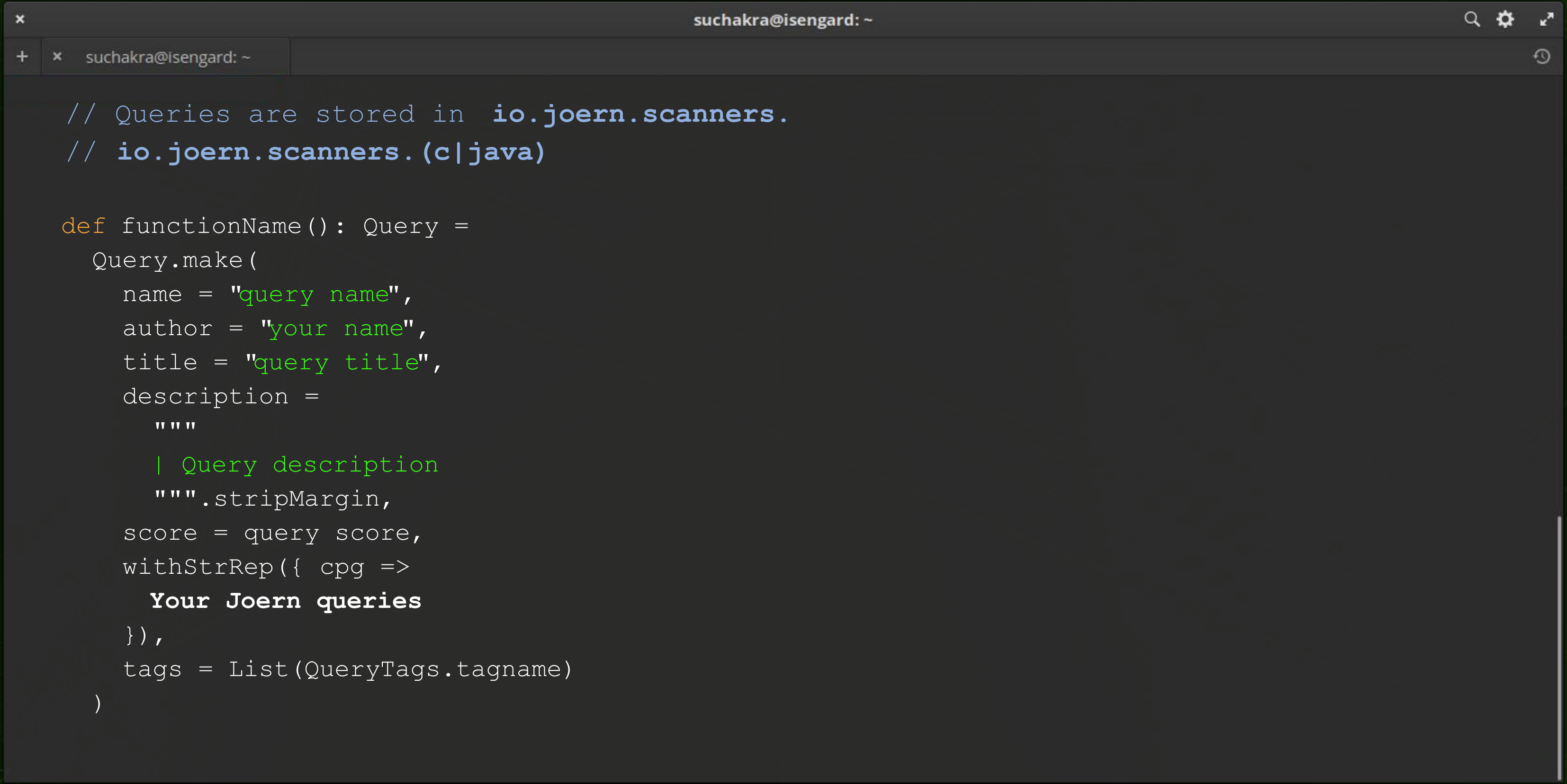
## 5. Custom Scanning - Extending Joern Scan



```
// Joern Scan ships with a default set of queries, the Joern Query Database.
// Contributions are welcomed via pull requests to:
// https://github.com/joernio/query-database.

$ git clone https://github.com/joernio/query-database/

$ cd query-database

$ ./install.sh

$ ./joern-scan /file/to/scan
```

Module 5

## 6. Custom Scanning - Adding Your Own Queries



suchakra@isengard: ~

```
// Queries are stored in  io.joern.scanners.
// io.joern.scanners.(c|java)

def functionName(): Query =
  Query.make(
    name = "query name",
    author = "your name",
    title = "query title",
    description =
      """
      | Query description
      """.stripMargin,
    score = query score,
    withStrRep({ cpg =>
      Your Joern queries
    }),
    tags = List(QueryTags.tagname)
  )
```

## Open Forum

Q&A - Please use Discord

## Fin

http://joern.io