This is an eland

OpenCV

Dependency Extraction

eLand

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Overview

1. Program Dependency Extraction
2. Implemented Techniques
3. Quantitative and Qualitative Comparison
4. Limitations and Lessons Learned

Program Dependency Extraction

Understand Include srcML

Understand

- SciTools' "Understand" software is an IDE, with multiple tools for code analysis:
  - Code navigation
  - Dependency analysis
  - Visualize with graphs
  - Compliance validation
  - Measure code with metrics

Understand™
by SciTools

Understand Extraction Process

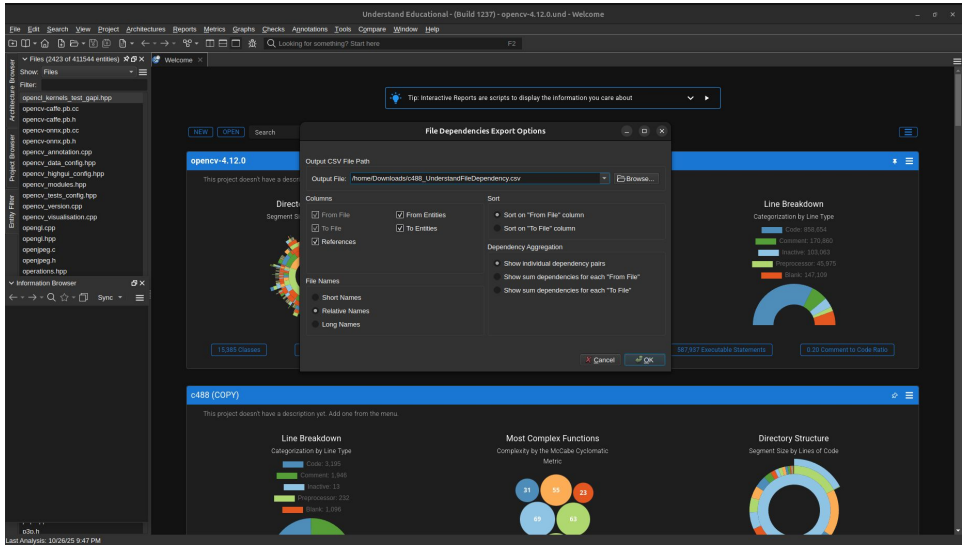
~/opencv-4.12.0/build

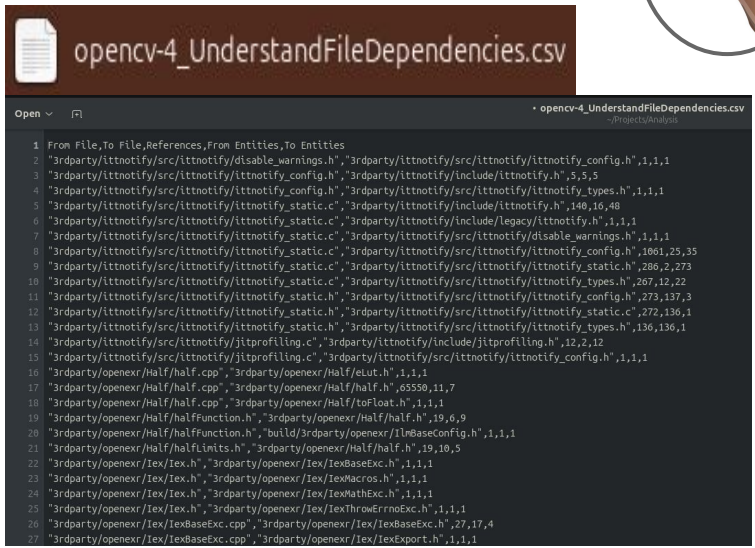
```
:~/opencv-4.12.0/build$ cmake ../build
-- ocv_init_download: OpenCV source tree is not fetched as git repository. 3rdparty resources will be downloaded from github.com by
 default.
-- Detected processor: x86_64
-- Looking for ccache - not found
-- Could NOT find AVIF (missing: AVIF_LIBRARY AVIF_INCLUDE_DIR)
-- Could NOT find OpenJPEG (minimal suitable version: 2.0, recommended version >= 2.3.1). OpenJPEG will be built from sources
-- OpenJPEG: VERSION = 2.5.3, BUILD = opencv-4.12.0-openjp2-2.5.3
-- OpenJPEG libraries will be built from sources: libopenjp2 (version "2.5.3")
-- libva: missing va.h header (VA_INCLUDE_DIR)
-- found Intel IPP (ICV version): 2022.1.0 [2022.1.0]
-- at: /home/metalgeardull/opencv-4.12.0/build/3rdparty/ippicv/ippicv_lnx/icv
-- found Intel IPP Integration Wrappers sources: 2022.1.0
-- at: /home/metalgeardull/opencv-4.12.0/build/3rdparty/ippicv/ippicv_lnx/iw
-- Could NOT find Atlas (missing: Atlas_CBLAS_INCLUDE_DIR Atlas_CLAPACK_INCLUDE_DIR Atlas_CBLAS_LIBRARY Atlas_BLAS_LIBRARY Atlas_LA
PACK_LIBRARY)
-- Could NOT find BLAS (missing: BLAS_LIBRARIES)
-- Could NOT find LAPACK (missing: LAPACK_LIBRARIES)
    Reason given by package: LAPACK could not be found because dependency BLAS could not be found.

-- Could NOT find JNI (missing: JAVA_INCLUDE_PATH JAVA_INCLUDE_PATH2 AWT)
-- VTK is not found. Please set -DVTK_DIR in CMake to VTK build directory, or to VTK install subdirectory with VTKConfig.cmake file
-- Checking for module 'gtk+-2.0'
--   Package 'gtk+-2.0', required by 'virtual:world', not found
-- Checking for modules 'libavcodec;libavformat;libavutil;libswscale'
--   Package 'libavcodec', required by 'virtual:world', not found
--   Package 'libavformat', required by 'virtual:world', not found
--   Package 'libavutil', required by 'virtual:world', not found
--   Package 'libswscale', required by 'virtual:world', not found
-- FFMPEG is disabled. Required libraries: libavcodec;libavformat;libavutil;libswscale. Missing libraries: libavcodec;libavformat;l
ibavutil;libswscale
-- Checking for module 'gstreamer-base-1.0'
```

compile_commands.json

- Configure OpenCV’s build system to create “compile_commands.json”.

Understand Extraction Process





- SciTools' "Understand" application analyses the file dependencies, uses the .json file for accuracy, and exports the file dependencies a .csv file

Understand Extraction Process

```
# EECS 4314 Lab Script
#       This script is used to transform the understand csv data into TA format
#
#/usr/bin/perl
#!"C:\Strawberry\perl\bin\perl.exe"

use strict;
use warnings;

my ($header, $from, $to, $reference, $v1, $v2, $output_file);
my (%FILE_HASH, %CALL_HASH, $name, $value, $count, $hash, $line);

$header = 0;

open INPUT, "$ARGV[0]";

if ($ARGV[0] =~ /(.*)\.csv/) {
        $output_file = $1 . ".raw.ta";
}

open OUTPUT, ">$output_file";

print OUTPUT "FACT TUPLE :\n";


while (<INPUT>) {
        $line =~;
        chomp $line;

        if ($header == 0) {
                $header++;
                next;
        }

        ($from, $to, $reference, $v1, $v2) = split(/,/, $line);

        # comment out if we don't want to consider header files
#       if ($from =~ /\.h/ or $to =~ /\.h/) {
#               next;
#       }

        $FILE_HASH{$from}++;
        $FILE_HASH{$to}++;
        $CALL_HASH{$from}{$to}++;
}

# output the list of files
while (($name, $value) = (each %FILE_HASH)) {
        # $INSTANCE cocoxen.o[.text+0x0] function
        print OUTPUT "$INSTANCE $name cFile\n";
}

# output the list of call relations
while (($name, $hash) = (each %CALL_HASH)) {
        while (($value, $count) = (each %$hash)) {
                # clinks cocoxen.o[.text+0x173] semantics.o[.bss+0x0]
                # print OUTPUT "contain $name $value\n";
                print OUTPUT "clinks $name $value\n";
        }
}

close INPUT;
close OUTPUT;
```

opencv-4_UnderstandFileDependencies.raw.ta

Open ~/Projects/Analysis

opencv-4_UnderstandFileDependencies.raw.ta

```
FACT TUPLE :
$INSTANCE "3rdparty/include/opencl/1.2/CL/cl.h" cFile
$INSTANCE "3rdparty/ittnotify/include/ittnotify.h" cFile
$INSTANCE "3rdparty/ittnotify/include/jitprofiling.h" cFile
$INSTANCE "3rdparty/ittnotify/include/legacy/ittnotify.h" cFile
$INSTANCE "3rdparty/ittnotify/src/ittnotify/disable_warnings.h" cFile
$INSTANCE "3rdparty/ittnotify/src/ittnotify/ittnotify_config.h" cFile
$INSTANCE "3rdparty/ittnotify/src/ittnotify/ittnotify_static.c" cFile
$INSTANCE "3rdparty/ittnotify/src/ittnotify/ittnotify_static.h" cFile
$INSTANCE "3rdparty/ittnotify/src/ittnotify/ittnotify_types.h" cFile
$INSTANCE "3rdparty/ittnotify/src/ittnotify/jitprofiling.c" cFile
$INSTANCE "3rdparty/openexr/Half/eLut.h" cFile
$INSTANCE "3rdparty/openexr/Half/half.cpp" cFile
$INSTANCE "3rdparty/openexr/Half/half.h" cFile
$INSTANCE "3rdparty/openexr/Half/halfFunction.h" cFile
$INSTANCE "3rdparty/openexr/Half/halfLimits.h" cFile
```

- A perl script reads the csv file to create a .ta file

Understand Extraction Process

```java
import java.io.*;
import java.util.*;

public class GenerateContainRelations {
    Run | Debug
    public static void main(String[] args) {
        String inputFile = "opencv-4_UnderstandFileDependencies.raw.ta";
        String outputFile = "opencv-4_UnderstandFileDependencies.contain";

        Set<String> seenRelations = new HashSet<>();

        try (BufferedReader br = new BufferedReader(new FileReader(inputFile));
             PrintWriter pw = new PrintWriter(new FileWriter(outputFile))) {

            String line;
            while ((line = br.readLine()) != null) {
                line = line.trim();

                if (!line.startsWith("$INSTANCE")) continue;

                int start = line.indexOf('"');
                int end = line.lastIndexOf('"');
                if (start == -1 || end == -1 || start >= end) continue;

                String path = line.substring(start + 1, end);
                String[] parts = path.split("/");

                for (int i = 0; i < parts.length - 1; i++) {
                    String parentPath = String.join("/", Arrays.copyOfRange(parts, 0, i + 1));
                    String childPath = String.join("/", Arrays.copyOfRange(parts, 0, i + 2));
                    String relation = "contain \"" + parentPath + "\" \"" + childPath + "\"";

                    if (seenRelations.add(relation)) {
                        pw.println(relation);
                    }
                }
            }

            System.out.println("Containment relationships written to " + outputFile);

        } catch (IOException e) {
            System.err.println("Error processing file: " + e.getMessage());
        }
    }
}
```

opencv-4_UnderstandFileDependencies.contain

Open

opencv-4_UnderstandFileDependencies.contain
~/Projects/ExtractContains

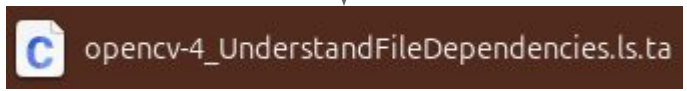
```
contain "3rdparty" "3rdparty/include"
contain "3rdparty/include" "3rdparty/include/opencl"
contain "3rdparty/include/opencl" "3rdparty/include/opencl/1.2"
contain "3rdparty/include/opencl/1.2" "3rdparty/include/opencl/1.2/CL"
contain "3rdparty/include/opencl/1.2/CL" "3rdparty/include/opencl/1.2/CL/cl.h"
contain "3rdparty" "3rdparty/ittnotify"
contain "3rdparty/ittnotify" "3rdparty/ittnotify/include"
contain "3rdparty/ittnotify/include" "3rdparty/ittnotify/include/ittnotify.h"
contain "3rdparty/ittnotify/include" "3rdparty/ittnotify/include/jitprofiling.h"
contain "3rdparty/ittnotify/include" "3rdparty/ittnotify/include/legacy"
contain "3rdparty/ittnotify/include/legacy" "3rdparty/ittnotify/include/legacy/ittnotify.h"
contain "3rdparty/ittnotify" "3rdparty/ittnotify/src"
contain "3rdparty/ittnotify/src" "3rdparty/ittnotify/src/ittnotify"
contain "3rdparty/ittnotify/src/ittnotify" "3rdparty/ittnotify/src/ittnotify/disable_warnings.h"
contain "3rdparty/ittnotify/src/ittnotify" "3rdparty/ittnotify/src/ittnotify/ittnotify_config.h"
contain "3rdparty/ittnotify/src/ittnotify" "3rdparty/ittnotify/src/ittnotify/ittnotify_static.c"
contain "3rdparty/ittnotify/src/ittnotify" "3rdparty/ittnotify/src/ittnotify/ittnotify_static.h"
contain "3rdparty/ittnotify/src/ittnotify" "3rdparty/ittnotify/src/ittnotify/ittnotify_types.h"
contain "3rdparty/ittnotify/src/ittnotify" "3rdparty/ittnotify/src/ittnotify/jitprofiling.c"
contain "3rdparty" "3rdparty/openexr"
contain "3rdparty/openexr" "3rdparty/openexr/Half"
contain "3rdparty/openexr/Half" "3rdparty/openexr/Half/eLut.h"
contain "3rdparty/openexr/Half" "3rdparty/openexr/Half/half.cpp"
contain "3rdparty/openexr/Half" "3rdparty/openexr/Half/half.h"
contain "3rdparty/openexr/Half" "3rdparty/openexr/Half/halfFunction.h"
contain "3rdparty/openexr/Half" "3rdparty/openexr/Half/halfLimits.h"
```

- Our Java program reads the .ta file to create our containment file.

Understand Extraction Process

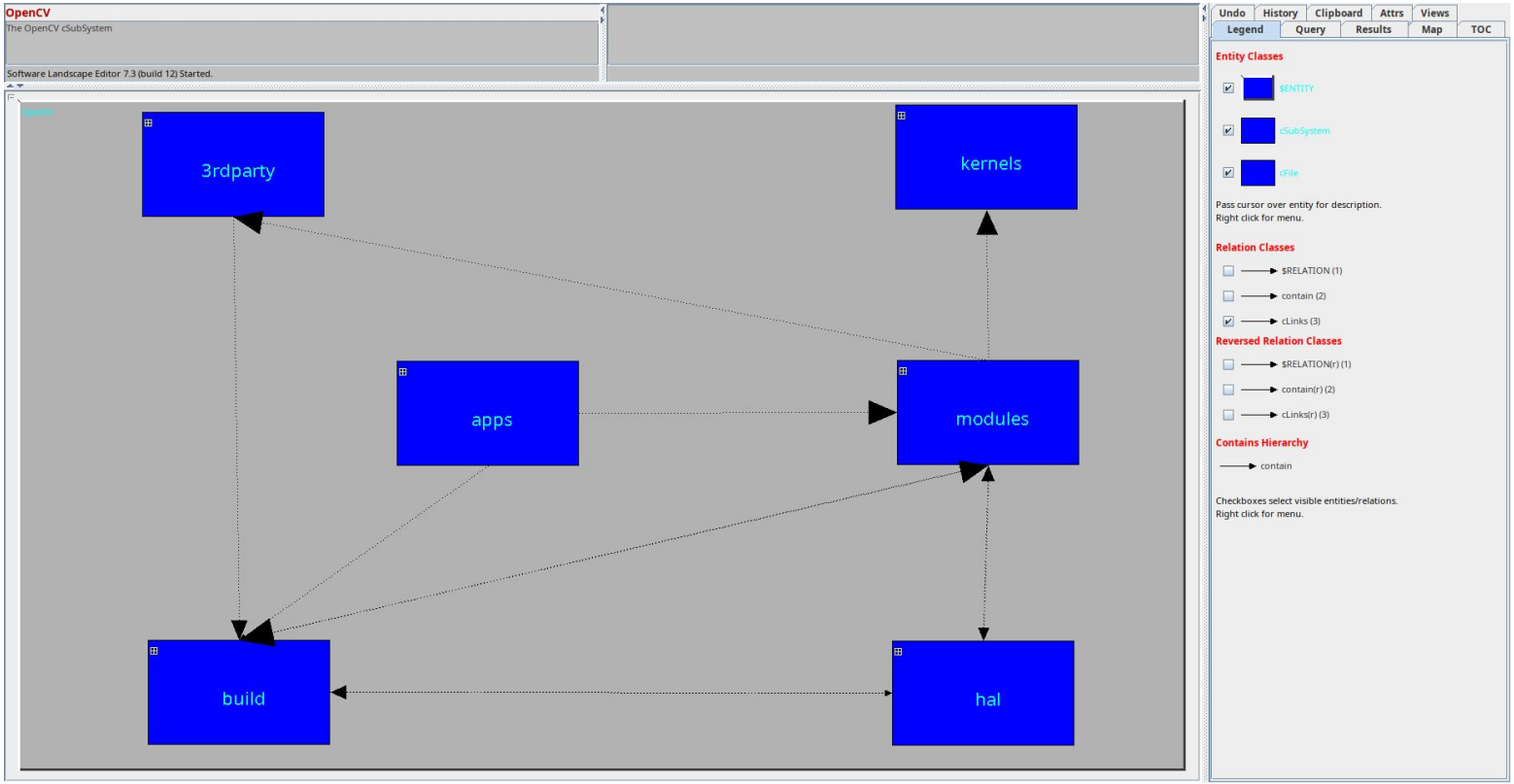
createContainment.sh
~/Projects/Analysis

```
1 #!/bin/bash
2 java -Xms256M -Xmx1024M -classpath ql.jar ca.uwaterloo.cs.ql.Main
  addcontain.ql opencv-4_UnderstandFileDependencies.contain
  opencv-4_UnderstandFileDependencies.raw.ta
  opencv-4_UnderstandFileDependencies.con.ta
3 cat schema.asv.ta opencv-4_UnderstandFileDependencies.con.ta >
  opencv-4_UnderstandFileDependencies.ls.ta
```



- A script reads our containment file to produce a landscape file of OpenCV’s architecture. This is then opened in LSEdit.

Understand Extraction Process



Include Directive Extraction

```
def findFilesFirst(root_path):

    valid_exts = {".c",".cpp",".cxx",".h",".hpp",".hh",".cc",".cpp"}
    for dirpath, _, filenames in os.walk(root_path):
        for filename in filenames:
            if os.path.splitext(filename)[1] in valid_exts:
                yield os.path.join(dirpath, filename)
```

```
regX = re.compile(r'^\s*#\s*include\s*(<|")([^">]+)(>|")')
```

Include Directive Extraction

```
for src_file in files:
    incs = findImports(src_file)

    for inc, line_no in incs:
        found_paths = edtPath(args.root, inc)

        for resolved in found_paths:
            out.write(f"{src_file},{resolved},{line_no}\n")
```

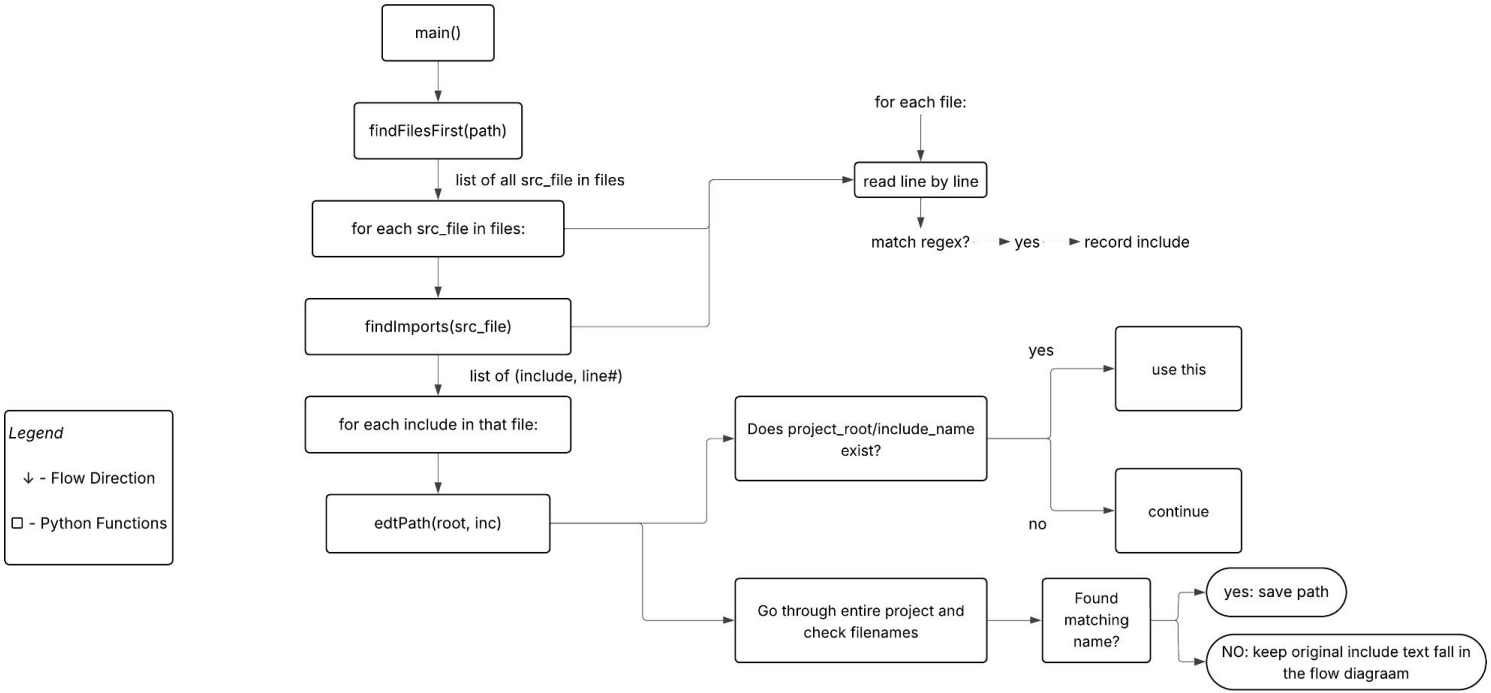
Include Directive Extraction

```python
def findImports(file_path):
    incs = []
    try:
        with open(file_path, "r", errors="ignore") as f:
            for line_number, line in enumerate(f, 1):
                match = regX.match(line)
                if match:
                    inc = match.group(2)
                    incs.append((inc, line_number))
    except Exception:
        pass
    return incs
```

```python
def edtPath(toor, inc):

    results = []
    p1 = os.path.join(toor, inc)
    if os.path.exists(p1):
        results.append(os.path.abspath(p1))

    base = os.path.basename(inc)
    for dirpath, _, filenames in os.walk(toor):
        if base in filenames:
            results.append(os.path.abspath(os.path.join(dirpath, base)))

    if not results:
        return [inc]
    return results
```

Flow Diagram of Include

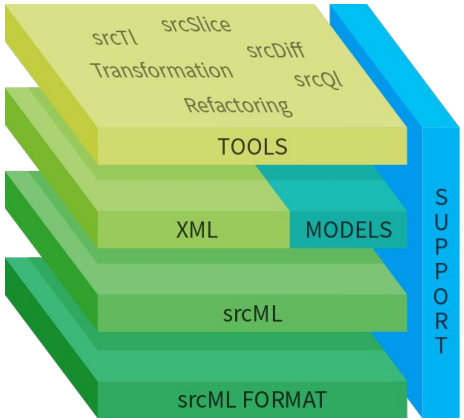
Flow Diagram of include extraction



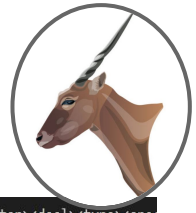
srcML

<srcML>

- Creates a XML representation of source code while keeping originally information intact
- Use XML queries to manipulate data, takes about 3 minutes to ran
- Today we will be using to it extract source code from OpenCV



srcML Extraction Process

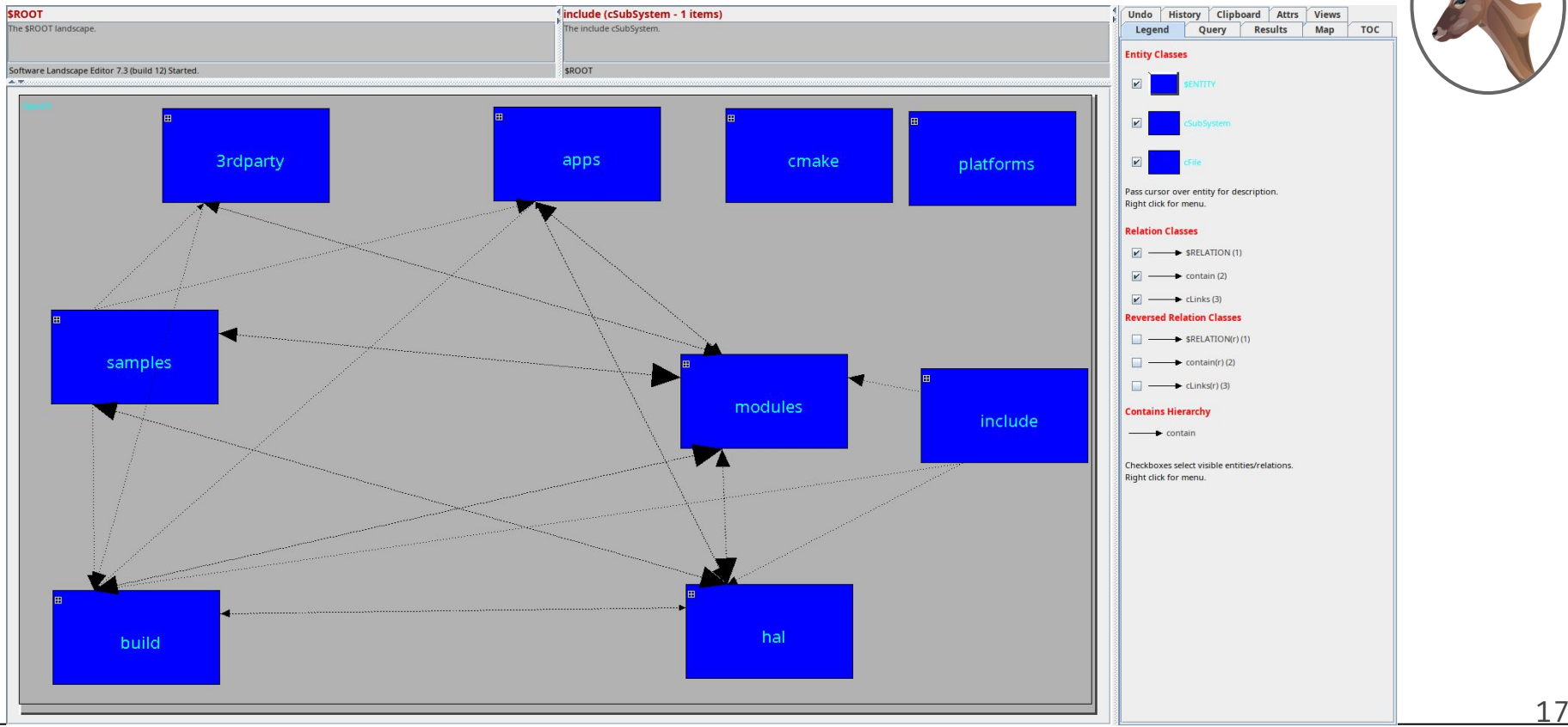


- First a shell script reads every OpenCV file into srcML XML and writes them into "files.txt"
- Then another shell script converts each file into a srcML XML file (one per OpenCV file)
- Finally using a Python script we parse each XML file and extract the dependencies

```
<function><type><name>void</name></type> <name>CopyMatrixToVector</name><parameter_list>(<parameter><decl><type><spec
<block>{<block_content>
    <decl_stmt><decl><type><name>int</name><modifier>*</modifier></type> <name>data</name> <init>= <expr><operator>(
    <for>for <control>(<init><decl><type><name>int</name></type> <name>i</name> <init>= <expr><literal type="number">
    <block>{<block_content>
        <expr_stmt><expr><call><name><name>vector</name><operator>.</operator><name>push_back</name></name><argument_
    </block_content>}</block></for>
</block_content>}</block></function>
</unit>
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<unit xmlns="http://www.srcML.org/srcML/src" xmlns:cpp="http://www.srcML.org/srcML/cpp" revision="1.0.0" language="C+
<comment type="line">// pch.cpp</comment>
<comment type="line">// Include the standard header and generate the precompiled header.</comment>
<comment type="line">//</comment>
```

```
cLinks "build/modules/core/test/test_intrin128.sse4_1.cpp" "modules/core/test/test_intrin128.simd.hpp"
cLinks "build/modules/core/test/test_intrin128.sse4_1.cpp" "modules/core/test/test_precomp.hpp"
cLinks "build/modules/core/test/test_intrin128.sse4_2.cpp" "modules/core/test/test_intrin128.simd.hpp"
cLinks "build/modules/core/test/test_intrin128.sse4_2.cpp" "modules/core/test/test_precomp.hpp"
cLinks "build/modules/core/test/test_intrin128.ssse3.cpp" "modules/core/test/test_intrin128.simd.hpp"
cLinks "build/modules/core/test/test_intrin128.ssse3.cpp" "modules/core/test/test_precomp.hpp"
cLinks "build/modules/core/test/test_intrin256.avx2.cpp" "modules/core/test/test_intrin256.simd.hpp"
cLinks "build/modules/core/test/test_intrin256.avx2.cpp" "modules/core/test/test_precomp.hpp"
cLinks "build/modules/core/test/test_intrin256.avx512_skx.cpp" "modules/core/test/test_intrin256.simd.hpp"
cLinks "build/modules/core/test/test_intrin256.avx512_skx.cpp" "modules/core/test/test_precomp.hpp"
cLinks "build/modules/core/test/test_intrin256.simd_declarations.hpp" "modules/core/include/opencv2/core/private/
cLinks "build/modules/core/test/test_intrin512.avx512_skx.cpp" "modules/core/test/test_intrin512.simd.hpp"
cLinks "build/modules/core/test/test_intrin512.avx512_skx.cpp" "modules/core/test/test_precomp.hpp"
cLinks "build/modules/core/test/test_intrin512.simd_declarations.hpp" "modules/core/include/opencv2/core/private/
```

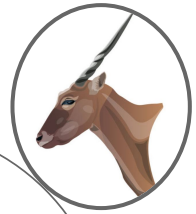
srcML Extraction Process

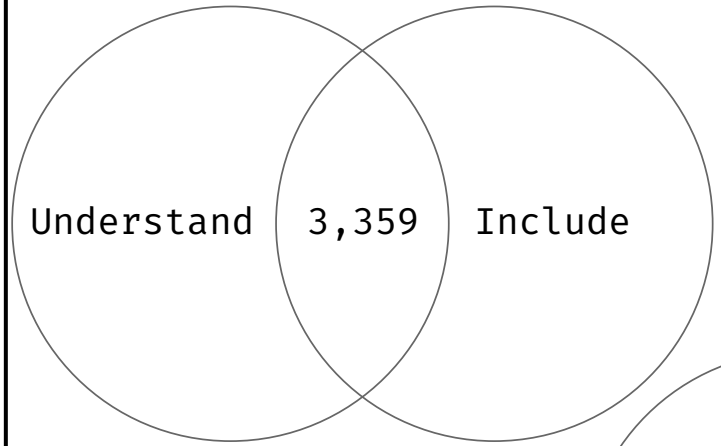


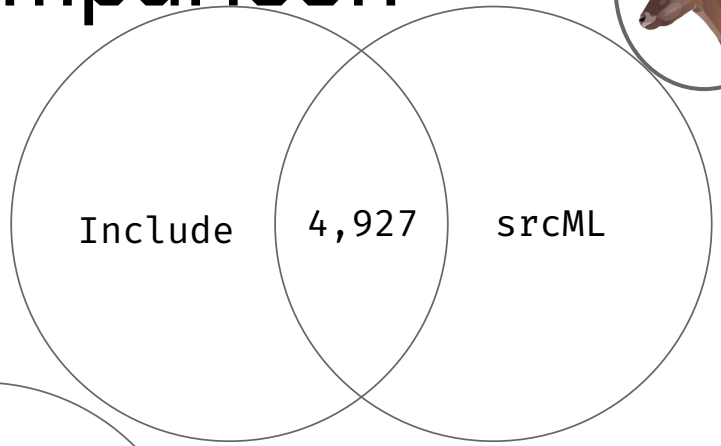
Quantitative Comparison

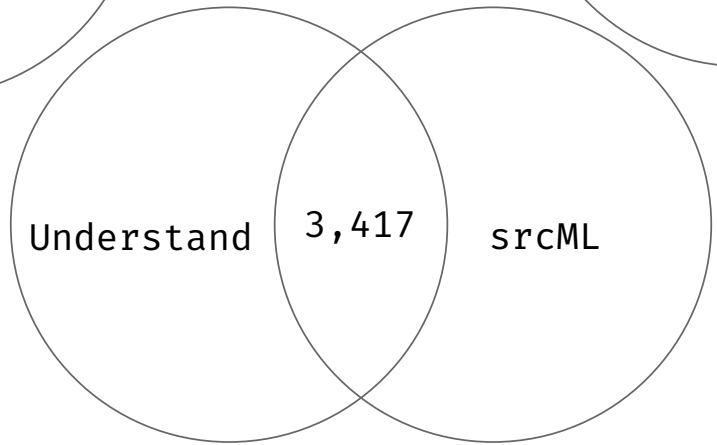
Dependency Technique	Total Dependencies
Understand	26,058
Include	31,041
srcML	9,280

Quantitative Comparison









Qualitative Analysis

Differences:

- Semantic-Level Extraction
- Structural-Level Extraction
- Syntactic-Level Extraction

Precision & Recall

$$\text{Precision} = \frac{\text{Edges found in tool(true)}}{\text{Edges found in tool(true) + Edges found in tool (false)}}$$

$$\text{Recall} = \frac{\text{Edges found in tool(true)}}{\text{Edges found in tool(true) + Edges NOT found in tool}}$$

Qualitative Analysis

Understand vs Include

Determine Sample Size

Confidence Level: (•) 95% ( ) 99%

Confidence Interval: 5

Population: 57099

Calculate Clear

Sample size needed: 382

Precision of Include = 27.78%

Recall of Include = 35%

Qualitative Analysis

Understand vs srcML

Determine Sample Size

Confidence Level: (•) 95% ( ) 99%

Confidence Interval: 5

Population: 35338

Calculate Clear

Sample size needed: 380

Precision of srcML = 66.67%

Recall of srcML = 11.11%

Qualitative Analysis

Include vs srcML

Determine Sample Size

Confidence Level: (•) 95% ( ) 99%

Confidence Interval: 5

Population: 40321

Calculate Clear

Sample size needed: 381

Precision of srcML = 42.17%

Recall of srcML = 10.51%

Limitations of Our Findings

Lessons Learned

1. Include extraction is fast
2. Understand excels in full-architecture extraction
3. A hybrid approach may be ideal

Conclusion

Questions?