Introduction to Procedural Debugging through Binary Libification

Pr. Jonathan Brossard

August 2024

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THE ADVANCED COMPUTING SYSTEMS ASSOCIATION

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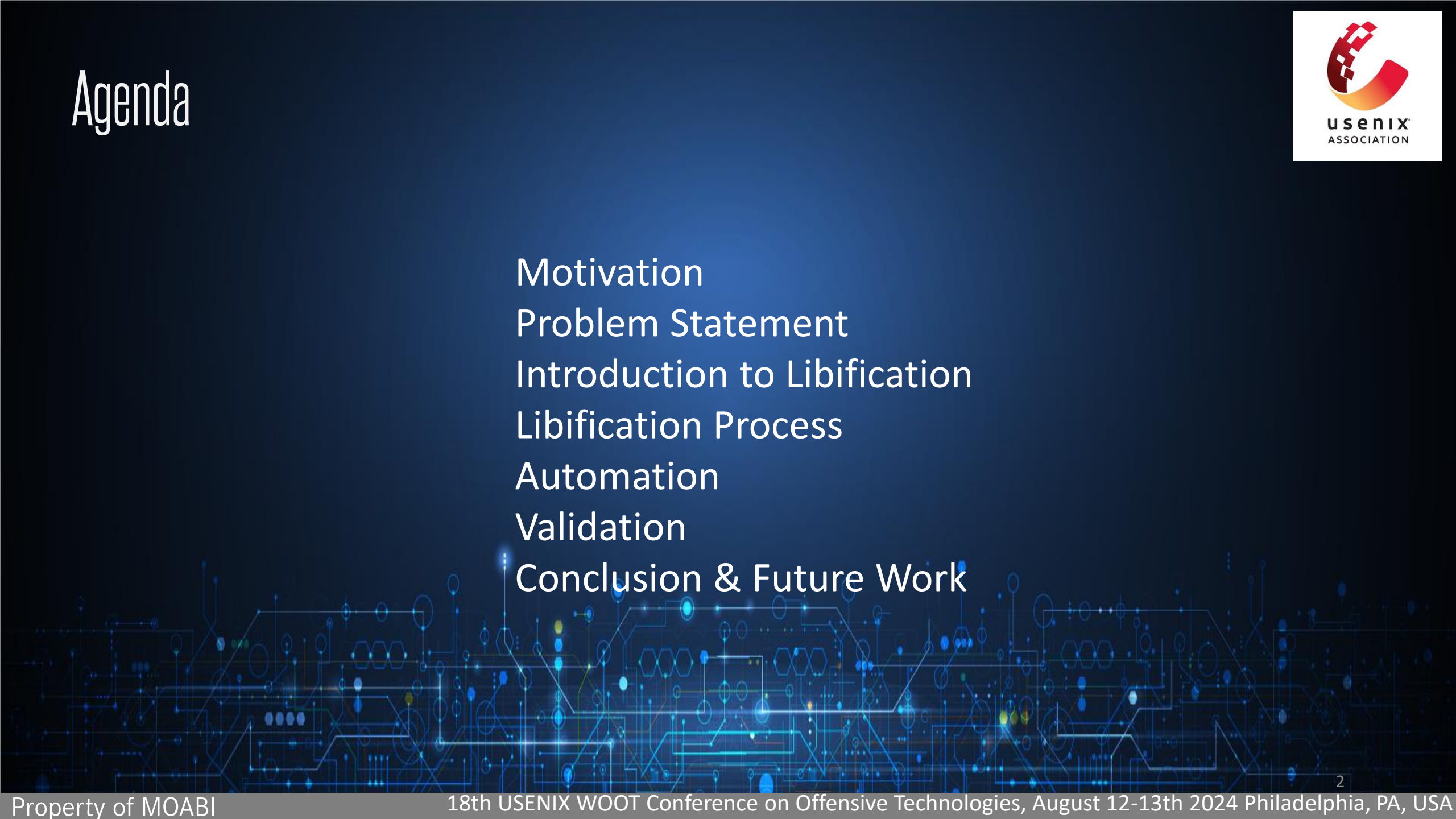
Agenda



- Motivation
- Problem Statement
- Introduction to Libification
- Libification Process
- Automation
- Validation
- Conclusion & Future Work

Motivation

Motivation : SBOMs vulnerability assessments don't scale well

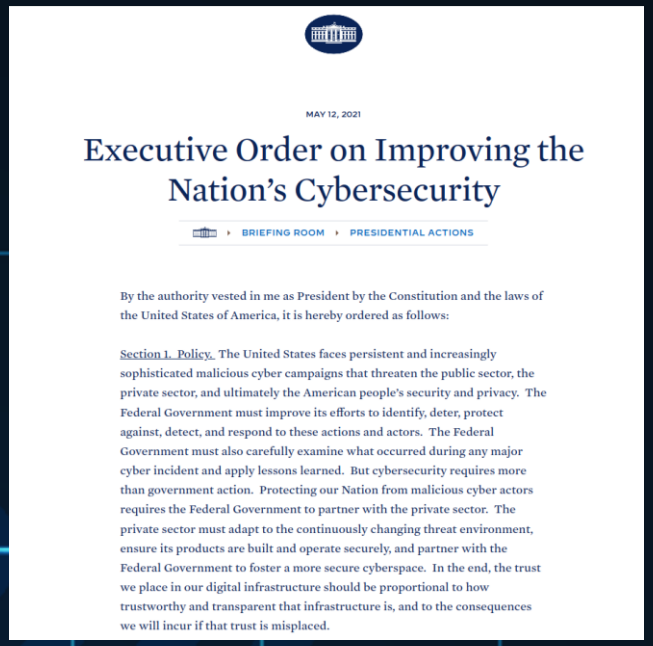
Software Bill of Materials (SBOMs) contain lists of CPEs or Package URLS (purl) describing all the components of a given Software.

They allow to perform vulnerability assessments by comparing the CPEs to the dictionaries published by the NIST for each CVE.


```
"components": [
  {
    "type": "application",
    "name": "sshd",
    "hashes": [{
      "alg": "MD5",
      "content": "0e6e1c30f8e10e45647ba5d9d4ea6948"
    },{
      "alg": "SHA-1",
      "content": "399e5d00e2d91628792eefe066489f64a6310486"
    },{
      "alg": "SHA-256",
      "content": "5bd9544d2da6daf7519ee8d6efcd71d6edc16a507f86a90e233174bbebb843c2"
    }]
  }
  ,
  {
    "type": "application",
    "description": "sshd",
    "group": "openbsd",
    "name": "openssh",
    "version": "9.6p1",
    "cpe": "cpe:2.3:a:openbsd:openssh:9.6p1:*:*:*:*:*:*:*",
    "externalReferences": [{
        "type": "website",
        "url": "https://www.openssh.com/"
    }],
    "licenses": [{
      "license": {
        "id": "BSD-2-clause"
      },
      "license": {
        "id": "BSD-3-clause"
      },
```


Software Bill of Materials are becoming mandatory

Motivation : SBOMs vulnerability assessments don't scale well



MAY 12, 2021

Executive Order on Improving the Nation's Cybersecurity

BRIEFING ROOM › PRESIDENTIAL ACTIONS

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. Policy. The United States faces persistent and increasingly sophisticated malicious cyber campaigns that threaten the public sector, the private sector, and ultimately the American people's security and privacy. The Federal Government must improve its efforts to identify, deter, protect against, detect, and respond to these actions and actors. The Federal Government must also carefully examine what occurred during any major cyber incident and apply lessons learned. But cybersecurity requires more than government action. Protecting our Nation from malicious cyber actors requires the Federal Government to partner with the private sector. The private sector must adapt to the continuously changing threat environment, ensure its products are built and operate securely, and partner with the Federal Government to foster a more secure cyberspace. In the end, the trust we place in our digital infrastructure should be proportional to how trustworthy and transparent that infrastructure is, and to the consequences we will incur if that trust is misplaced.

EU Cyber Resilience Act

New EU cybersecurity rules ensure safer hardware and software.

From baby-monitors to smart-watches, products and software that contain a digital component are omnipresent in our daily lives. Less apparent to many users is the security risk such products and software may present.

The Cyber Resilience Act (CRA) aims to safeguard consumers and businesses buying or using products or software with a digital component. The Act would see inadequate security features become a thing of the past with the introduction of mandatory cybersecurity requirements for manufacturers and retailers of such products, with this protection extending throughout the product lifecycle.

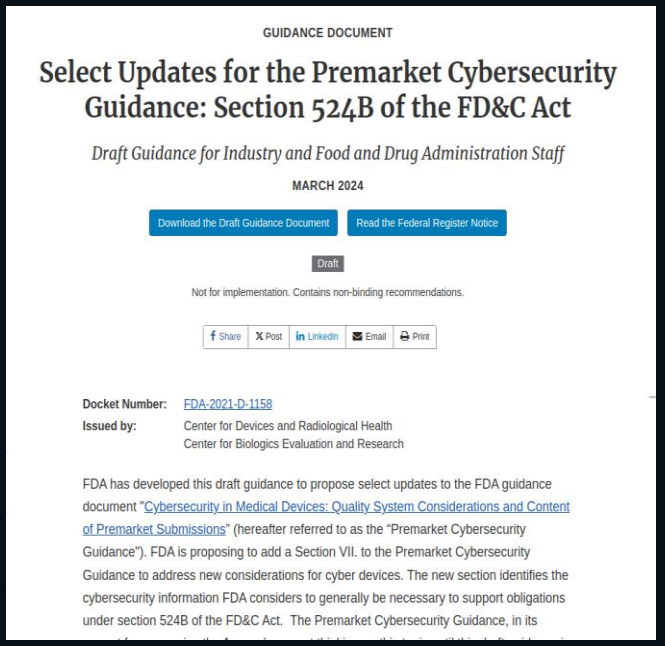
The problem addressed by the Regulation is two-fold.

First is the inadequate level of cybersecurity inherent in many products, or inadequate security updates to such products and software.

Second is the inability of consumers and businesses to currently determine which products are cybersecure, or to set them up in a way that ensures their cybersecurity is protected.

The Cyber Resilience Act will guarantee:

- harmonised rules when bringing to market products or software with a digital component;



GUIDANCE DOCUMENT

Select Updates for the Premarket Cybersecurity Guidance: Section 524B of the FD&C Act

Draft Guidance for Industry and Food and Drug Administration Staff

MARCH 2024

Download the Draft Guidance Document | Read the Federal Register Notice

Draft

Not for implementation. Contains non-binding recommendations.

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Docket Number: FDA-2021-D-1158
Issued by: Center for Devices and Radiological Health
Center for Biologics Evaluation and Research

FDA has developed this draft guidance to propose select updates to the FDA guidance document "Cybersecurity in Medical Devices: Quality System Considerations and Content of Premarket Submissions" (hereafter referred to as the "Premarket Cybersecurity Guidance"). FDA is proposing to add a Section VII. to the Premarket Cybersecurity Guidance to address new considerations for cyber devices. The new section identifies the cybersecurity information FDA considers to generally be necessary to support obligations under section 524B of the FD&C Act. The Premarket Cybersecurity Guidance, in its

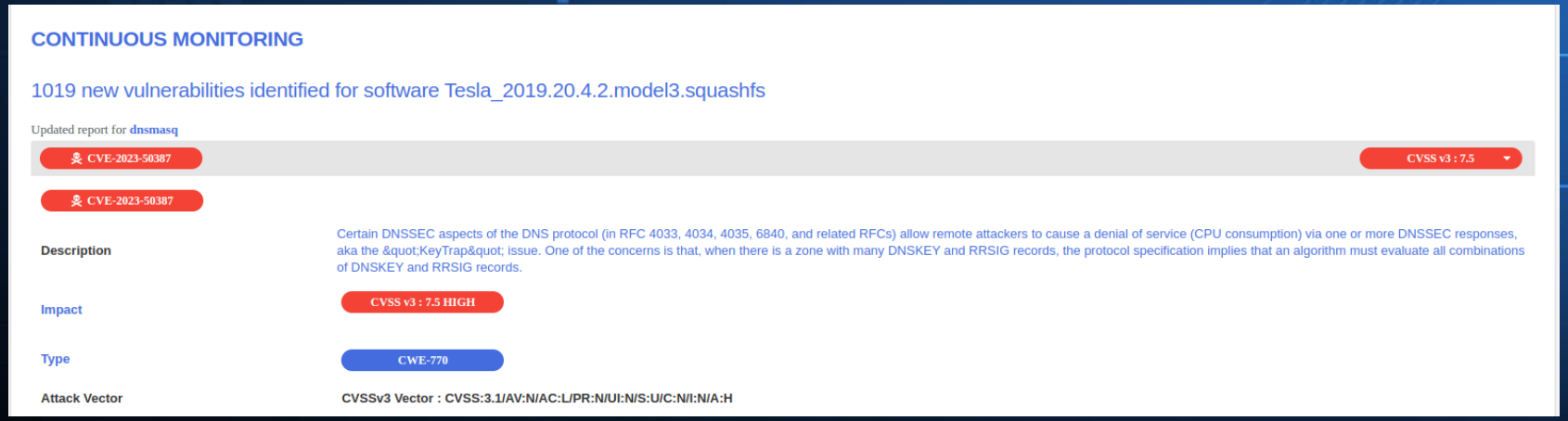
Software Bill of Materials are becoming mandatory

Motivation : SBOMs vulnerability assessments don't scale well

243 SOFTWARE MONITORED

SOFTWARE	SCAN DATE	NEW CVEs	Last Modified
Hyundai.update.zip	10 August 2022	1230	8 August 2024
psa_rcc.zip	10 August 2022	1151	8 August 2024
Firmware.bin	17 October 2022	952	8 August 2024
Tesla_2019.20.4.2.model3.squashfs	20 June 2023	467	8 August 2024

SBOMs provide possible CVES.
For each vulnerability : is it true ?



CONTINUOUS MONITORING

1019 new vulnerabilities identified for software Tesla_2019.20.4.2.model3.squashfs

Updated report for dnsmasq

CVE-2023-50387 CVSS v3 : 7.5

CVE-2023-50387

Description: Certain DNSSEC aspects of the DNS protocol (in RFC 4033, 4034, 4035, 6840, and related RFCs) allow remote attackers to cause a denial of service (CPU consumption) via one or more DNSSEC responses, aka the "KeyTrap" issue. One of the concerns is that, when there is a zone with many DNSKEY and RRSIG records, the protocol specification implies that an algorithm must evaluate all combinations of DNSKEY and RRSIG records.

Impact: CVSS v3 : 7.5 HIGH

Type: CWE-770

Attack Vector: CVSSv3 Vector : CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:U/C:N/I:N/A:H

Problem Statement :

Partial Proofs of Vulnerabilities through Procedural Debugging

Proving Exploitability

Industry standard to Prove exploitability : Write an exploit

This bar is too high.

If we decompose an exploit into 3 problems:

- Reach the vulnerable function
- Trigger the vulnerability
- Achieve code execution/Weaponize

The first step alone is already undecidable ("reachability problem").

Undecidable

Proving Exploitability : Partial Proof of Vulnerability

Let's do only step 2:

If we decompose an exploit into 3 problems:

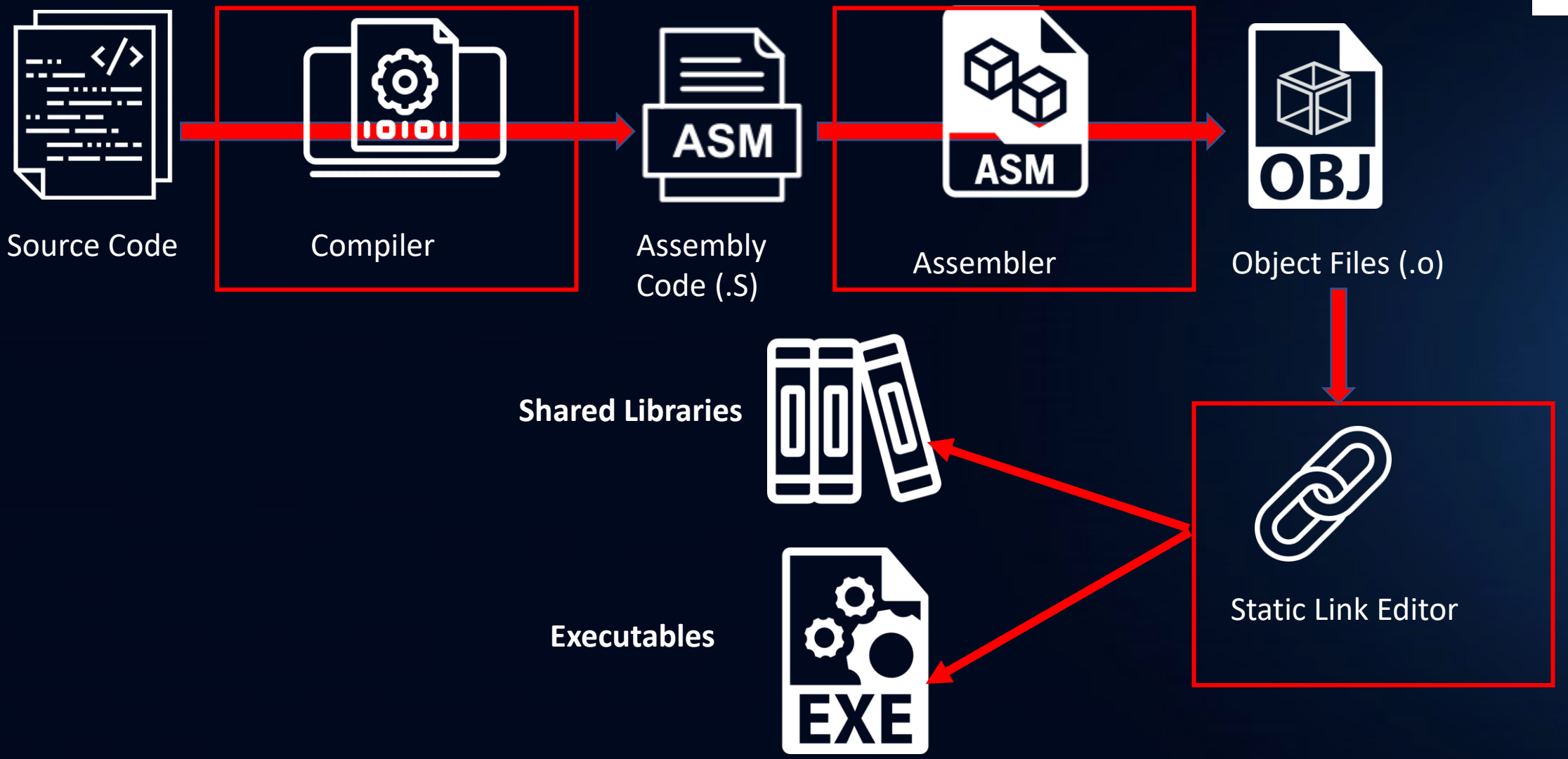
- ~~Reach the vulnerable function~~
- Trigger the vulnerability
- ~~Achieve code execution/Weaponize~~

This a reasonable heuristic to determine vulnerability of the application.

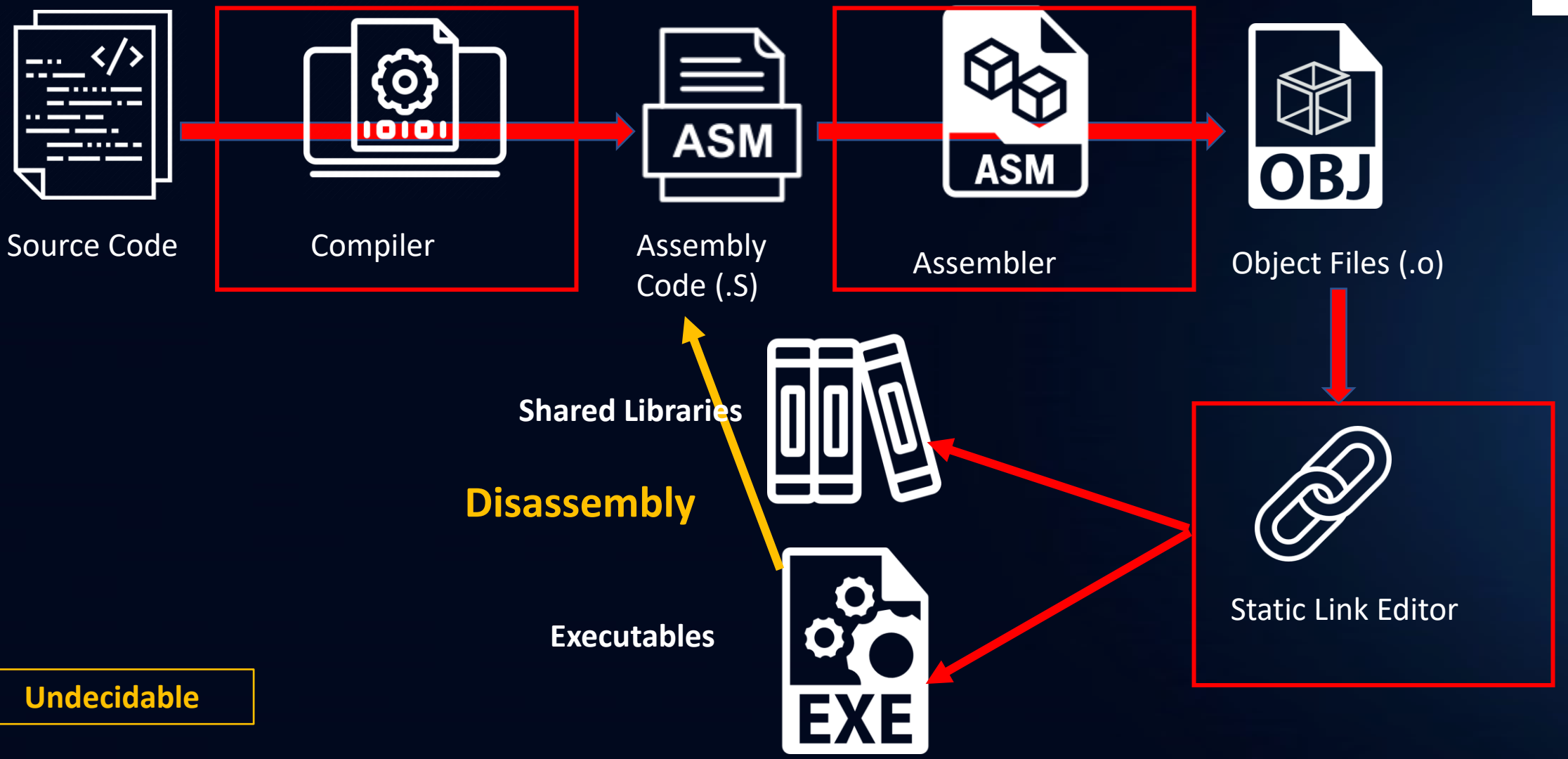
We'd like to be able to call the vulnerable function directly.
Problem : How to do this out of context ?
Proposal : Let's turn the vulnerable application into a shared library !

Introduction to Libification

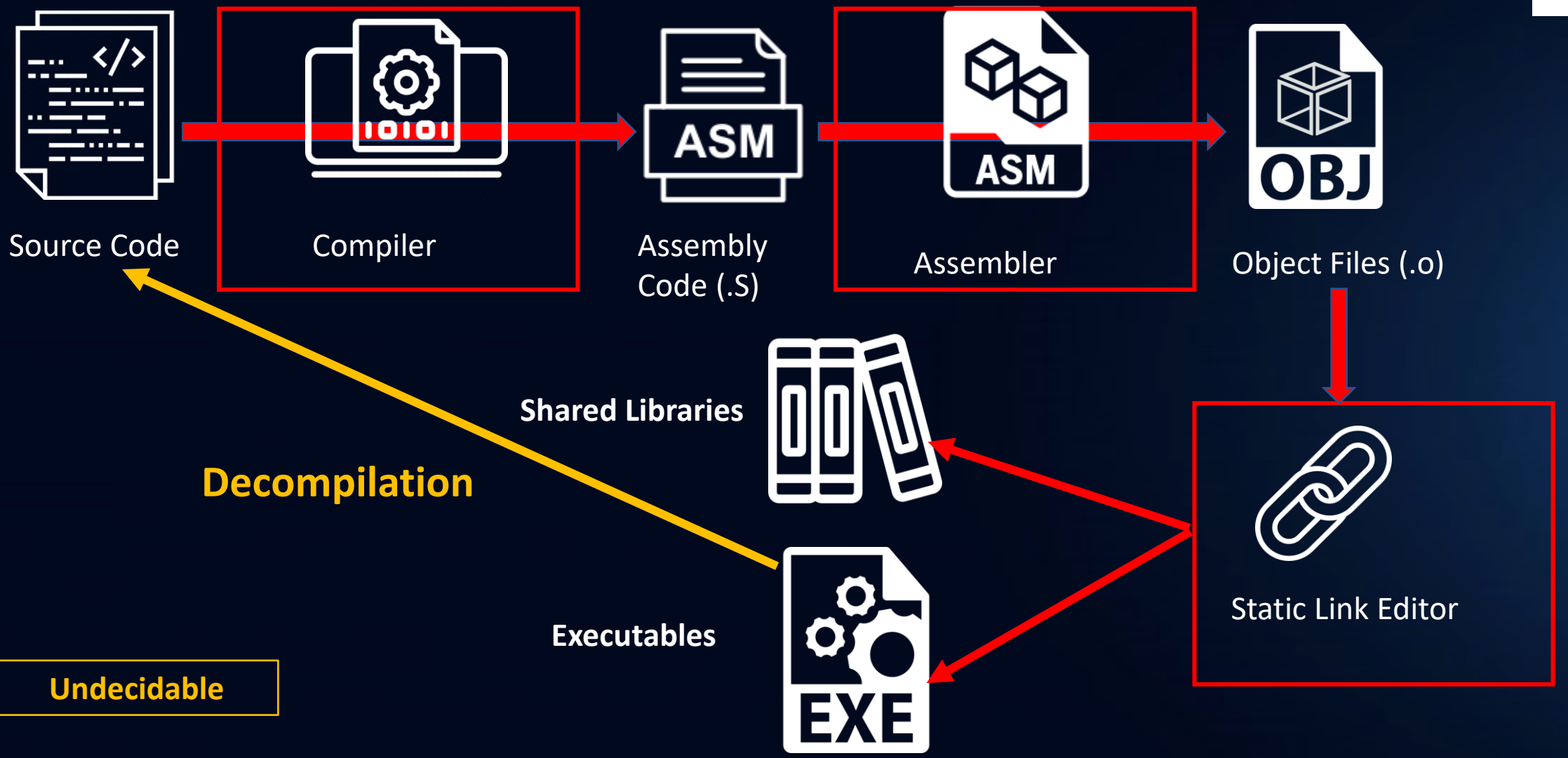
Reverse Engineering : Compilation Process



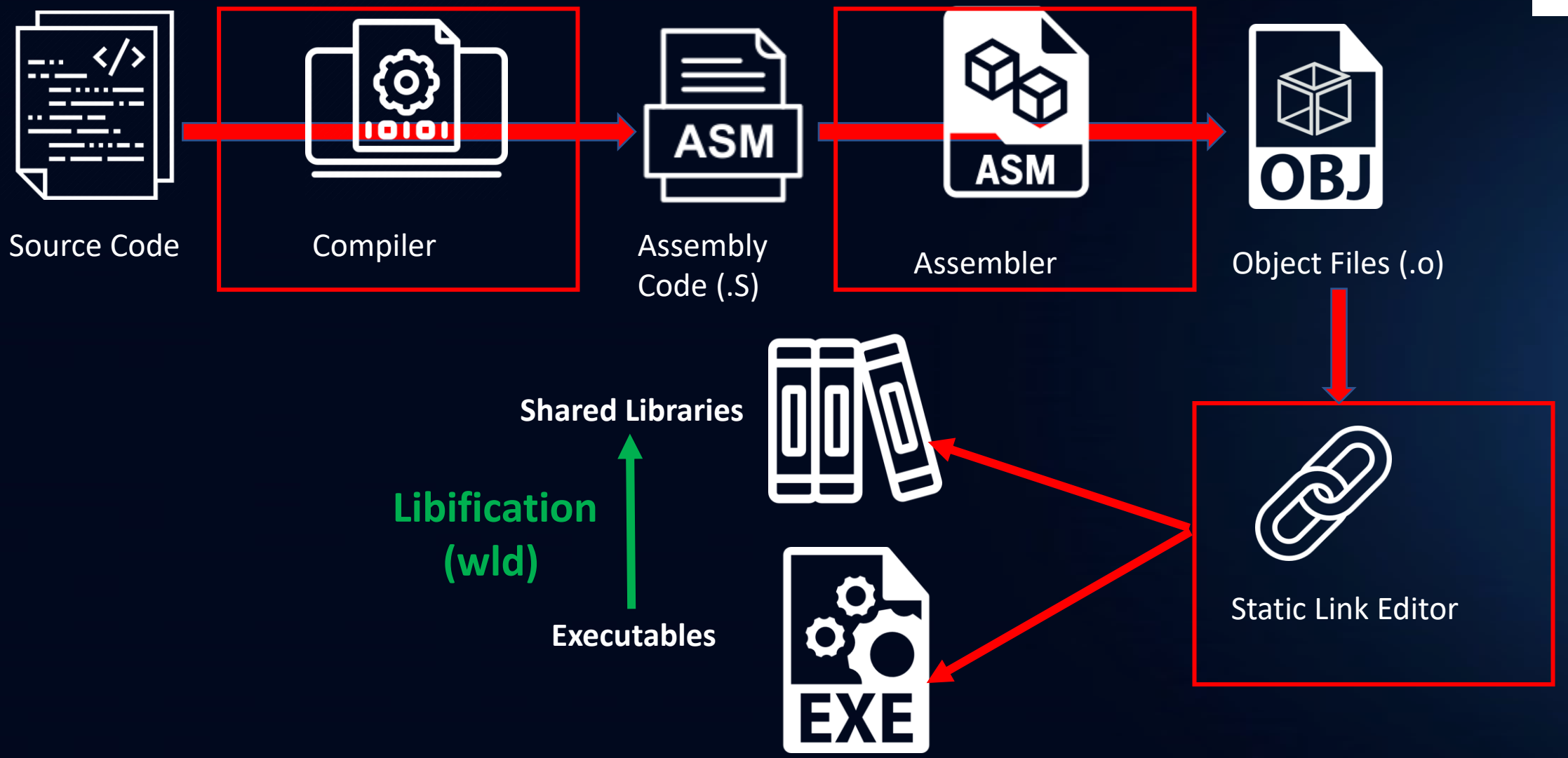
Reverse Engineering : Disassembly



Reverse Engineering : Decompilation

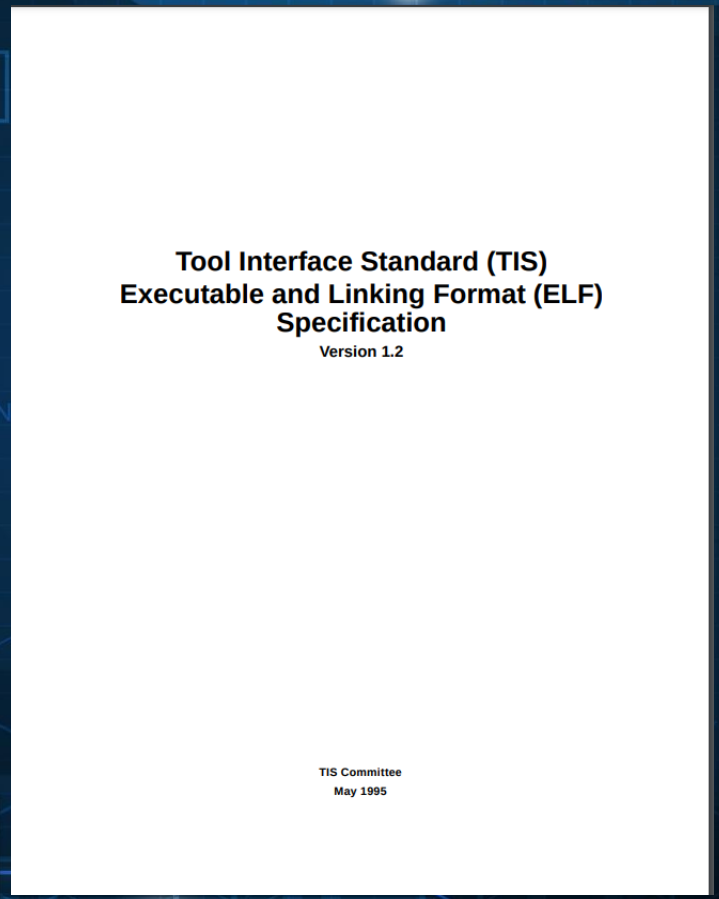


Reverse Engineering : Libification



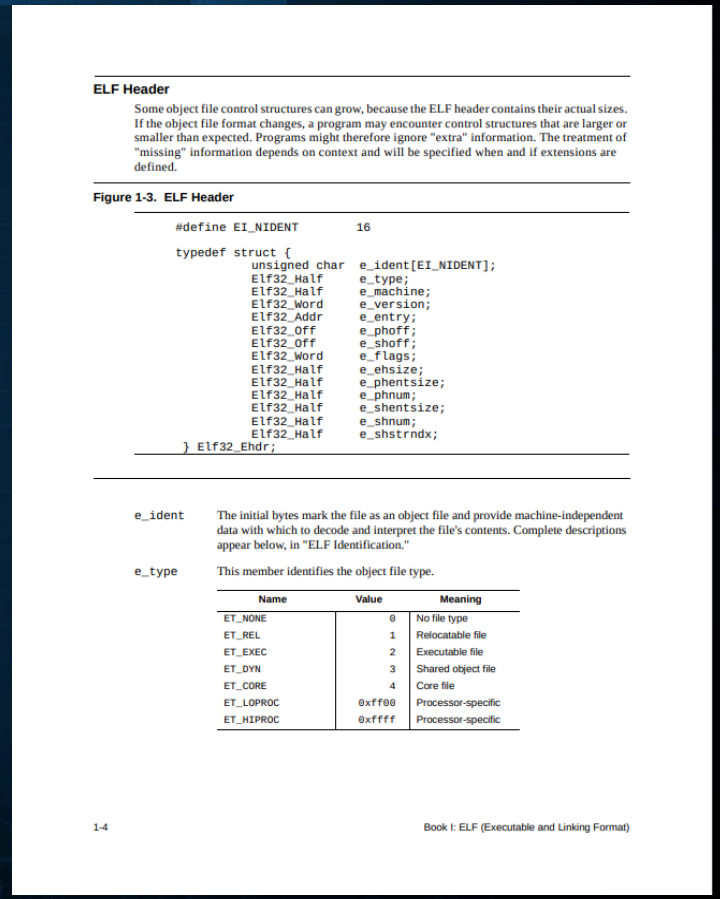
Executables vs Shared Libraries : How Do They Differ ?

Same headers, same segments, same sections. They mostly differ through their **metadata (various ELF headers)**



Tool Interface Standard (TIS)
Executable and Linking Format (ELF)
Specification
Version 1.2

TIS Committee
May 1995



ELF Header

Some object file control structures can grow, because the ELF header contains their actual sizes. If the object file format changes, a program may encounter control structures that are larger or smaller than expected. Programs might therefore ignore "extra" information. The treatment of "missing" information depends on context and will be specified when and if extensions are defined.

Figure 1-3. ELF Header

```
#define EI_NIDENT       16

typedef struct {
        unsigned char   e_ident[EI_NIDENT];
        Elf32_Half      e_type;
        Elf32_Half      e_machine;
        Elf32_Word      e_version;
        Elf32_Addr      e_entry;
        Elf32_Off       e_phoff;
        Elf32_Off       e_shoff;
        Elf32_Word      e_flags;
        Elf32_Half      e_ehsize;
        Elf32_Half      e_phentsize;
        Elf32_Half      e_phnum;
        Elf32_Half      e_shentsize;
        Elf32_Half      e_shnum;
        Elf32_Half      e_shstrndx;
} Elf32_Ehdr;
```

`e_ident` The initial bytes mark the file as an object file and provide machine-independent data with which to decode and interpret the file's contents. Complete descriptions appear below, in "ELF Identification."

`e_type` This member identifies the object file type.

Name	Value	Meaning
ET_NONE	0	No file type
ET_REL	1	Relocatable file
ET_EXEC	2	Executable file
ET_DYN	3	Shared object file
ET_CORE	4	Core file
ET_LOPROC	0xff00	Processor-specific
ET_HIPROC	0xffff	Processor-specific

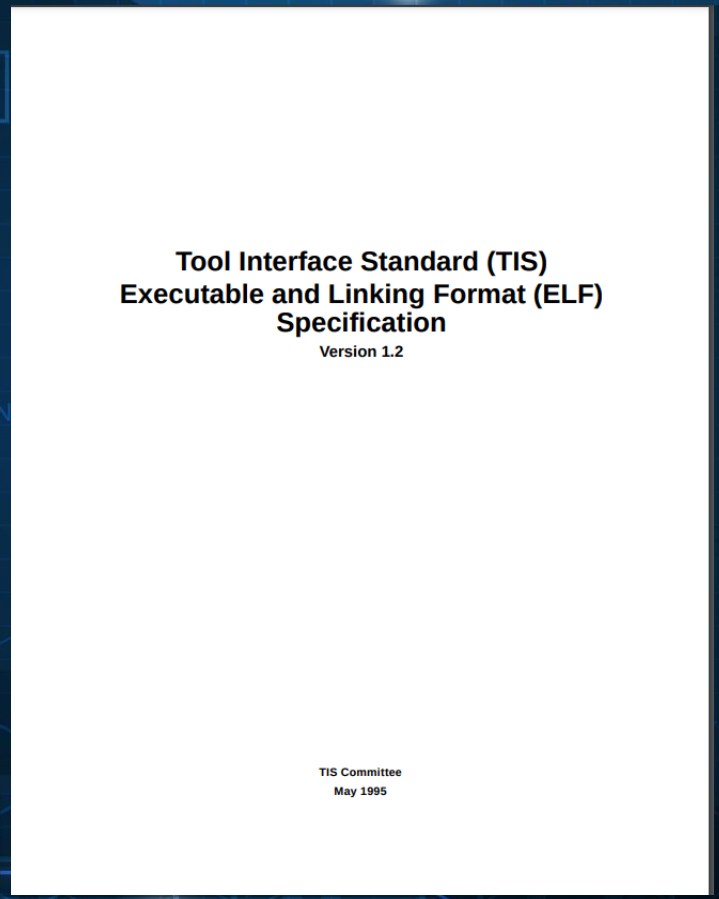
1-4 Book I: ELF (Executable and Linking Format)

Executables vs Shared Libraries : How Do They Differ ?

Same headers, same segments, same sections. They mostly differ through their **metadata (various ELF headers)**

The work to be done:

Modify the various ELF headers to turn an Executable into a Shared Library



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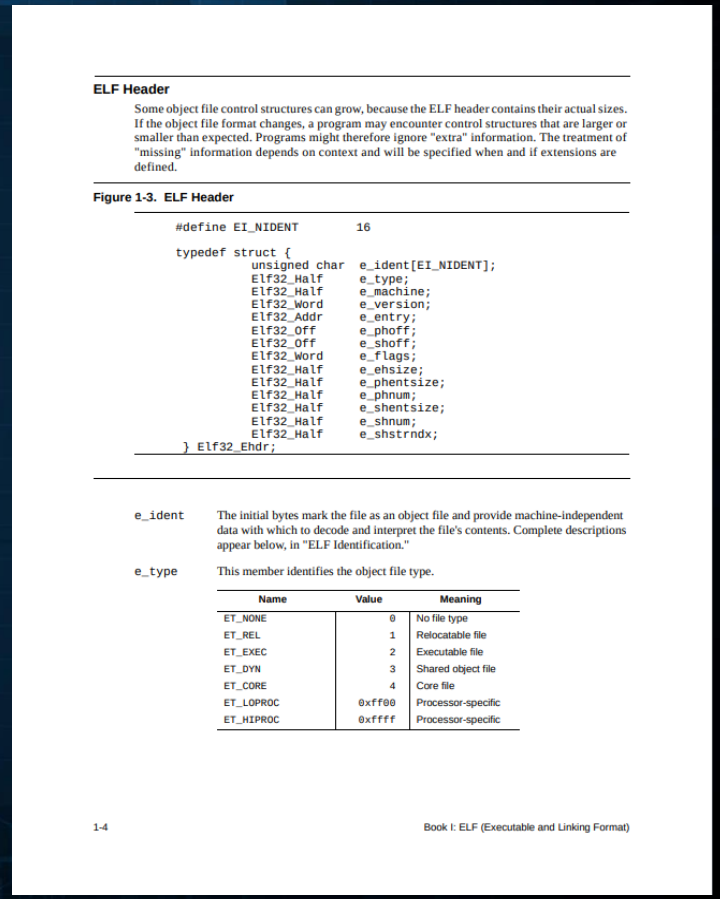

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typedef struct {
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        Elf32_Half      e_type;
        Elf32_Half      e_machine;
        Elf32_Word      e_version;
        Elf32_Addr      e_entry;
        Elf32_Off       e_phoff;
        Elf32_Off       e_shoff;
        Elf32_Word      e_flags;
        Elf32_Half      e_ehsize;
        Elf32_Half      e_phentsize;
        Elf32_Half      e_phnum;
        Elf32_Half      e_shentsize;
        Elf32_Half      e_shnum;
        Elf32_Half      e_shstrndx;
} Elf32_Ehdr;
```

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1-4 Book I: ELF (Executable and Linking Format)

Libification Process

Libification : From Executable to Shared Library

Libification Oracle

Let's modify a test binary (ls) until we manage to load it in memory...

```c
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <dlfcn.h>
#include <errno.h>
#include <string.h>

int main(void){
        void *handle;

        handle = dlopen("./ls", RTLD_LAZY);
        if(handle <= 0){
                printf(" !! ERROR : %s\n", dlerror());
                exit(EXIT_FAILURE);
        }

        printf("Loading of Library successful\n");
        return 0;
}
```

Libification : From Executable to Shared Library

```
typedef struct elf64_hdr {
  unsigned char e_ident[EI_NIDENT]; /* ELF "magic number" */
  Elf64_Half e_type; = ET_DYN
  Elf64_Half e_machine;
  Elf64_Word e_version;
  Elf64_Addr e_entry; /* Entry point virtual address */
  Elf64_Off e_phoff; /* Program header table file offset */
  Elf64_Off e_shoff; /* Section header table file offset */
  Elf64_Word e_flags;
  Elf64_Half e_ehsize;
  Elf64_Half e_phentsize;
  Elf64_Half e_phnum;
  Elf64_Half e_shentsize;
  Elf64_Half e_shnum;
  Elf64_Half e_shstrndx;
} Elf64_Ehdr;
```

Modify the ELF type from ET_EXEC to ET_DYN in the ELF header.

Libification : From Executable to Shared Library

```
typedef struct elf64_shdr {
  Elf64_Word sh_name;       /* Section name, index in string tbl */
  Elf64_Word sh_type;        SHT_DYNAMIC
  Elf64_Xword sh_flags;     /* Miscellaneous section attributes */
  Elf64_Addr sh_addr;      /* Section virtual addr at execution */
  Elf64_Off sh_offset;     /* Section file offset */
  Elf64_Xword sh_size;      /* Size of section in bytes */
  Elf64_Word sh_link;      /* Index of another section */
  Elf64_Word sh_info;      /* Additional section information */
  Elf64_Xword sh_addralign;   /* Section alignment */
  Elf64_Xword sh_entsize;   /* Entry size if section holds table */
}
```

Parse the array of section headers, identify the section with .dynamic section with type SHT_DYNAMIC

If section headers are missing, parsing the array of segments and identifying the PT_DYNAMIC segment leads to the same .dynamic content.

Libification : From Executable to Shared Library

```
typedef struct {
  Elf64_Sxword d_tag;
  union {
    Elf64_Xword d_val;
    Elf64_Addr d_ptr;
  } d_un;
} Elf64_Dyn;
```

The .dynamic section contains an array of Elf64_Dyn entries.

Replace any optional DT_BIND_NOW entry with a d_tag = DT_NULL entry and a pointer of value d_ptr = –1.

If the binary features a DT_FLAGS_1 entry, remove the flags Remove DF_1_NOOPEN and DF_1_PIE flags if present:

```
dyn->d_un.d_val = dyn->d_un.d_val & ~DF_1_NOOPEN;
dyn->d_un.d_val = dyn->d_un.d_val & ~DF_1_PIE;
```

Optionally ignore constructors and destructors by zeroing the d_val values associated with DT_INIT_ARRAYSZ, DT_INIT_ARRAY and DT_FINI_ARRAYSZ, DT_FINI_ARRAY respectively.

Automation

Automated Libification : the Witchcraft Linker

URL: https://github.com/endrazine/wcc
License: MIT/BSD-2

```
jonathan@blackbox: ~/woot
Fichier  Édition  Affichage  Rechercher  Terminal  Aide
jonathan@blackbox:~/woot$ file ls
ls: ELF 64-bit LSB pie executable, x86-64, version 1 (SYSV), dynamicall
y linked, interpreter /lib64/ld-linux-x86-64.so.2, BuildID[sha1]=3eca7e
3905b37d48cf0a88b576faa7b95cc3097b, for GNU/Linux 3.2.0, stripped
jonathan@blackbox:~/woot$ wld -libify ./ls
jonathan@blackbox:~/woot$ file ls
ls: ELF 64-bit LSB shared object, x86-64, version 1 (SYSV), dynamically
 linked, interpreter /lib64/ld-linux-x86-64.so.2, BuildID[sha1]=3eca7e3
905b37d48cf0a88b576faa7b95cc3097b, for GNU/Linux 3.2.0, stripped
jonathan@blackbox:~/woot$
```

https://zenodo.org/doi/10.5281/zenodo.11298208

Validation

Validation

Test Repository:
https://github.com/endrazine/wcc-tests

Test Plan:
Libify The 435 binaries of a default Ubuntu 24.04 amd64 LTS distribution

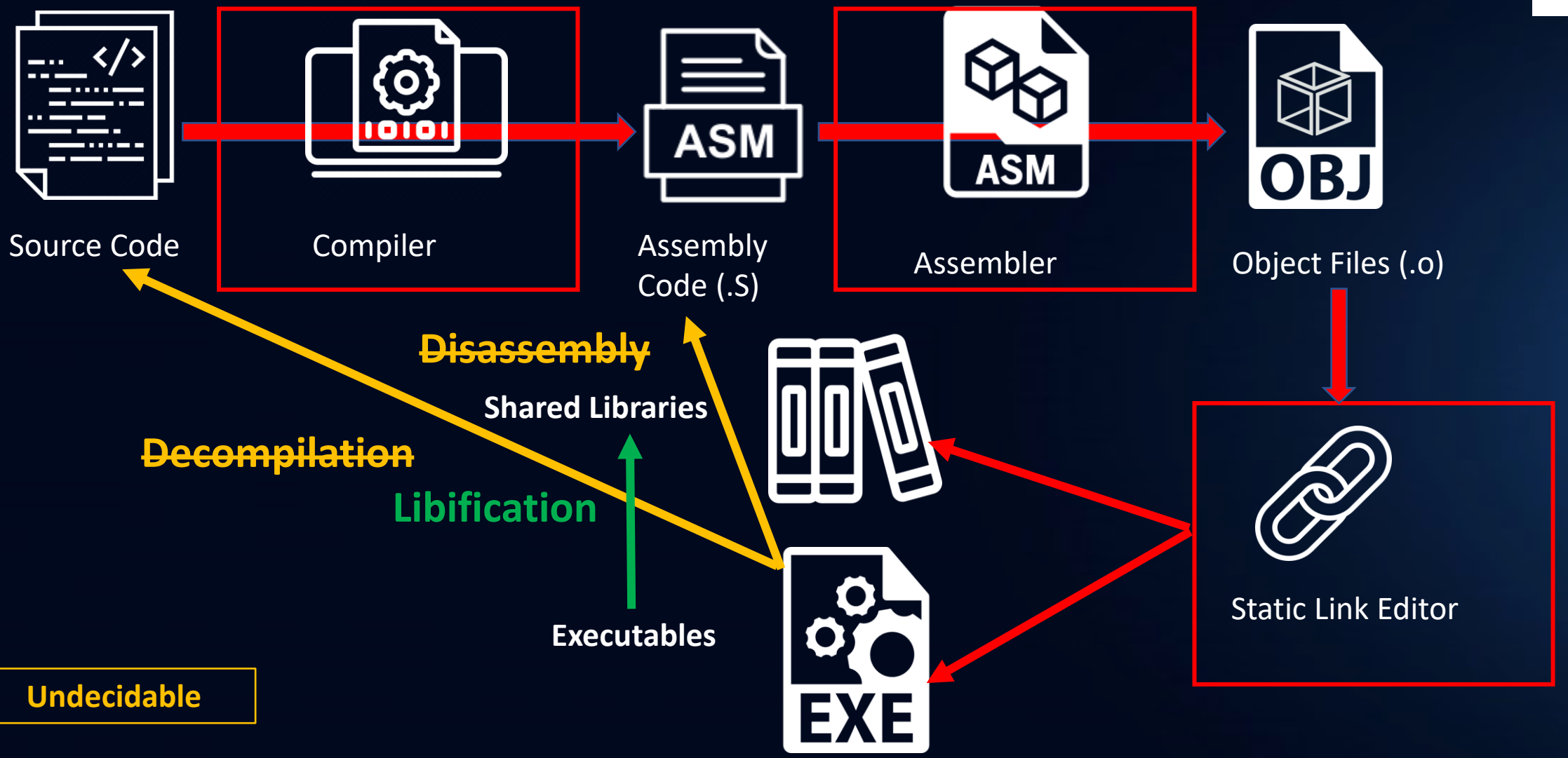
Libification Test	Count
Passed	435
Failed	0

Time taken (total) : 3 seconds

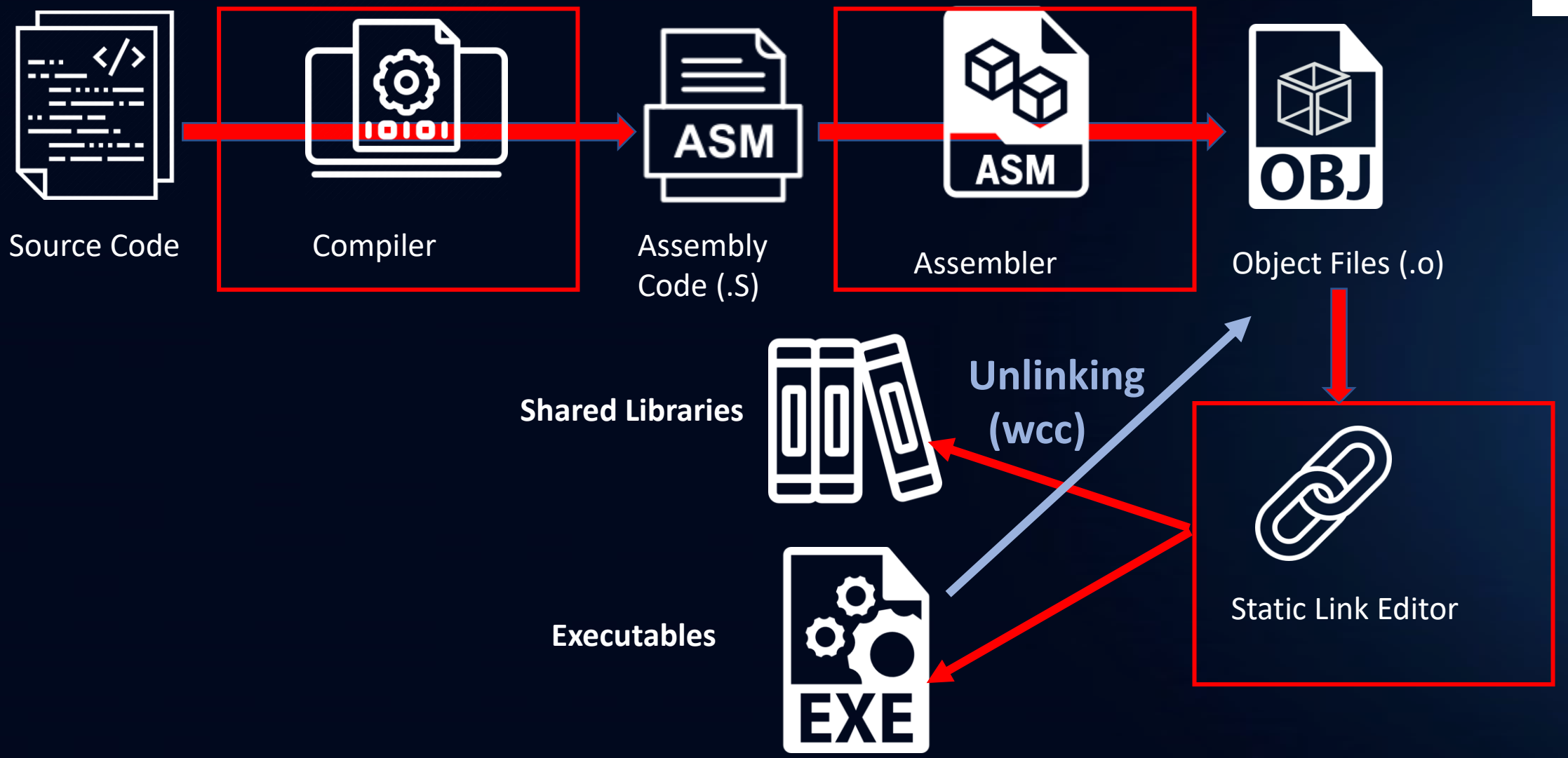
https://zenodo.org/doi/10.5281/zenodo.11301408

Conclusion & Future Work

Witchcraft Linker : Libification

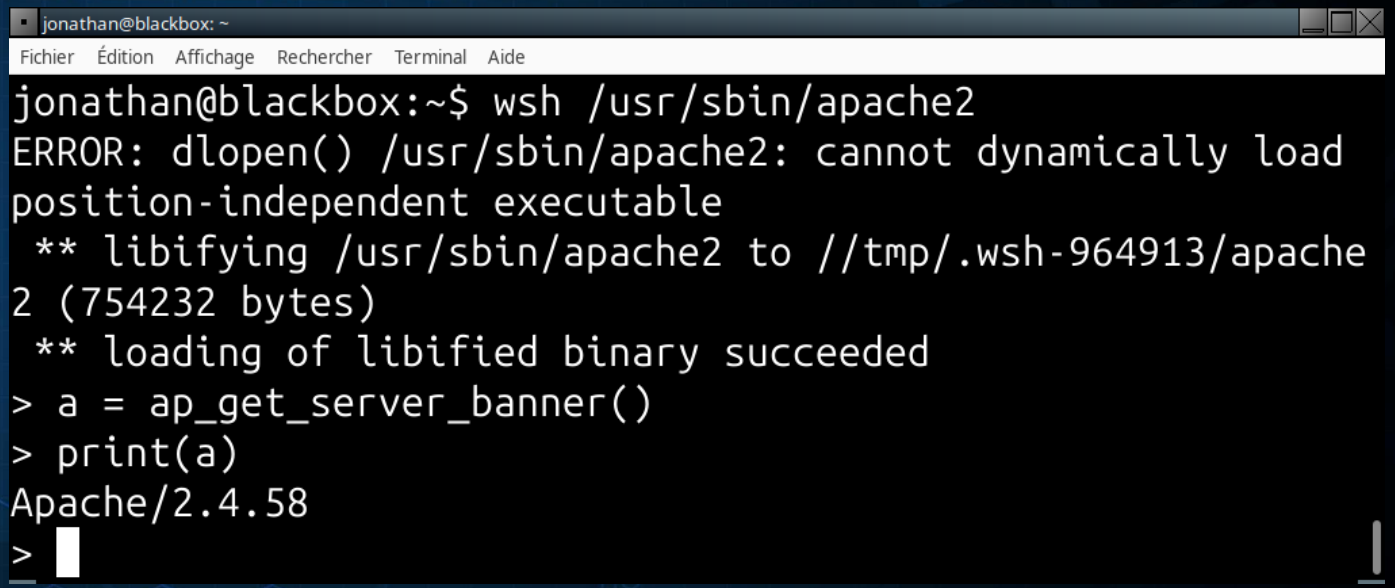


Witchcraft Compiler: Unlinking



Witchcraft Shell : Procedural Debugging

- Libify ELF executables
- Make ELF executables scriptable
- Call arbitrary functions (procedural debugging)



URL: https://github.com/endrazine/wcc
License: MIT/BSD-2

Future Work : Partial Proofs of Vulnerabilities

The ability to turn ELF executables into libraries will allow us to create partial proofs of vulnerabilities in the form of WSH test scripts.

```
root@b80e8606fba6: ~/wcc-tests
Fichier  Édition  Affichage  Rechercher  Terminal  Aide
root@b80e8606fba6:~/wcc-tests# cat ./scripts/CVE-2022-3786.wsh
print(" [*] testing for CVE-2022-3786")

-- Input arguments:
teststring = "a.b.c.d.e.f.g.h.i.j.k.l.m.n.o.p.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--
.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--.xn--"
out = calloc(1,16)
outlen = calloc(1,2)
memset(outlen,0x10,1)

-- Trigger the stack overflow:
res = ossl_a2ulabel(teststring, out, outlen)

if res == 0 then print(" [*] Not vulnerable to CVE-2022-3786") end
root@b80e8606fba6:~/wcc-tests# wsh ../openssl/build-3.0.8/libcrypto.a < ./scripts/CVE-2022-3786.wsh
 -- relinked static library (ar archive) ../openssl/build-3.0.8/libcrypto.a into dynamic shared library /tmp/.wsh-51/libcrypto.a.so
 [*] testing for CVE-2022-3786
 [*] Not vulnerable to CVE-2022-3786
root@b80e8606fba6:~/wcc-tests# wsh ../openssl/build-3.0.7/libcrypto.a < ./scripts/CVE-2022-3786.wsh
 -- relinked static library (ar archive) ../openssl/build-3.0.7/libcrypto.a into dynamic shared library /tmp/.wsh-56/libcrypto.a.so
 [*] testing for CVE-2022-3786
 [*] Not vulnerable to CVE-2022-3786
root@b80e8606fba6:~/wcc-tests# wsh ../openssl/build-3.0.6/libcrypto.a < ./scripts/CVE-2022-3786.wsh
 -- relinked static library (ar archive) ../openssl/build-3.0.6/libcrypto.a into dynamic shared library /tmp/.wsh-61/libcrypto.a.so
 [*] testing for CVE-2022-3786
free(): invalid next size (fast)

[SIGABRT]       Read    0x3d        (Error code -6)
        0x7a20993c89fc    /lib/x86_64-linux-gnu/libc.so.6(pthread_kill+0x12c)
        0x7a2099374476    /lib/x86_64-linux-gnu/libc.so.6(raise+0x16)
        0x7a209935a7f3    /lib/x86_64-linux-gnu/libc.so.6(abort+0xd3)
        0x7a20993bb676    /lib/x86_64-linux-gnu/libc.so.6(+0x89676)
        0x7a20993d2cfc    /lib/x86_64-linux-gnu/libc.so.6(+0xa0cfc)
        0x7a20993d4a9d    /lib/x86_64-linux-gnu/libc.so.6(+0xa2a9d)
*** longjmp causes uninitialized stack frame ***: terminated
```

THANK YOU FOR YOUR ATTENTION

Jonathan Brossard
jonathan.brossard@lecnam.net