Three Heads Are Better Than One: Mastering NSA's Ghidra Reverse Engineering Tool

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github.com/0xAlexei/INFILTRATE2019

Disclaimer

This material is based on the publicly released Ghidra, there is no classified information in this presentation

Alexei Bulazel @0xAlexei

- Senior Security Researcher at River Loop Security

- Research presentations and publications:
  - Presentations at REcon (MTL & BRX), SummerCon, DEFCON, Black Hat, etc.
  - Academic publications at USENIX WOOT and ROOTS
  - Cyber policy in Lawfare, etc.

- Collaborated with Jeremy on research at RPI, MIT Lincoln Laboratory, and Boston Cybernetics Institute

- Proud RPISEC alumnus

RPISEC

Jeremy Blackthorne @0xJeremy

- Instructor at the Boston Cybernetics Institute
- PhD candidate at RPI focused on environmental keying
- Former researcher at MIT Lincoln Laboratory
- United States Marine Corps 2002 - 2006
- RPISEC alumnus

RPISEC

Outline

1. Intro
2. Interactive Exercises
   a. Manual Static Analysis
   b. Scripting Ghidra
3. P-Code & SLEIGH
4. Discussion
5. Conclusion

Participating

1. Install OpenJDK 11, add its `bin` directory to your `PATH`
   - `jdk.java.net/11`

2. Download Ghidra
   - `ghidra-sre.org`
   - `github.com/NationalSecurityAgency/ghidra/releases`

3. Download our demo scripts and binaries
   - `github.com/0xAlexei/INFILTRATE2019`

Ghidra

- Java-based interactive reverse engineering tool developed by US National Security Agency - similar in functionality to IDA Pro, Binary Ninja, etc…
  - Static analysis only currently, debugger support promised to be coming soon
  - Runs on Mac, Linux, and Windows

- All credit for creating Ghidra goes to the developers at NSA
- Released open source at RSA in March 2019
  - 1.2M+ lines of code
- NSA has not discussed the history of the tool, but comments in source files go as far back as February 1999

```
$ grep -r "1999" * --include *.java
src/Generic-src/ghidra/util/exception/NotYetImplementedException.java: * @version 1999/02/05
src/SoftwareModeling-src/ghidra/program/model/address/AddressOutOfBoundsException.java: * @version 1999-03-31
src/SoftwareModeling-src/ghidra/program/model/scalar/ScalarOverflowException.java: * @version 1999-03-31
src/SoftwareModeling-src/ghidra/program/model/scalar/ScalarFormat.java: * @version 1999/02/04
```

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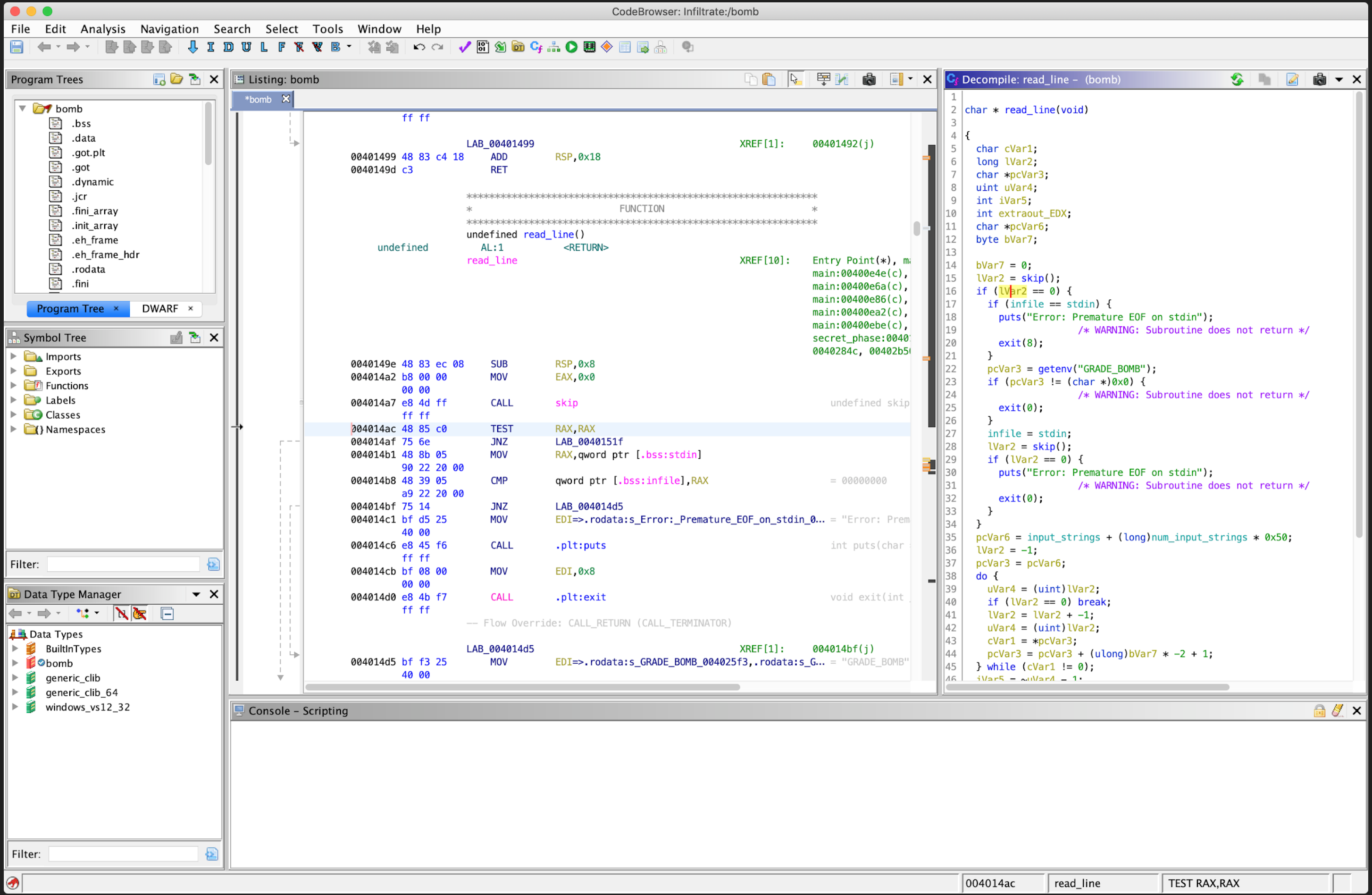
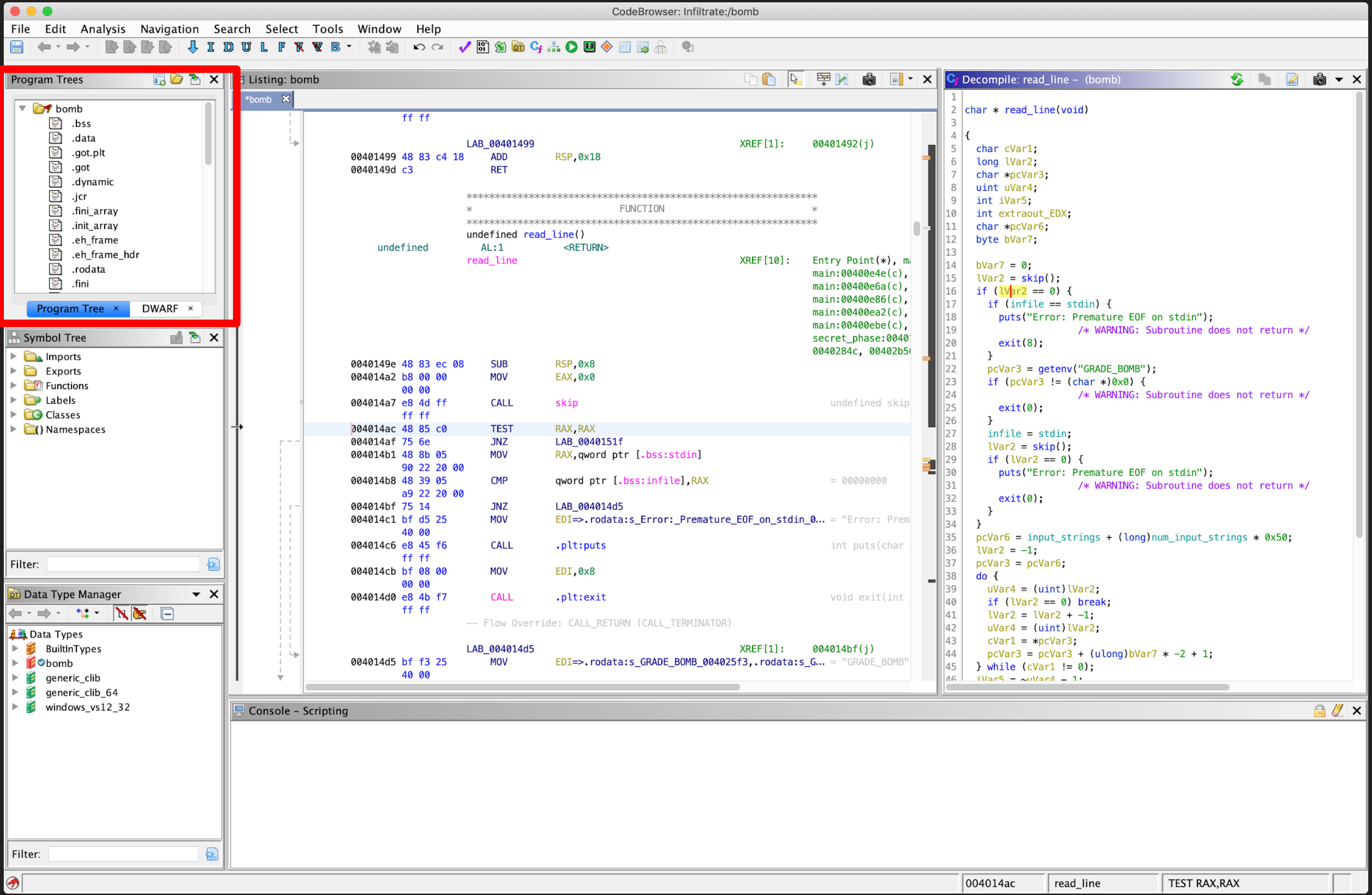
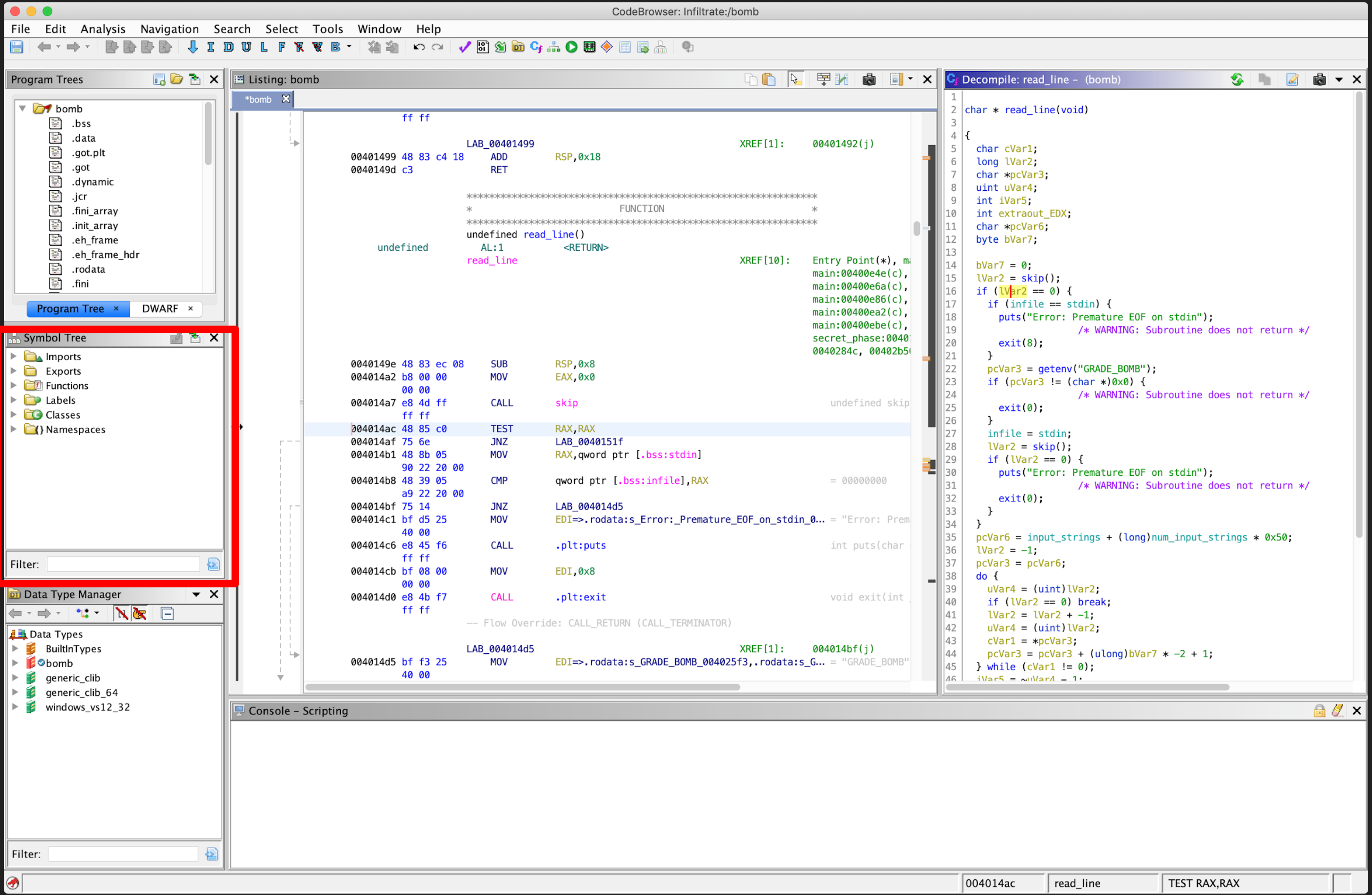
Default UI - CodeBrowser



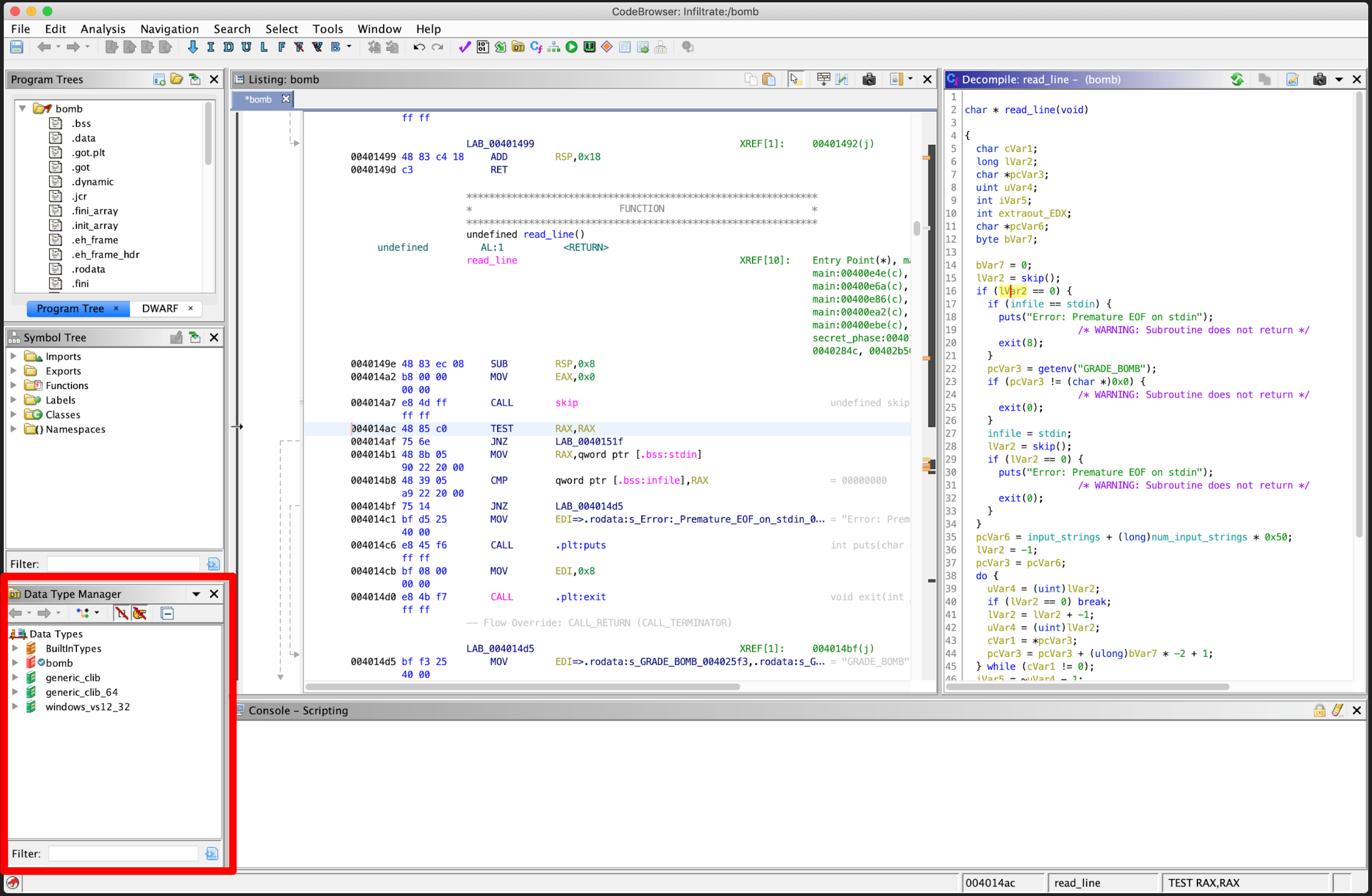
Default UI - Program Trees



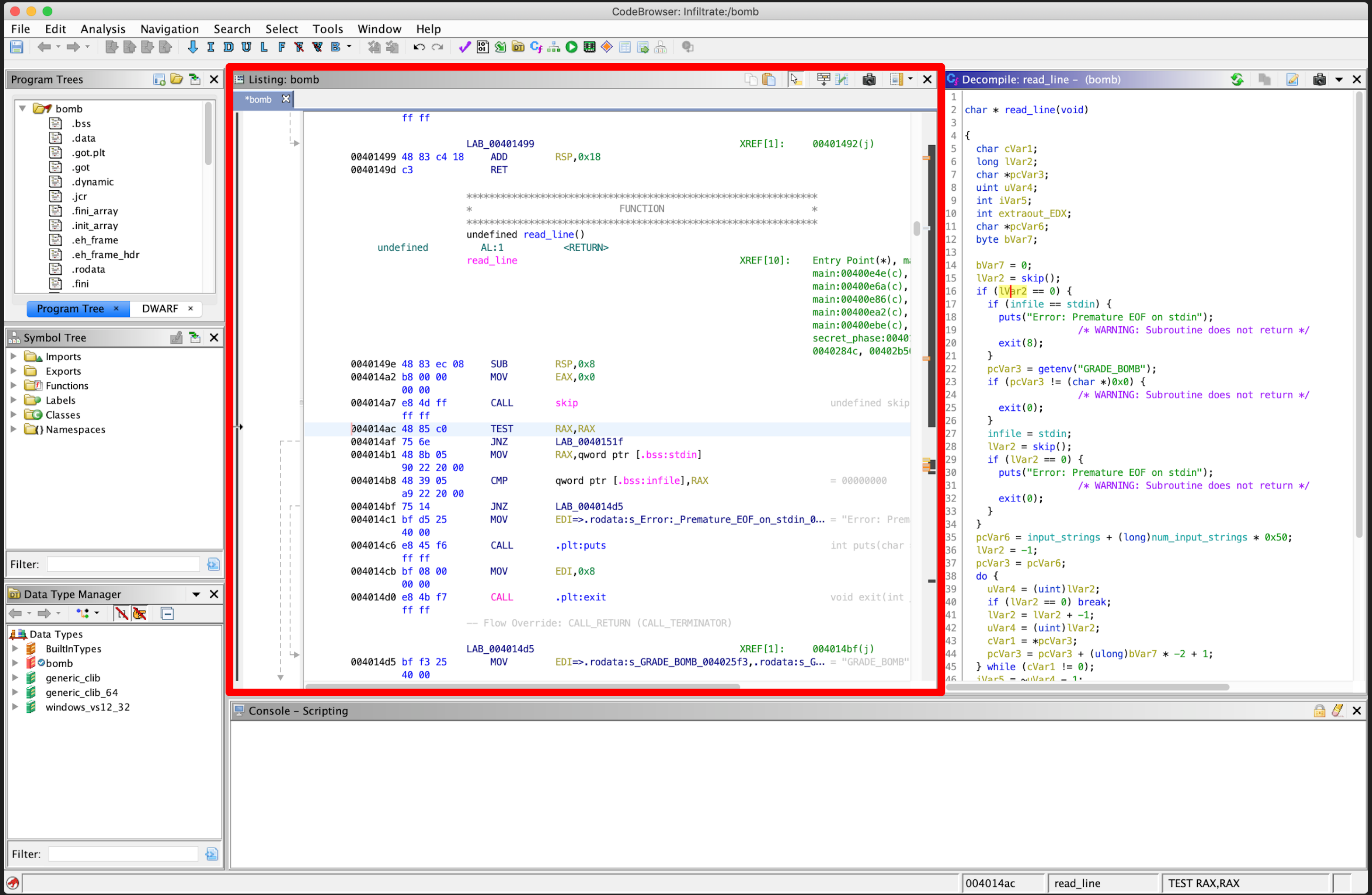
Default UI - Symbol Tree



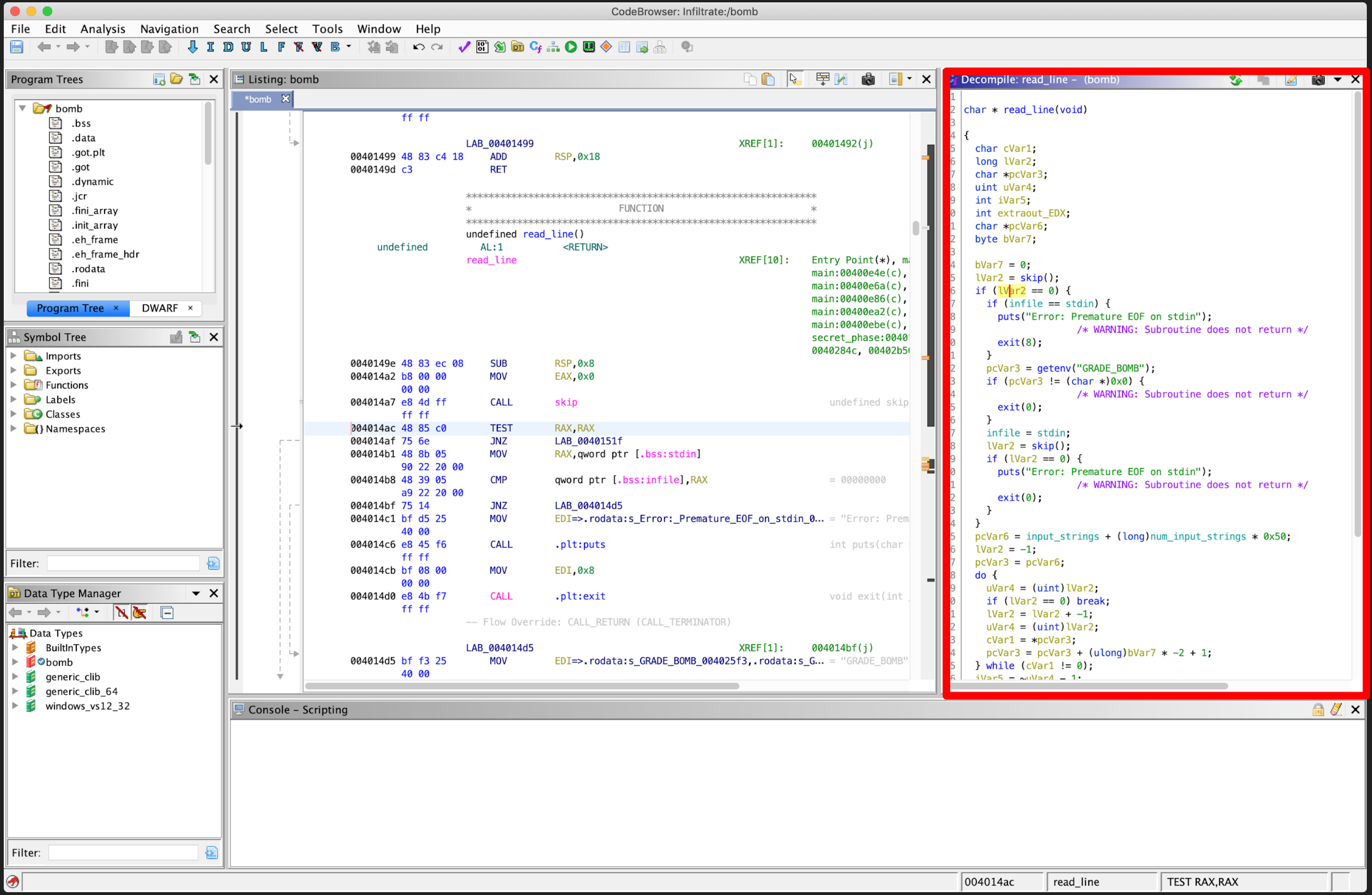
Default UI - Data Type Manager



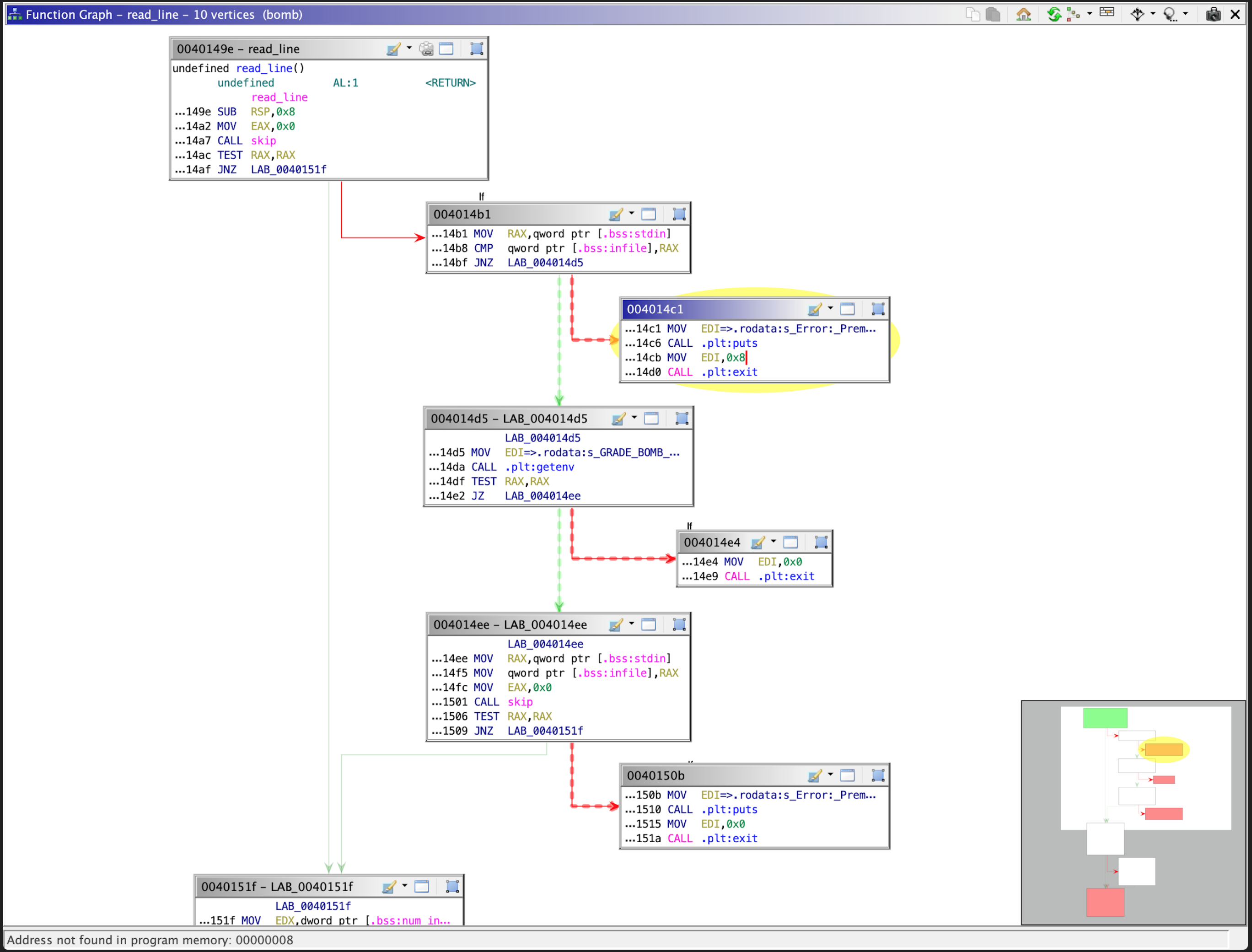
Default UI - Listing (Disassembly)



Default UI - Decompiler



Control Flow Graph



Disassembly with P-Code

Listing: bomb

*bomb

```
004014cb bf 08 00      MOV      EDI,0x8
         00 00
                                    (register, 0x38, 8) = COPY (const, 0x8, 8)
004014d0 e8 4b f7      CALL     .plt:exit                             void exit(int __status)
         ff ff
                                    (register, 0x20, 8) = INT_SUB (register, 0x20, 8), (const, 0x8, 8)
                                    STORE (const, 0x131, 8), (register, 0x20, 8), (const, 0x4014d5, 8)
                                    CALL (ram, 0x400c20, 8)
                                    RETURN (const, 0x0, 8)
                     -- Flow Override: CALL_RETURN (CALL_TERMINATOR)

                     LAB_004014d5                    XREF[1]:     004014bf(j)
004014d5 bf f3 25      MOV      EDI=>.rodata:s_GRADE_BOMB_004025f3,.rodata:s_G... = "GRADE_BOMB"
         40 00
                                    (register, 0x38, 8) = COPY (const, 0x4025f3, 8)
004014da e8 01 f6      CALL     .plt:getenv                           char * getenv(char * __name)
         ff ff
                                    (register, 0x20, 8) = INT_SUB (register, 0x20, 8), (const, 0x8, 8)
                                    STORE (const, 0x131, 8), (register, 0x20, 8), (const, 0x4014df, 8)
                                    CALL (ram, 0x400ae0, 8)
004014df 48 85 c0      TEST     RAX,RAX
                                    (register, 0x200, 1) = COPY (const, 0x0, 1)
                                    (register, 0x20b, 1) = COPY (const, 0x0, 1)
                                    (unique, 0xbb10, 8) = INT_AND (register, 0x0, 8), (register, 0x0, 8)
                                    (register, 0x207, 1) = INT_SLESS (unique, 0xbb10, 8), (const, 0x0, 8)
                                    (register, 0x206, 1) = INT_EQUAL (unique, 0xbb10, 8), (const, 0x0, 8)
004014e2 74 0a         JZ       LAB_004014ee
                                    CBRANCH (ram, 0x4014ee, 8), (register, 0x206, 1)
004014e4 bf 00 00      MOV      EDI,0x0
         00 00
                                    (register, 0x38, 8) = COPY (const, 0x0, 8)
004014e9 e8 32 f7      CALL     .plt:exit                             void exit(int __status)
         ff ff
                                    (register, 0x20, 8) = INT_SUB (register, 0x20, 8), (const, 0x8, 8)
                                    STORE (const, 0x131, 8), (register, 0x20, 8), (const, 0x4014ee, 8)
                                    CALL (ram, 0x400c20, 8)
                                    RETURN (const, 0x0, 8)
                     -- Flow Override: CALL_RETURN (CALL_TERMINATOR)

                     LAB_004014ee                    XREF[1]:     004014e2(j)
004014ee 48 8b 05      MOV      RAX,qword ptr [.bss:stdin]
         53 22 20 00
                                    (register, 0x0, 8) = COPY (ram, 0x603748, 8)
004014f5 48 89 05      MOV      qword ptr [.bss:infile],RAX           = 00000000
         6c 22 20 00
                                    (ram, 0x603768, 8) = COPY (register, 0x0, 8)
004014fc b8 00 00      MOV      EAX,0x0
         00 00
```

Decompilation Across Architectures - x64

Listing: elf-Linux-x64-bash

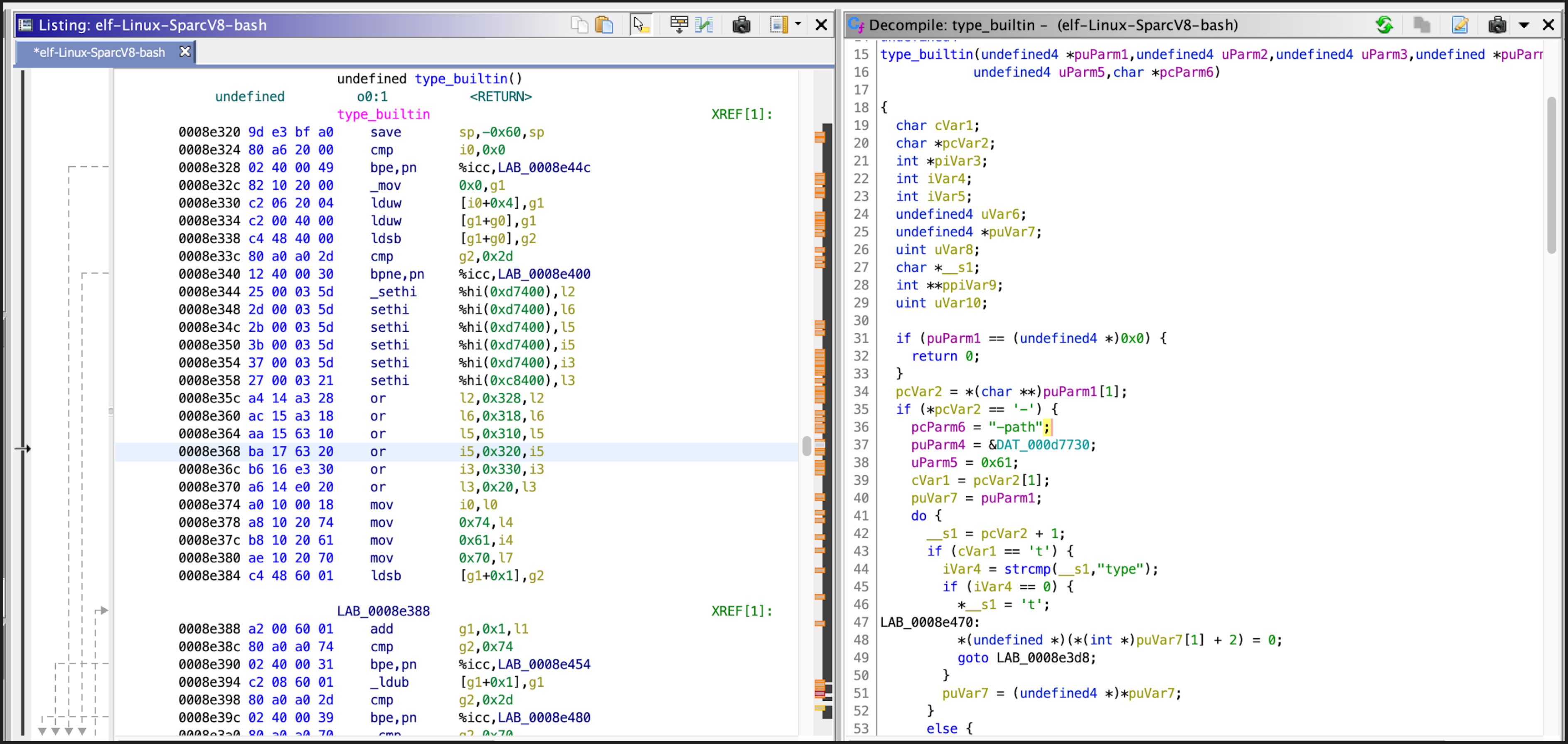
*elf-Linux-x64-bash

```
00493a9e 75 c0          JNZ       LAB_00493a60

                     LAB_00493aa0                          XREF[2]:
00493aa0 e8 0b af       CALL      rl_end_undo_group
         00 00
00493aa5 48 8b 7c       MOV       RDI,qword ptr [RSP + local_50]
         24 08
00493aaa e9 01 ff       JMP       LAB_004939b0
         ff ff
00493aaf 90             ??        90h

                     LAB_00493ab0                          XREF[1]:
00493ab0 48 8b 7c       MOV       RDI=>local_50,qword ptr [RSP + 0x8]
         24 08

                     LAB_00493ab5                          XREF[2]:
00493ab5 e8 86 ee       CALL      FUN_00492940
         ff ff
00493aba 48 8b 7c       MOV       RDI,qword ptr [RSP + local_50]
         24 08
00493abf e9 ec fe       JMP       LAB_004939b0
         ff ff
00493ac4 0f             ??        0Fh
00493ac5 1f             ??        1Fh
00493ac6 40             ??        40h    @
00493ac7 00             ??        00h

                     LAB_00493ac8                          XREF[1]:
00493ac8 48 8b 0d       MOV       RCX,qword ptr [.bss:rl_line_buffer]
         d9 16 25 00
00493acf 48 63 d5       MOVSXD    RDX,EBP
00493ad2 3a 44 11 ff    CMP       AL,byte ptr [RCX + RDX*0x1 + -0x1]
00493ad6 0f 94 c0       SETZ      AL
00493ad9 0f b6 c0       MOVZX     EAX,AL
00493adc 29 c5          SUB       EBP,EAX
00493ade e9 48 ff       JMP       LAB_00493a2b
         ff ff
00493ae3 0f             ??        0Fh
00493ae4 1f             ??        1Fh
00493ae5 44             ??        44h    D
00493ae6 00             ??        00h
00493ae7 00             ??        00h
```

Decompile: rl_complete_internal - (elf-Linux-x64-bash)

```c
  pcVar9 = rl_completion_entry_function;
  if (rl_completion_entry_function == (code *)0x0) {
    pcVar9 = rl_filename_completion_function;
  }
  uVar5 = 0;
  if (rl_point != 0) {
    local_39[0] = _rl_find_completion_word(&local_44,&local_40);
    uVar5 = rl_point;
  }
  rl_point = uVar1;
  __src = (char *)rl_copy_text((ulong)uVar5,(ulong)uVar1);
  uVar7 = 0;
  local_50 = (char **)FUN_00492490(__src,(ulong)uVar5,(ulong)uVar1,pcVar9,(ulong)loc
                                   (ulong)(uint)(int)local_39[0]);
  if (local_50 != (char **)0x0) {
    iVar3 = strcmp(__src,*local_50);
    uVar7 = (ulong)(iVar3 != 0);
  }
  free(__src);
  if ((local_50 == (char **)0x0) ||
     (iVar3 = FUN_00490cb0(&local_50,(ulong)rl_filename_completion_desired), ppcVar8
     iVar3 == 0)) {
    rl_ding();
    if (__dest != (char *)0x0) {
      free(__dest);
    }
    rl_readline_state = rl_readline_state & 0xffffbfff;
    DAT_006e5570 = 0;
    rl_completion_found_quote = 0;
    rl_completion_quote_character = 0;
    return 0;
  }
  if (uParm1 == 0x2a) {
    rl_begin_undo_group();
    if ((uVar5 != 0) && (local_39[0] != 0)) {
      uVar5 = uVar5 - (uint)(local_39[0] == rl_line_buffer[(long)(int)uVar5 + -1]);
    }
    rl_delete_text((ulong)uVar5,(ulong)rl_point);
    __src = ppcVar8[1];
    if (__src == (char *)0x0) {
      rl_point = uVar5;
      __src = (char *)FUN_004916e0(*ppcVar8,1,local_39);
      rl_insert_text(__src);
      rl_insert_text(&DAT_004ad25a);
```

Decompilation Across Architectures - SPARC



Decompilation Across Architectures - PowerPC

Listing: MachO-OSX-ppc-openssl-1.0.1h

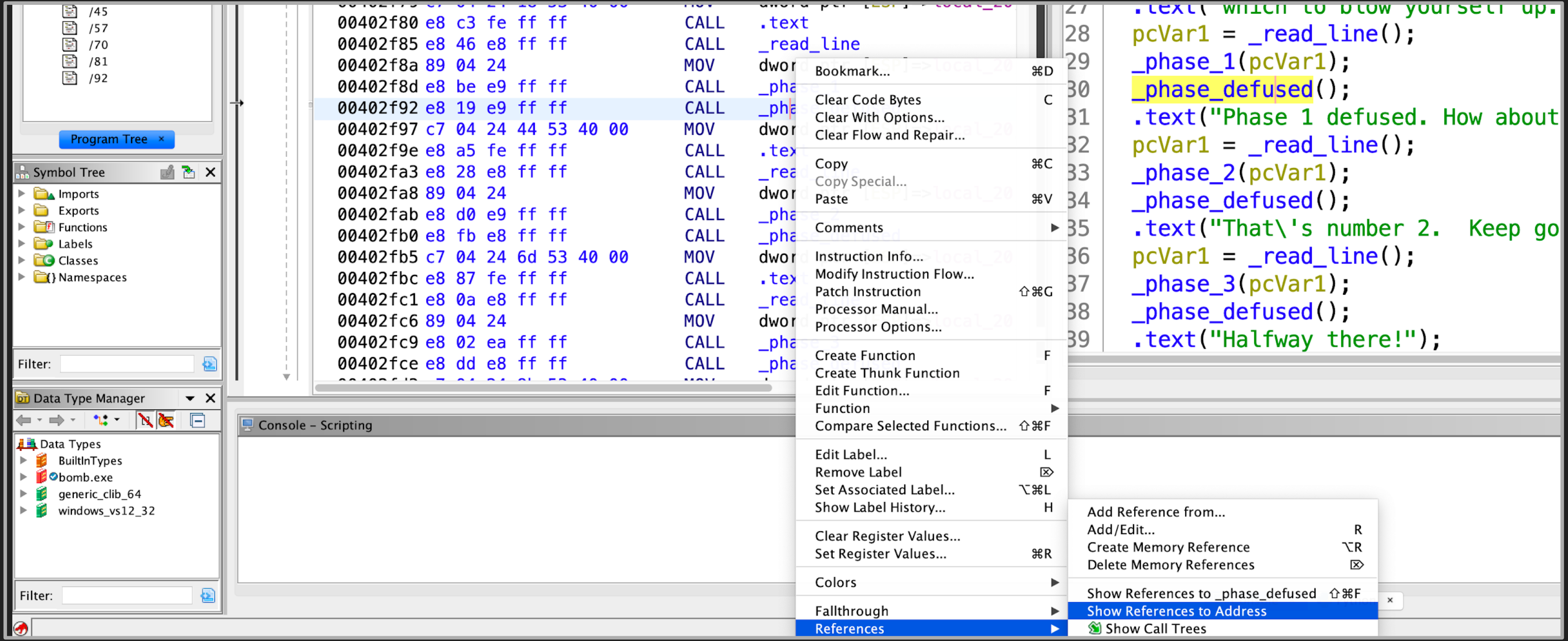
*elf-Linux-SparcV8-bash | *MachO-OSX-ppc-openssl-1.0.1h

```
                     LAB_000212c8                          XR
000212c8 40 9e 00 10     bne        cr7,LAB_000212d8
000212cc 48 00 00 18     b          LAB_000212e4

                     LAB_000212d0                          XR
000212d0 2f 82 00 00     cmpwi      cr7,r2,0x0
000212d4 40 9e 00 10     bne        cr7,LAB_000212e4

                     LAB_000212d8                          XR
000212d8 68 02 00 2f     xori       r2,r0,0x2f
000212dc 7c 42 00 34     cntlzw     r2,r2
000212e0 54 42 d9 7e     rlwinm     r2,r2,0x1b,0x5,0x1f

                     LAB_000212e4                          XR
000212e4 39 29 00 01     addi       r9,r9,0x1

                     LAB_000212e8                          XR
000212e8 88 09 00 00     lbz        r0,0x0(r9)
000212ec 7c 00 07 75     extsb.     r0,r0
000212f0 40 82 ff 98     bne        LAB_00021288

                     LAB_000212f4                          XR
000212f4 2f 82 00 03     cmpwi      cr7,r2,0x3
000212f8 38 00 00 01     li         r0,0x1
000212fc 41 9e 00 10     beq        cr7,LAB_0002130c
00021300 38 02 00 01     addi       r0,r2,0x1
00021304 7c 00 00 34     cntlzw     r0,r0
00021308 54 00 d9 7e     rlwinm     r0,r0,0x1b,0x5,0x1f

                     LAB_0002130c                          XR
0002130c 40 82 00 24     bne        LAB_00021330
00021310 3c 9f 00 04     addis      r4,r31,0x4
00021314 7f 43 d3 78     or         r3,r26,r26
00021318 80 84 fe 18     lwz        r4=>__cstring:s_HTTP/1.0_200_ok_Cor

0002131c 48 02 39 51     bl         __symbol_stub1:__symbol_stub1::_BIC
00021320 3c 9f 00 03     addis      r4,r31,0x3
00021324 7f 85 e3 78     or         r5,r28,r28
00021328 38 84 30 50     addi       r4=>__cstring:s_'%s'_is_an_invalid_
0002132c 48 00 00 30     b          LAB_0002135c
```

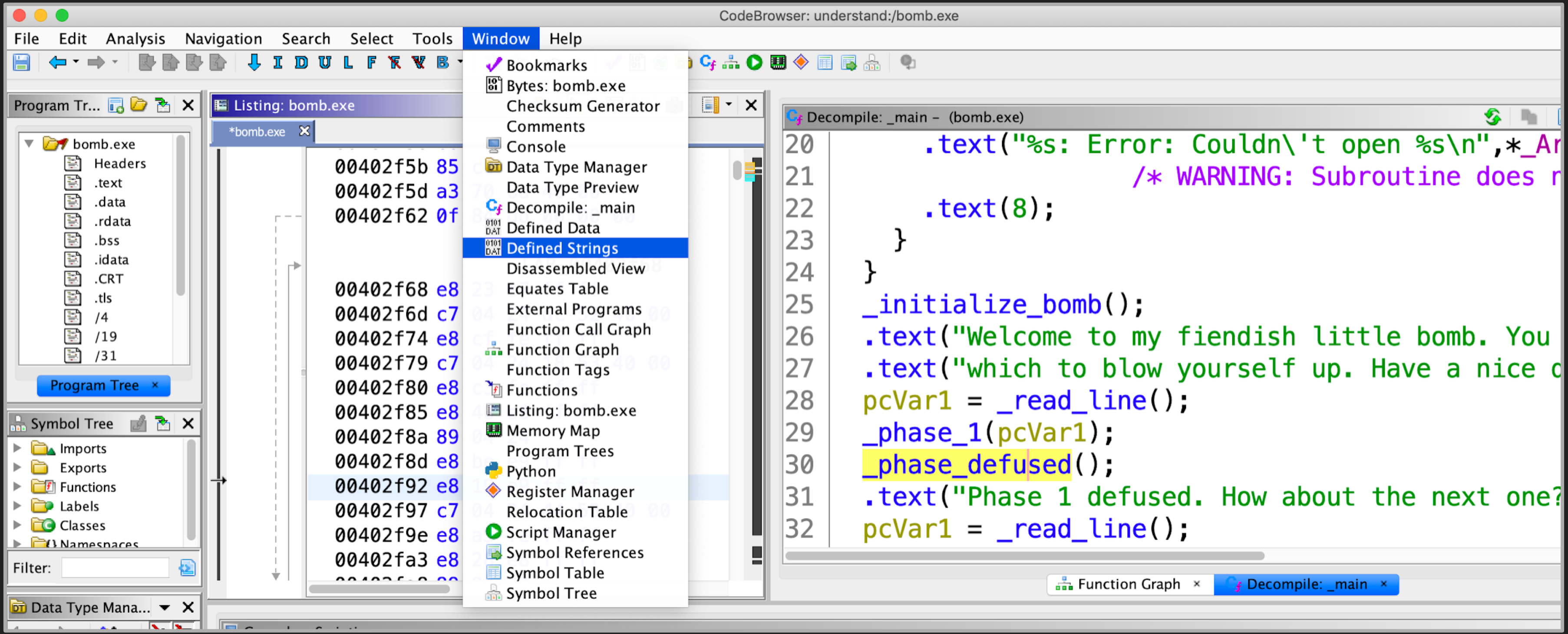
Decompile: UndefinedFunction_00020aec – (MachO-OSX-ppc-openssl-1.0.1h)

```c
  lVar11 = _BIO_int_ctrl(bp,0x75,0x4000,1);
  if ((lVar11 == 0) || (lVar5 = _SSL_new((ulonglong)_ctx), lVar5 == 0)) goto LAB_00021588;
  if (_s_tlsextdebug != 0) {
    _SSL_callback_ctrl(lVar5,0x38,ZEXT48(PTR__tlsext_cb_000603ac));
    _SSL_ctrl(lVar5,0x39,0,ZEXT48(_bio_s_out));
  }
  if ((char *)uParm3 != (char *)0x0) {
    sVar12 = _strlen((char *)uParm3);
    _SSL_set_session_id_context(lVar5,uParm3,sVar12);
  }
  append = _BIO_new_socket(iParm2,0);
  if (_s_nbio_test != 0) {
    type = _BIO_f_nbio_test();
    b = _BIO_new(type);
    append = _BIO_push(b,append);
  }
  _SSL_set_bio(lVar5,append,append);
  _SSL_set_accept_state(lVar5);
  _BIO_ctrl(bp_00,0x6d,1,(void *)lVar5);
  _BIO_push(bp,bp_00);
  if (_s_debug != 0) {
    _SSL_set_debug(lVar5,1);
    bp_00 = (BIO *)_SSL_get_rbio(lVar5);
    _BIO_set_callback(bp_00,(long (*)(bio_st *,int,char *,int,long,long))
                      PTR__bio_dump_callback_00060398);
    bp_00 = (BIO *)_SSL_get_rbio(lVar5);
    _BIO_set_callback_arg(bp_00,(char *)_bio_s_out);
  }
  if (_s_msg != 0) {
    _SSL_set_msg_callback(lVar5,ZEXT48(PTR__msg_cb_000603a8));
    _SSL_ctrl(lVar5,0x10,0,ZEXT48(_bio_s_out));
  }
LAB_00020d80:
  do {
    if (_hack != 0) {
      while ((uVar6 = _SSL_accept(lVar5), (int)uVar6 < 1 &&
             (iVar10 = _SSL_get_error(lVar5,uVar6), iVar10 == 4))) {
        _BIO_printf(_bio_s_out,"LOOKUP during accept %s\n",(ulonglong)_srp_callback_parm);
        DAT_000618e0 = _SRP_VBASE_get_by_user((ulonglong)DAT_000618dc,(ulonglong)_srp_callback_parm)
        ;
        if (DAT_000618e0 == 0) {
          _BIO_printf(_bio_s_out,"LOOKUP not successful\n");
        }
        else {
```

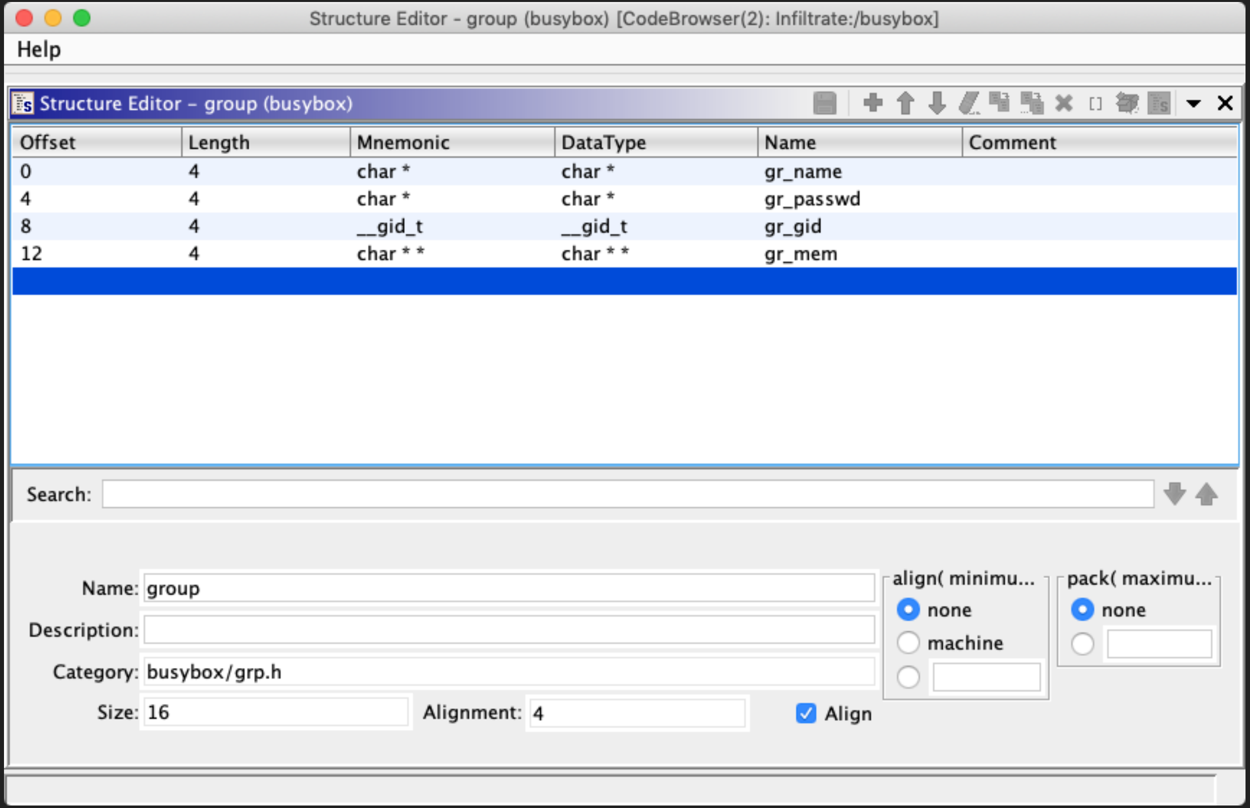
Cross-References



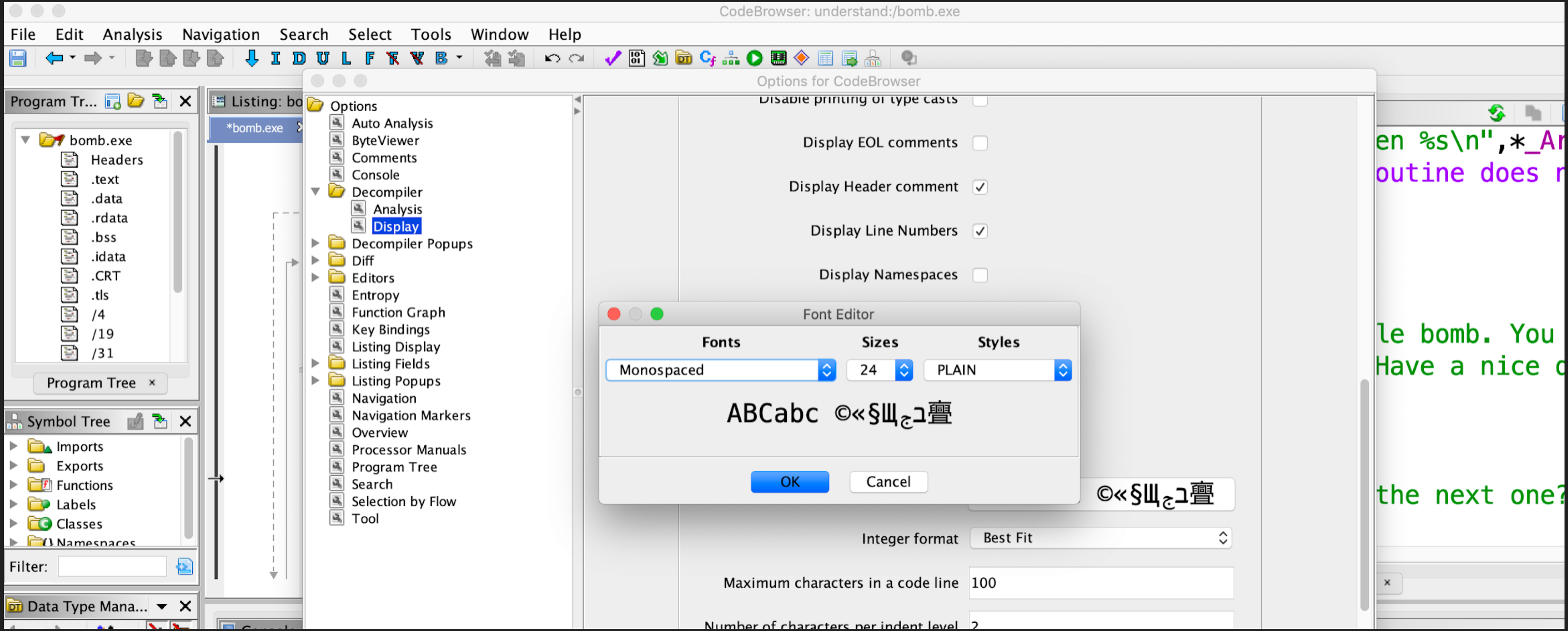
Strings


CodeBrowser: understand:/bomb.exe
File
Edit
Analysis
Navigation
Search
Select
Tools
Window
Help
Bookmarks
Bytes: bomb.exe
Checksum Generator
Comments
Console
Data Type Manager
Data Type Preview
Decompile: _main
Defined Data
Defined Strings
Disassembled View
Equates Table
External Programs
Function Call Graph
Function Graph
Function Tags
Functions
Listing: bomb.exe
Memory Map
Program Trees
Python
Register Manager
Relocation Table
Script Manager
Symbol References
Symbol Table
Symbol Tree
Program Tr...
bomb.exe
Headers
.text
.data
.rdata
.bss
.idata
.CRT
.tls
/4
/19
/31
Program Tree
Symbol Tree
Imports
Exports
Functions
Labels
Classes
Filter:
Data Type Mana...
Listing: bomb.exe
*bomb.exe
00402f5b 85
00402f5d a3
00402f62 0f
00402f68 e8
00402f6d c7
00402f74 e8
00402f79 c7
00402f80 e8
00402f85 e8
00402f8a 89
00402f8d e8
00402f92 e8
00402f97 c7
00402f9e e8
00402fa3 e8
Decompile: _main – (bomb.exe)
20 .text("%s: Error: Couldn\'t open %s\n",*_Ar
21 /* WARNING: Subroutine does r
22 .text(8);
23 }
24 }
25 _initialize_bomb();
26 .text("Welcome to my fiendish little bomb. You
27 .text("which to blow yourself up. Have a nice d
28 pcVar1 = _read_line();
29 _phase_1(pcVar1);
30 _phase_defused();
31 .text("Phase 1 defused. How about the next one?
32 pcVar1 = _read_line();
Function Graph
Decompile: _main

Type System / Structure Recovery

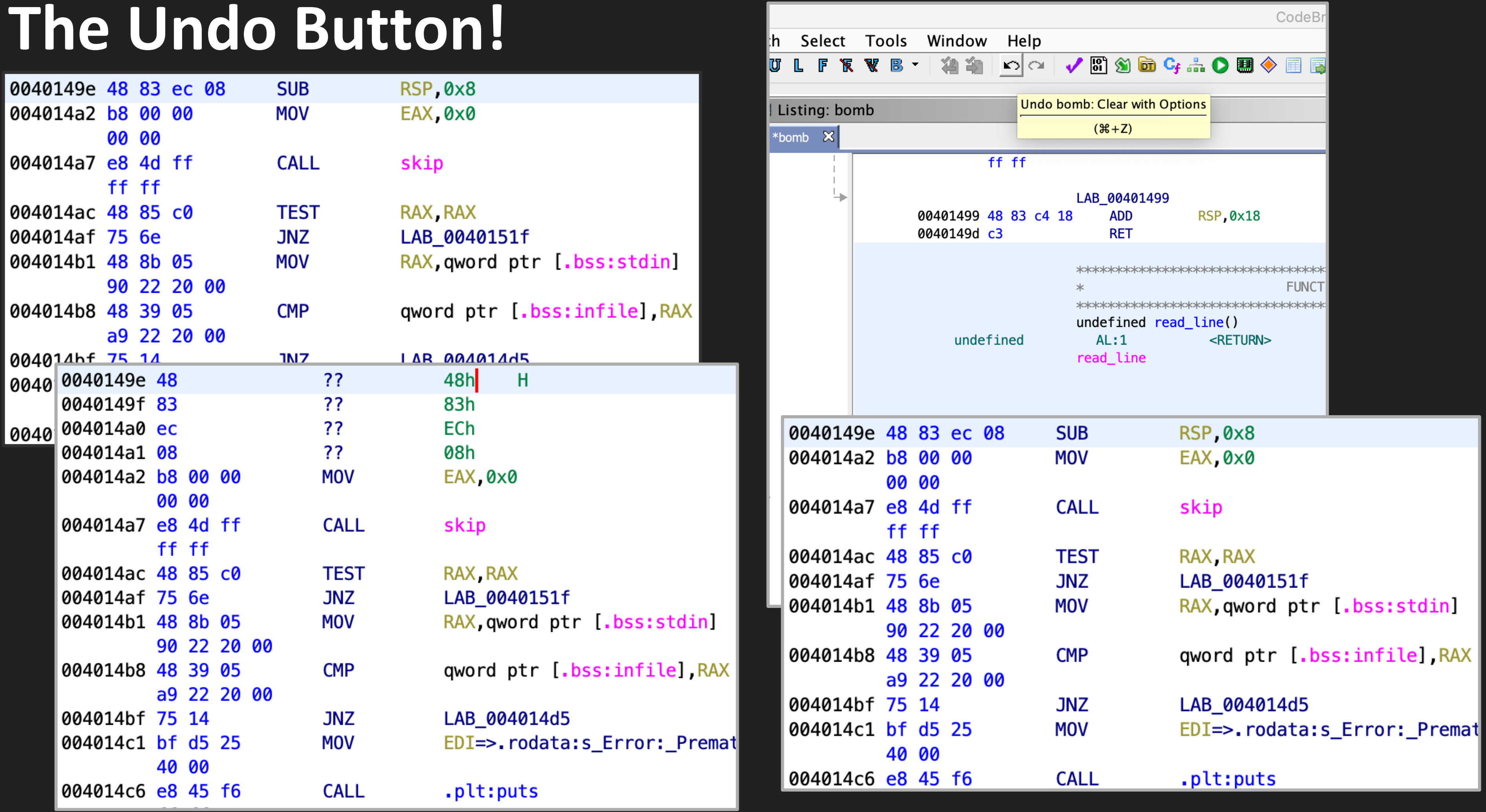


Customize Appearance



Edit >Tool Options → Filter: Fonts

The Undo Button!

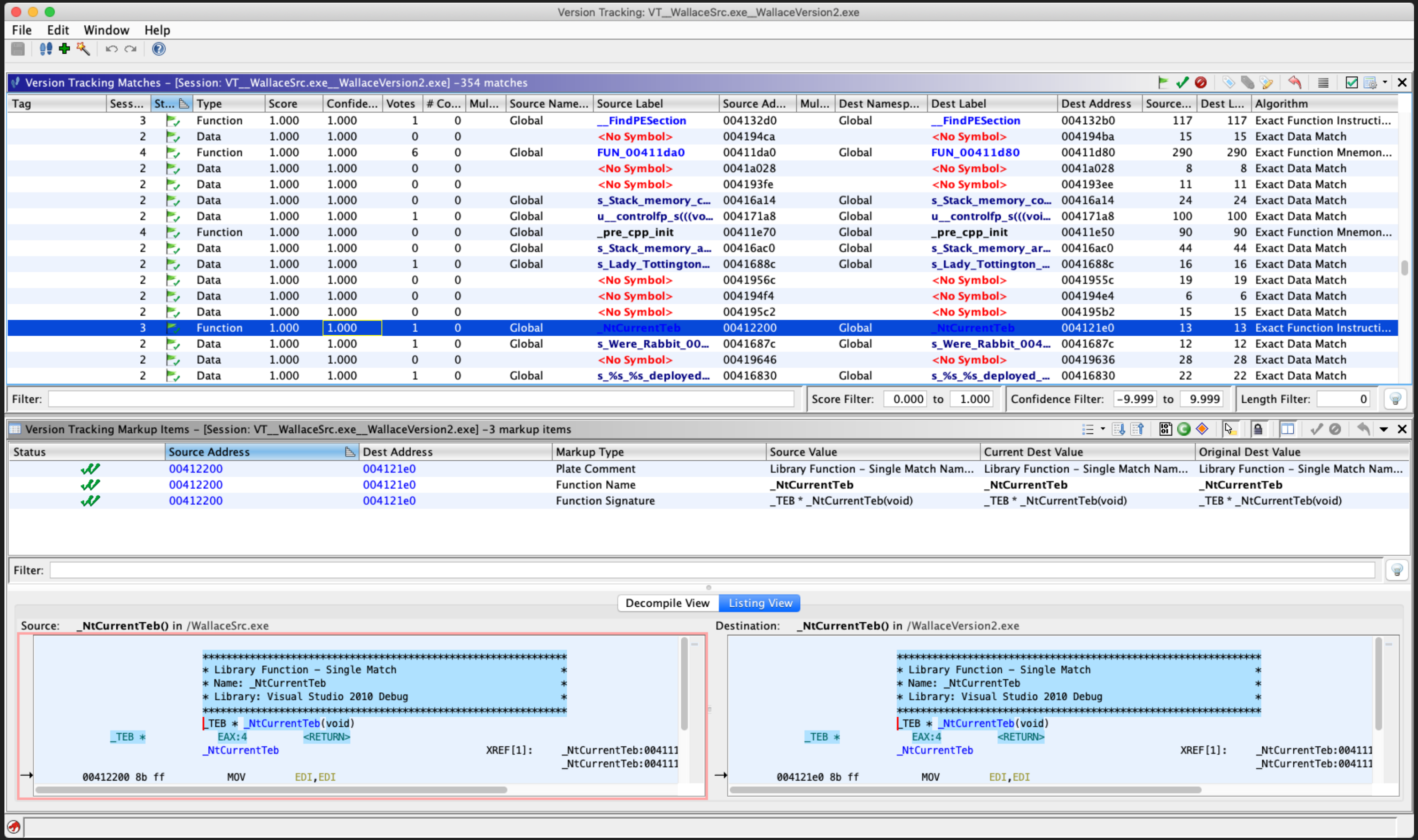


Version Tracker

- Feature for porting RE symbols, annotations, etc. between incrementally updated versions of the same program

- In our experience, not well suited for quick 1-day discovery in patch analysis
    - Use Diaphora or BinDiff for this purpose

Version Tracker - Overview



Version Tracker - Selecting Correlation Algorithms

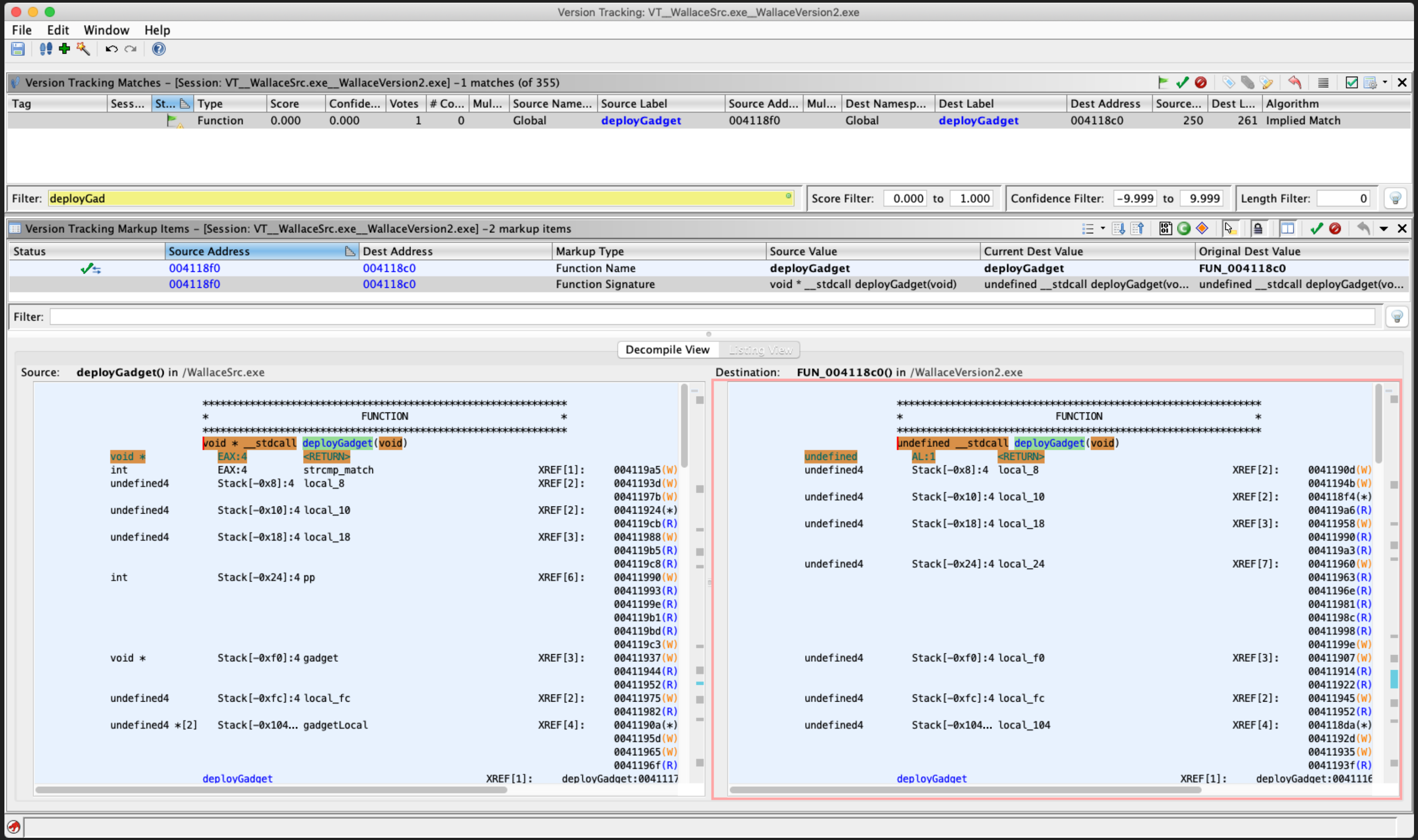
Version Tracking Wizard

Select Correlation Algorithm(s)

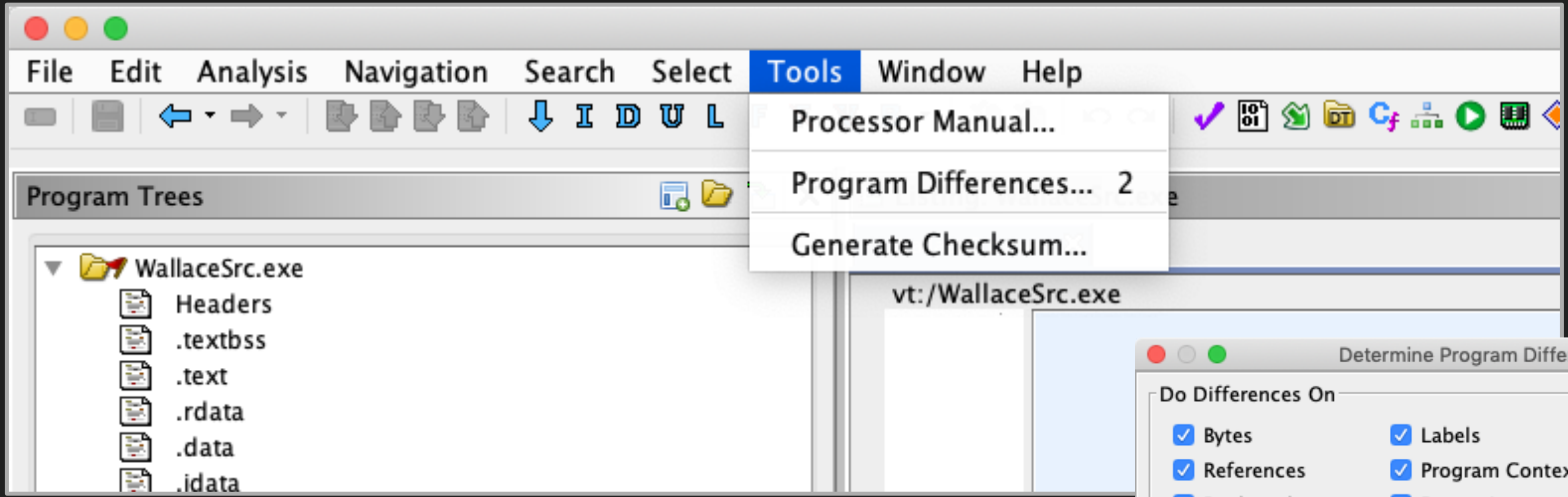
S...	Name	P...	Description
✓	Exact Data Match		Compares data by iterating over all defined data meeting the minimum size requirement in the source pro...
✓	Exact Function Bytes Match		Compares code by hashing bytes, looking for identical functions. It reports back any that have ONLY ONE...
✓	Exact Function Instructions Match		Compares code by hashing instructions, looking for identical functions. It reports back any that have ONL...
✓	Exact Function Mnemonics Match		Compares code by hashing instructions mnemonics, looking for identical functions. It reports back any t...
	Exact Symbol Name Match		Compares symbols by iterating over all defined function and data symbols meeting the minimum size req...
	Data Reference Match		Matches functions by the accepted data matches they have in common.
	Combined Function and Data Reference ...		Matches functions based on the accepted data and function matches they have in common.
	Function Reference Match		Matches functions by the accepted function matches they have in common.
	Duplicate Data Match		Compares data by iterating over all defined data meeting the minimum size requirement in the source pro...
	Duplicate Function Instructions Match		Compares code by hashing instructions (masking off operands), looking for identical functions. It report...
	Duplicate Exact Symbol Name Match		Compares symbols by iterating over all defined function and data symbols meeting the minimum size req...
	Similar Symbol Name Match		Compares symbols by iterating over all defined function and data symbols meeting the minimum size req...
	Similar Data Match		Compares data by iterating over all defined data meeting the minimum size requirement in the source pro...

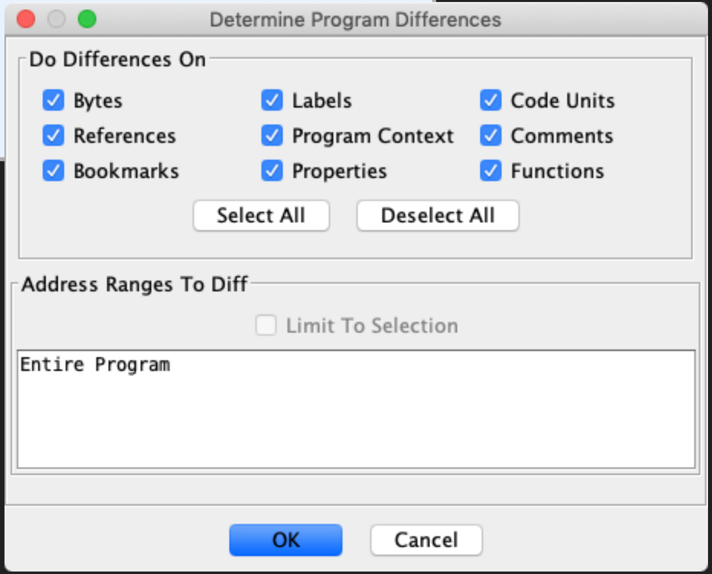
<< Back | Next >> | Finish | Cancel

Version Tracker - Function Name Ported



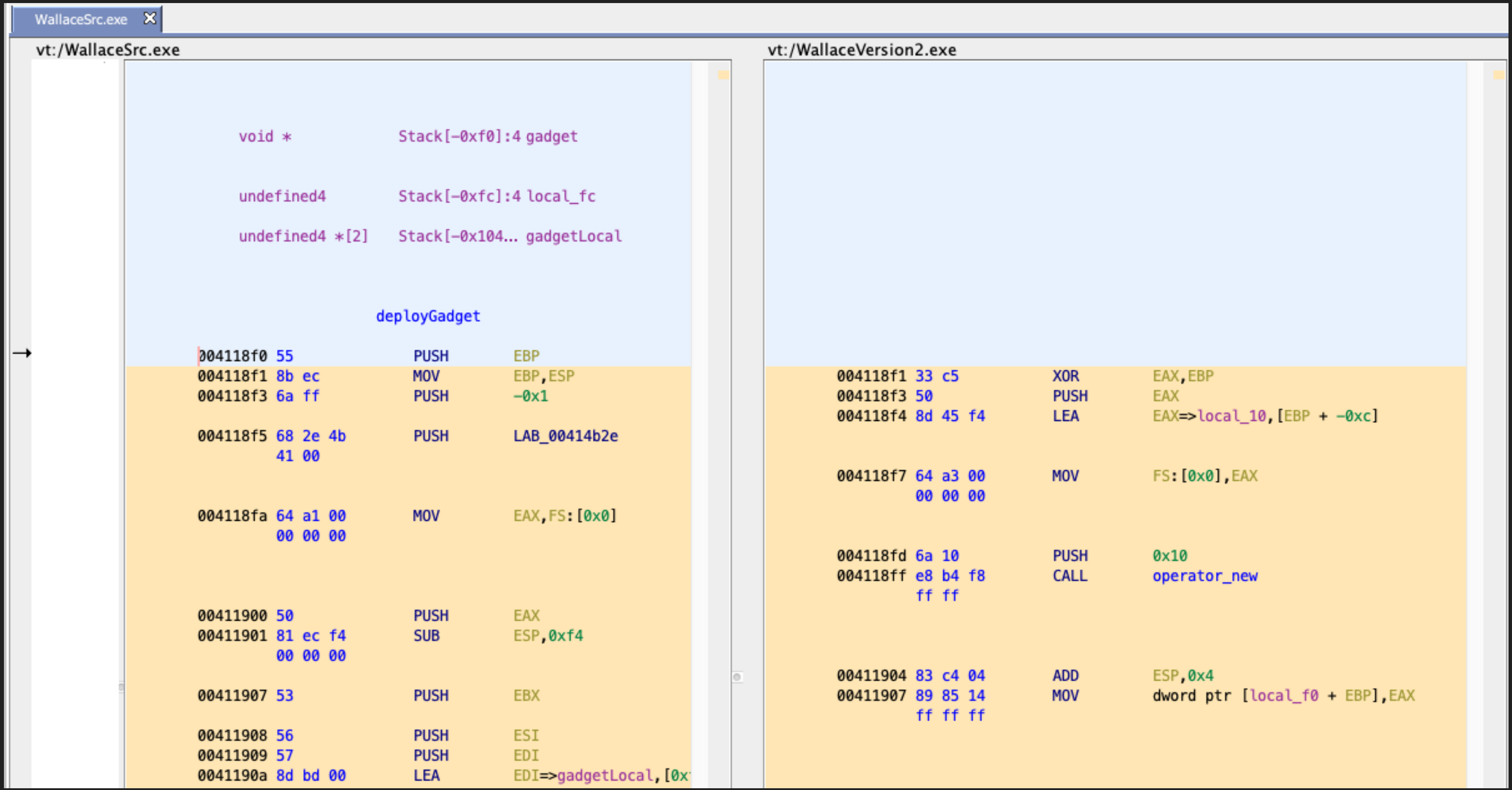
Program Differences



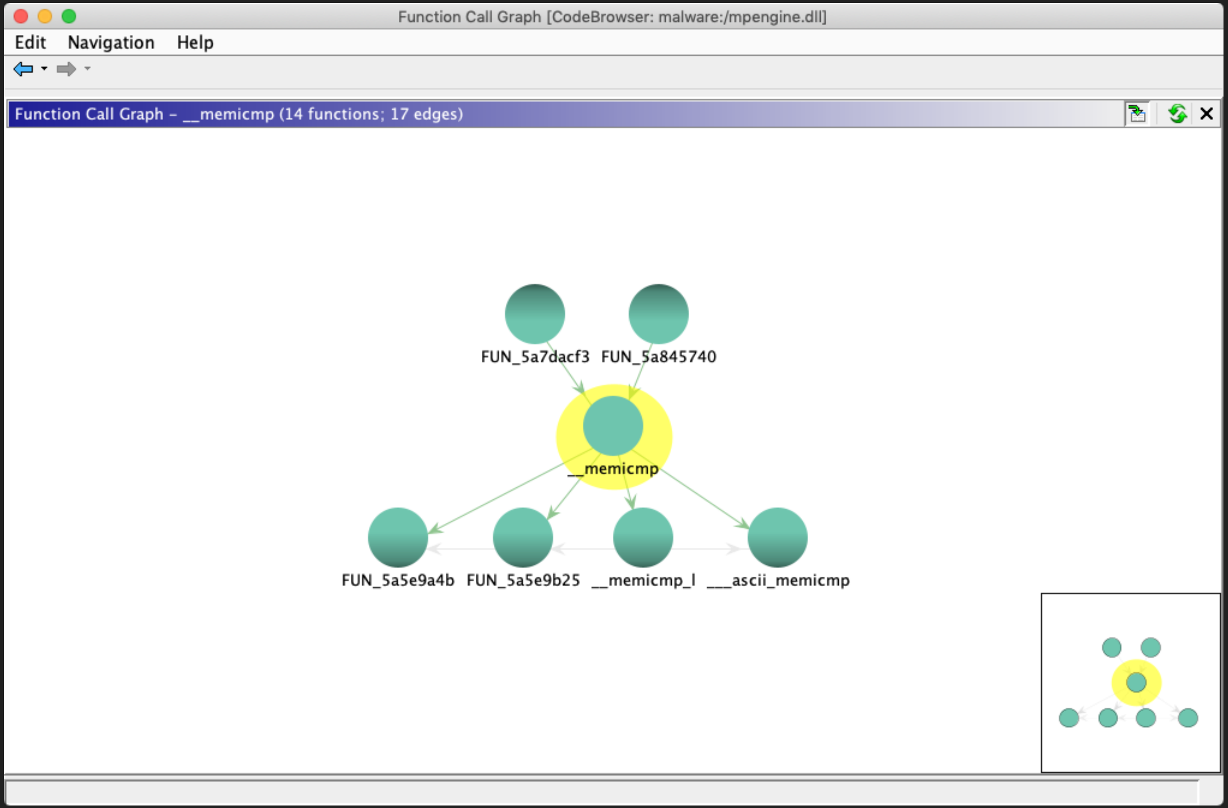


1:1 comparison of program memory ranges, only helpful if you had two annotated Ghidra databases for the same binary, or a version that had been statically patched

Program Differences

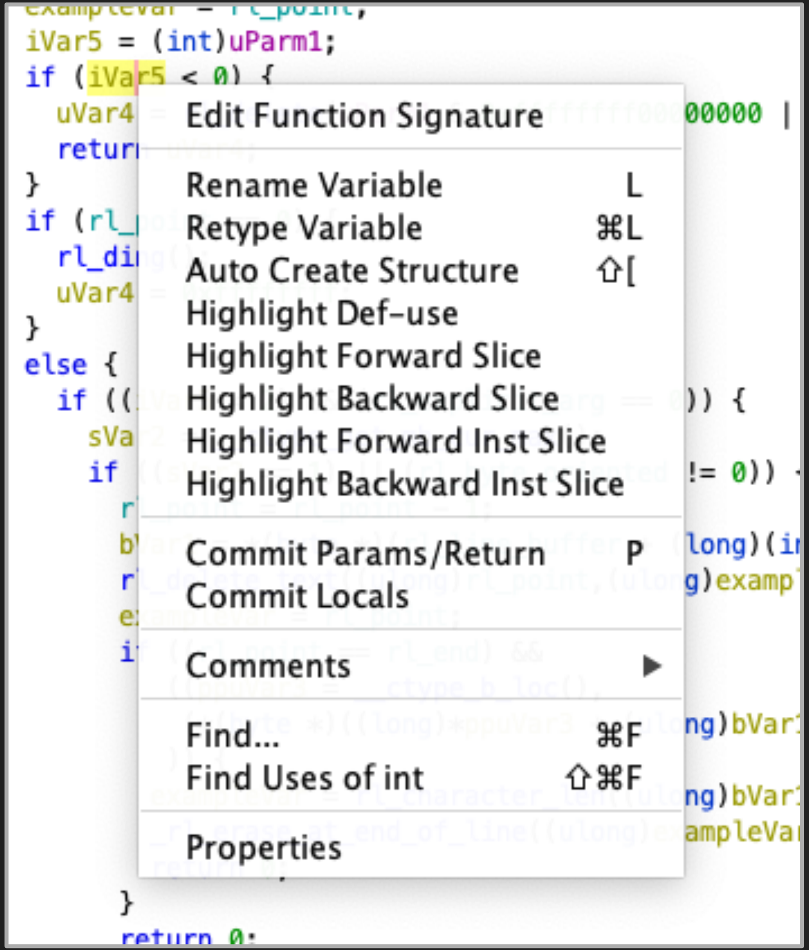


Function Call Graph



Decompiler Slicing

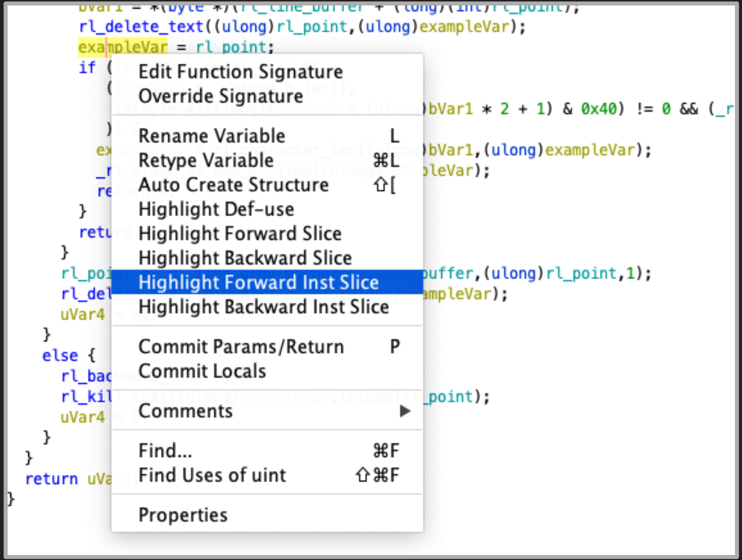
- Decompiler calculates data flow during auto-analysis
- Users can right-click on variables to view def-use chain and forward / backward slices
- Menu bar “Select” options allow users to trace flows to / from given points



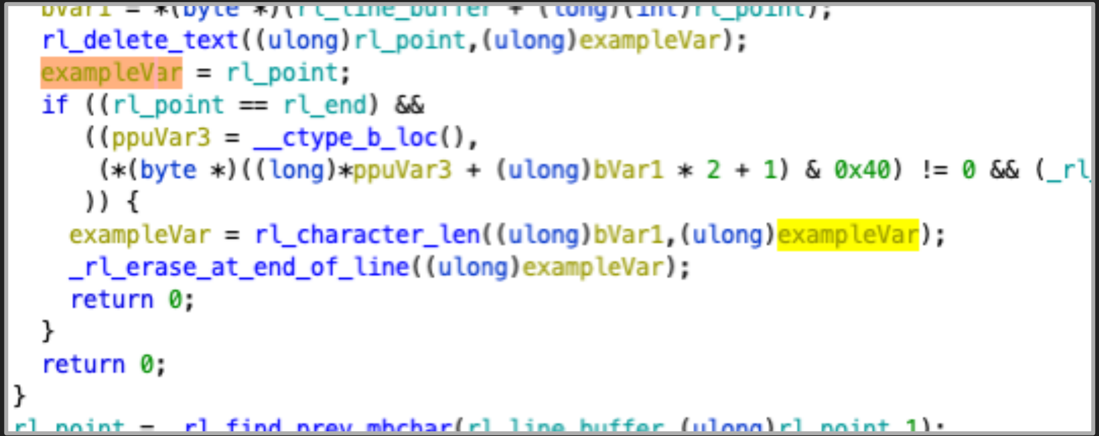
Decompiler Slicing

```
undefined8 _rl_rubout_char(ulong uParm1)

{
  byte bVar1;
  size_t sVar2;
  ushort **ppuVar3;
  undefined8 uVar4;
  int iVar5;
  uint exampleVar;

  exampleVar = rl_point;
  iVar5 = (int)uParm1;
  if (iVar5 < 0) {
    uVar4 = rl_delete(uParm1 & 0xffffffff00000000 | (ulong)(uint)-iVar5);
    return uVar4;
  }
  if (rl_point == 0) {
    rl_ding();
    uVar4 = 0xffffffff;
  }
  else {
    if ((iVar5 < 2) && (rl_explicit_arg == 0)) {
      sVar2 = __ctype_get_mb_cur_max();
      if ((sVar2 == 1) || (rl_byte_oriented != 0)) {
        rl_point = rl_point - 1;
        bVar1 = *(byte *)(rl_line_buffer + (long)(int)rl_point);
        rl_delete_text((ulong)rl_point,(ulong)exampleVar);
        exampleVar = rl_point;
        if ((rl_point == rl_end) &&
           ((ppuVar3 = __ctype_b_loc(),
            (*(byte *)((long)*ppuVar3 + (ulong)bVar1 * 2 + 1) & 0x40) != 0 &&
           )) {
          exampleVar = rl_character_len((ulong)bVar1,(ulong)exampleVar);
          _rl_erase_at_end_of_line((ulong)exampleVar);
          return 0;
        }
        return 0;
      }
      rl_point = _rl_find_prev_mbchar(rl_line_buffer,(ulong)rl_point,1);
      rl_delete_text((ulong)rl_point,(ulong)exampleVar);
      uVar4 = 0;
    }
    else {
      rl_backward_char();
      rl_kill_text((ulong)exampleVar,(ulong)rl_point);
      uVar4 = 0;
    }
  }
  return uVar4;
}
```

Middle Click

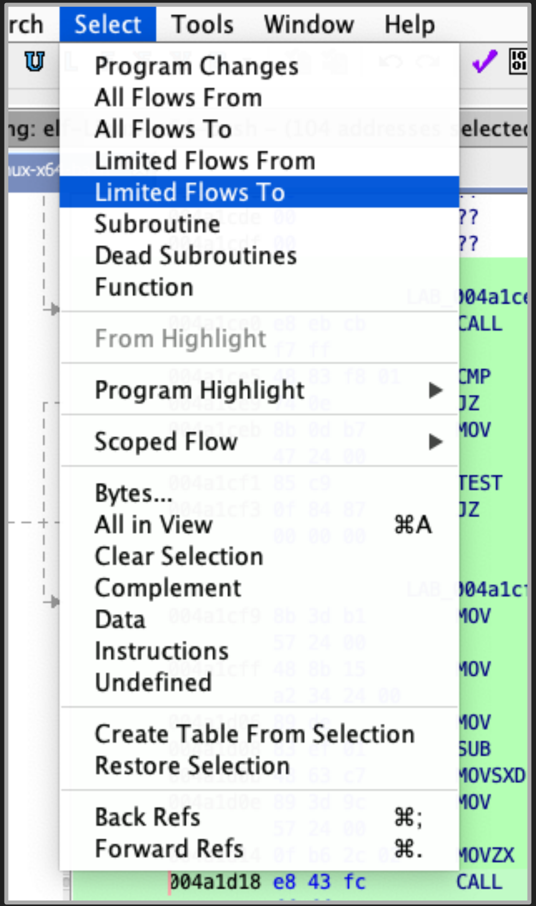


Highlight Forward Inst Slice



```
rl_delete_text((ulong)rl_point,(ulong)exampleVar);
exampleVar = rl_point;
if ((rl_point == rl_end) &&
   ((ppuVar3 = __ctype_b_loc(),
    (*(byte *)((long)*ppuVar3 + (ulong)bVar1 * 2 + 1) & 0x40) != 0 && (_rl
   )) {
  exampleVar = rl_character_len((ulong)bVar1,(ulong)exampleVar);
  _rl_erase_at_end_of_line((ulong)exampleVar);
  return 0;
}
return 0;
}
```

Decompiler Slicing




```c
undefined8 _rl_rubout_char(ulong uParm1)

{
  byte bVar1;
  size_t sVar2;
  ushort **ppuVar3;
  undefined8 uVar4;
  int iVar5;
  uint exampleVar;

  exampleVar = rl_point;
  iVar5 = (int)uParm1;
  if (iVar5 < 0) {
    uVar4 = rl_delete(uParm1 & 0xffffffff00000000 | (ulong)(uint)-iVar5);
    return uVar4;
  }
  if (rl_point == 0) {
    rl_ding();
    uVar4 = 0xffffffff;
  }
  else {
    if ((iVar5 < 2) && (rl_explicit_arg == 0)) {
      sVar2 = __ctype_get_mb_cur_max();
      if ((sVar2 == 1) || (rl_byte_oriented != 0)) {
        rl_point = rl_point - 1;
        bVar1 = *(byte *)(rl_line_buffer + (long)(int)rl_point);
        rl_delete_text((ulong)rl_point,(ulong)exampleVar);
        exampleVar = rl_point;
        if ((rl_point == rl_end) &&
           ((ppuVar3 = __ctype_b_loc(),
            (*(byte *)((long)*ppuVar3 + (ulong)bVar1 * 2 + 1) & 0x40) != 0 && (_rl_last_c_pos != 0))
           )) {
          exampleVar = rl_character_len((ulong)bVar1,(ulong)exampleVar);
          _rl_erase_at_end_of_line((ulong)exampleVar);
          return 0;
        }
        return 0;
      }
      rl_point = _rl_find_prev_mbchar(rl_line_buffer,(ulong)rl_point,1);
      rl_delete_text((ulong)rl_point,(ulong)exampleVar);
      uVar4 = 0;
    }
    else {
      rl_backward_char();
      rl_kill_text((ulong)exampleVar,(ulong)rl_point);
      uVar4 = 0;
    }
  }
  return uVar4;
}
```

Outline

1. Intro
2. Interactive Exercises
    a. Manual Static Analysis
    b. Scripting Ghidra
3. P-Code & SLEIGH
4. Discussion
5. Conclusion

Scripting With Ghidra

- Available in Java (natively) and Python (via Jython)
- Can be run with interactive GUI or in headless mode
- Ghidra comes with 230+ scripts pre-installed
  - Educational examples
  - Code patching
  - Import / export
  - Analysis enhancements
    - Windows, Mac, Linux, VXWorks
    - PE, ELF, Mach-O, COFF
    - x86, MIPS, ARM/THUMB, 8051, etc...

Ghidra APIs

FlatProgramAPI

- Simple “flattened” API for Ghidra scripting
- Programmatic access to common tasks
  - query / modify / iterate / create / delete - functions / data / instructions / comments
- Mostly doesn’t require the use of Java objects
- Stable

Ghidra Program API

- More complex rich API for deeper scripting
- Object-oriented (Program, Memory, Function, Instruction, etc…)
- Utility functions help with common scripting tasks
- UI scripting / interactivity
- Prone to change between versions

API Highlights

Rich Scripting Interface

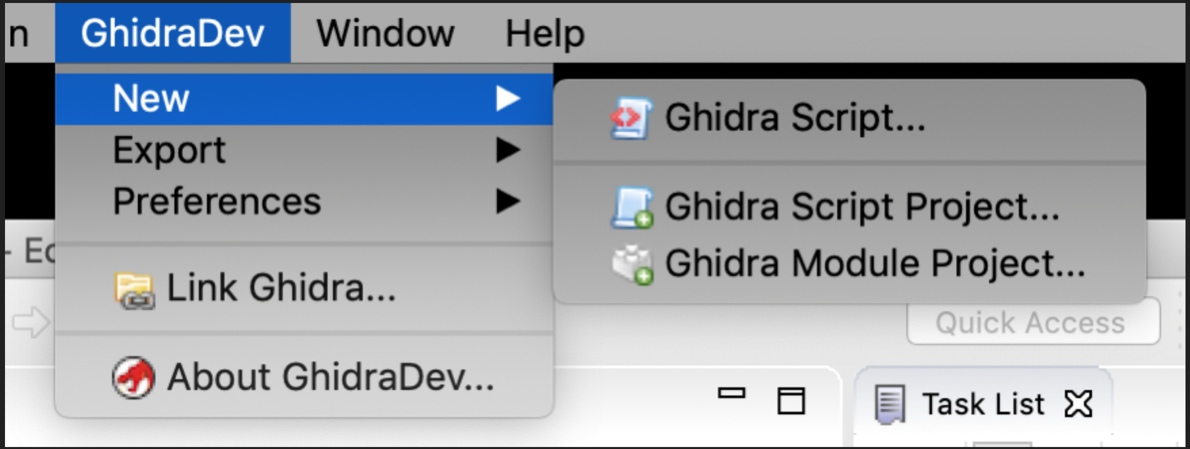
- Programmatic access to binary file formats
- P-code interaction
- Decompiler API
- C header parsing
- Interface for graphing (implementation not included)
- Cyclomatic complexity

Common Utilities Included

- UI windows
- Assembly
- Data serialization
- String manipulation
- Hashing
- Search / byte matching
- XML utilities

Eclipse Integration

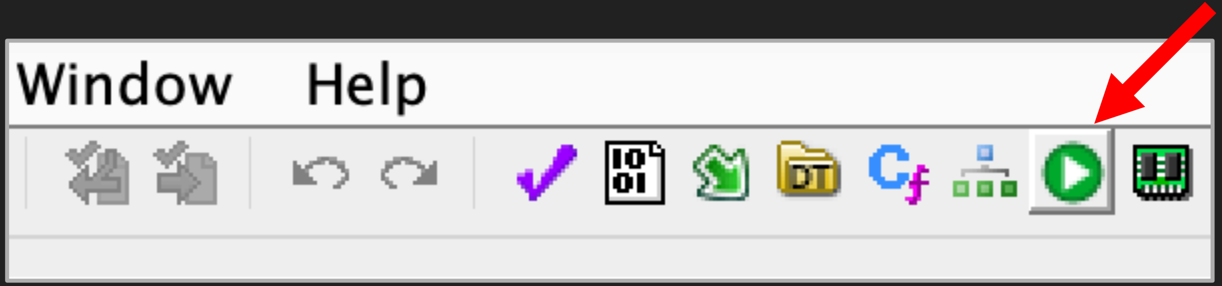
- Ghidra has built-in Eclipse integration, via its “GhidraDev” Eclipse plugin
- **NOTE:** For these exercises, we’ll be using Ghidra’s built-in basic editor - don’t waste time trying to get Eclipse set up during this workshop



Scripting Demos

1. Hello World
   a. Java
   b. Python
2. Crypto Constant Search
3. Cyclomatic Complexity
4. Xor with Python

Importing Demo Scripts



Click the “Display Script Manager” button to open the Script Manager Window

Importing Demo Scripts

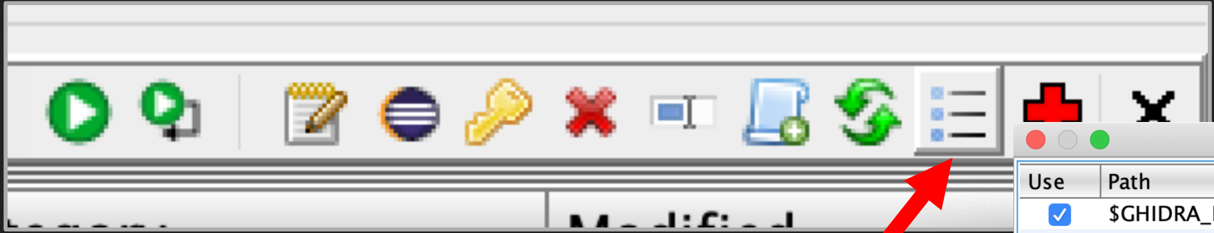
Click the “Display Script Manager” button to open the Script Manager Window

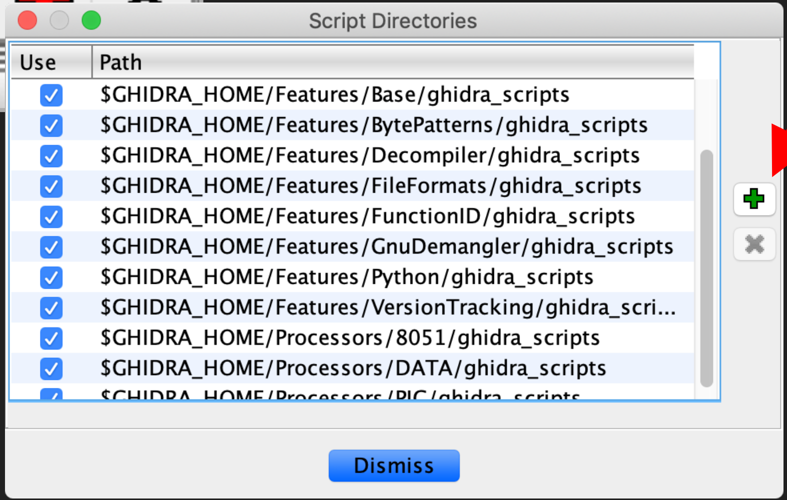
Click the “Script Directories” button on the Script Click the “Display Script Manager” button to open the Script Manager Window

Importing Demo Scripts

Click the “Display Script Manager” button to open the Script Manager Window

Click the green plus to open the file chooser, choose the script directory

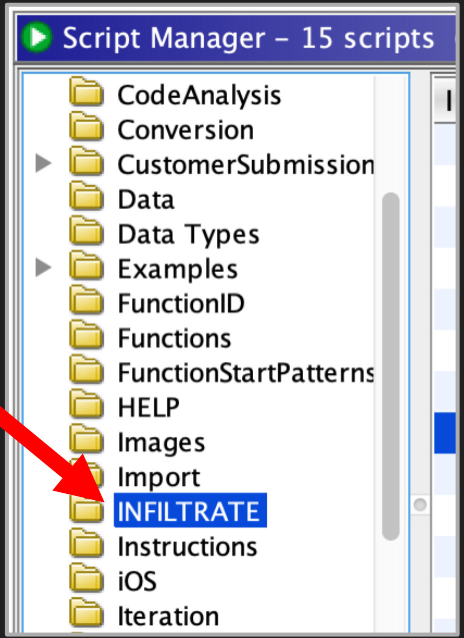




Click the “Script Directories” button on the Script Click the “Display Script Manager” button to open the Script Manager Window

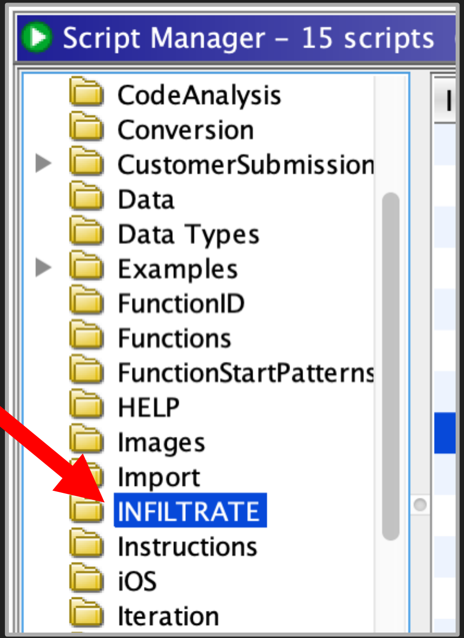
Running Script Demos

Find the "INFILTRATE" folder in the script manager

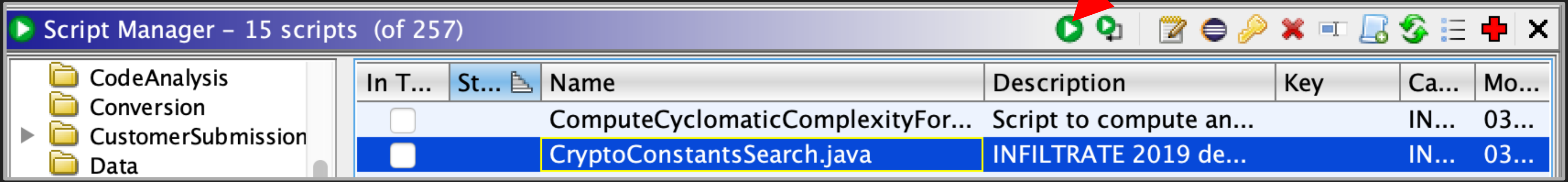


Running Script Demos

Find the "INFILTRATE" folder in the script manager

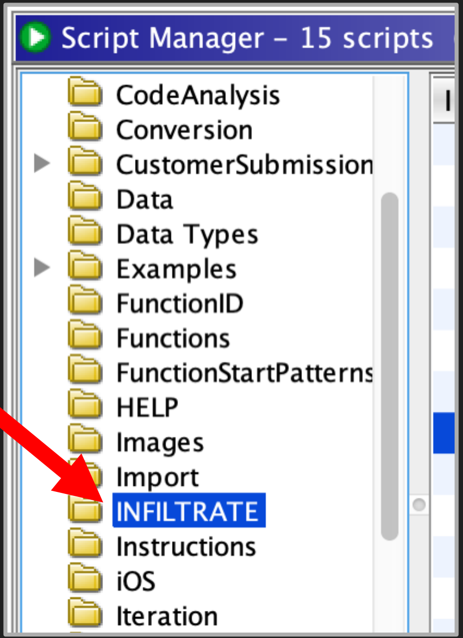


Choose a script and click "Run Script" to run

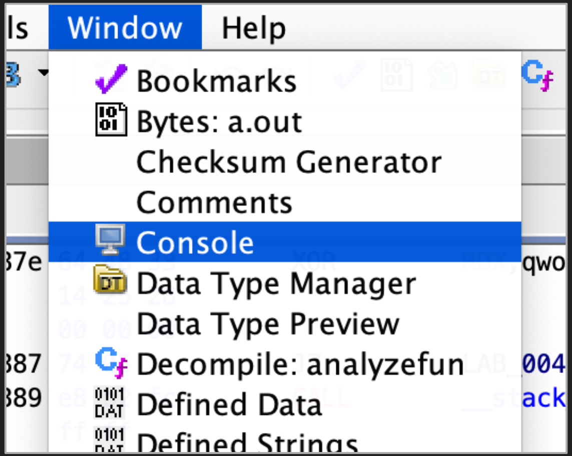


Running Script Demos

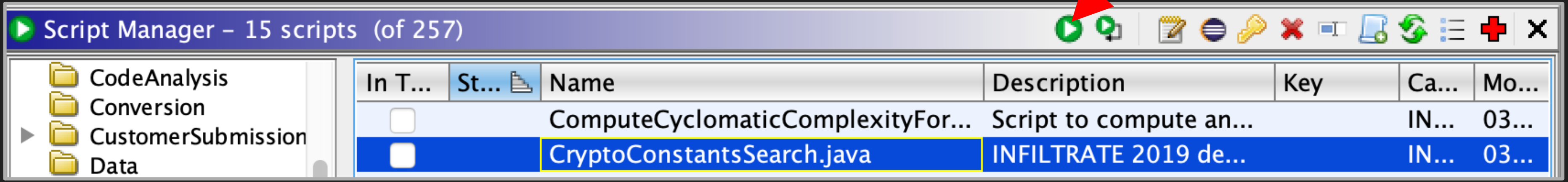
Find the "INFILTRATE" folder in the script manager



Make sure the "Console" window is open if you want to see output



Choose a script and click "Run Script" to run



DEMO: Hello World

- A simple script to print “Hello World” and then iterate over all functions in the program, printing out their names

- `HelloWorld.java`
- `HelloWorld.py`

Console - Scripting

```
HelloWorld.java> Running...
HelloWorld.java> Hello world
HelloWorld.java> _init
HelloWorld.java> FUN_00400ad0
HelloWorld.java> getenv
HelloWorld.java> __errno_location
HelloWorld.java> strcpy
HelloWorld.java> puts
HelloWorld.java> write
HelloWorld.java> __stack_chk_fail
HelloWorld.java> alarm
HelloWorld.java> close
HelloWorld.java> read
HelloWorld.java> __libc_start_main
```

```java
import ghidra.app.script.GhidraScript;

public class HelloWorld extends GhidraScript {

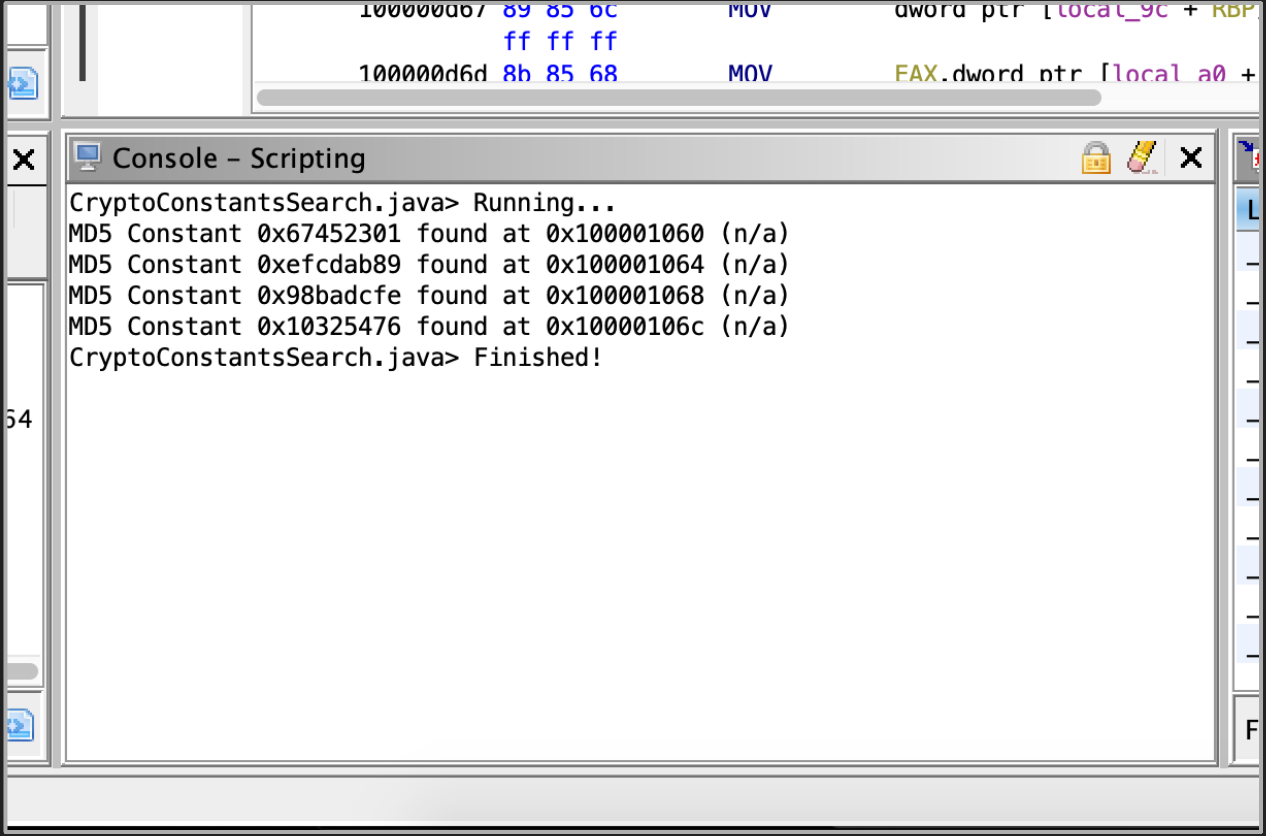
    public void run() throws Exception {
    println("Hello world");

    Function currentFunc = getFirstFunction();
    while (currentFunc != null){
        println(currentFunc.getName());
        currentFunc = getFunctionAfter(currentFunc);
    }
    }
}
```

DEMO: Crypto Search

- Find MD5 constants present in a binary, report offset and function name
- Take binary endianness into account automatically without user specification
- `CryptoConstantsSearch.java`

DEMO: Crypto Search



DEMO: Calculating Cyclomatic Complexity

- Leverage Ghidra’s API for calculating cyclomatic complexity* to easily analyze a whole program
- Pop a GUI window if running interactively, else print to the terminal in headless mode
- `ComputeCyclomaticComplexityForAllFunctions.java`

* cyclomatic complexity is a measure of the number of unique paths which may be taken through a given function. It can be helpful in finding complex functions likely to have vulnerabilities, e.g, complex parsing routines or state machines.

DEMO: Calculating Cyclomatic Complexity

elf-Linux-lib-x64.so - Function Cyclomatic Complexity

Location	Function Name	Cyclomatic Complexity
0012b610	cairo_device_flush	7
001c5ca0	FUN_001c5ca0	7
0019dfc0	FUN_0019dfc0	7
001614e0	cairo_region_destroy	7
001ba8b0	cairo_gl_surface_create_for_egl	7
0016ce70	FUN_0016ce70	7
001b3640	FUN_001b3640	7
001b40a0	FUN_001b40a0	7
00172ee0	FUN_00172ee0	7
001a70d0	FUN_001a70d0	7
001a3b20	FUN_001a3b20	7
0012f1c0	FUN_0012f1c0	7
0019c350	FUN_0019c350	8
001a59f0	FUN_001a59f0	8
0018e490	FUN_0018e490	8
001ce780	FUN_001ce780	8
001511f0	cairo_mesh_pattern_set_control_point	8
00123710	cairo_clip_extents	8
0016a010	FUN_0016a010	8
001dba60	FUN_001dba60	8
001d0070	FUN_001d0070	8
0015c250	FUN_0015c250	8
0013cd50	FUN_0013cd50	8
00183920	FUN_00183920	8
001c9140	FUN_001c9140	8
0015d120	FUN_0015d120	8
001ad4b0	FUN_001ad4b0	8
001cdd50	FUN_001cdd50	8
001b9b70	cairo_gl_surface_set_size	8

Filter:

Dismiss

support — -bash — ⌥⌘1

```
INFO  FUN_001d0070 complexity: 8 (GhidraScript)
INFO  FUN_001d0170 complexity: 8 (GhidraScript)
INFO  FUN_001d0260 complexity: 18 (GhidraScript)
INFO  FUN_001d05a0 complexity: 29 (GhidraScript)
INFO  FUN_001d0b30 complexity: 2 (GhidraScript)
INFO  FUN_001d0bb0 complexity: 19 (GhidraScript)
INFO  FUN_001d1060 complexity: 17 (GhidraScript)
INFO  FUN_001d1490 complexity: 36 (GhidraScript)
INFO  FUN_001d1c50 complexity: 6 (GhidraScript)
INFO  FUN_001d1dc0 complexity: 28 (GhidraScript)
INFO  FUN_001d2260 complexity: 22 (GhidraScript)
INFO  FUN_001d26a0 complexity: 34 (GhidraScript)
INFO  FUN_001d2db0 complexity: 16 (GhidraScript)
INFO  FUN_001d3040 complexity: 24 (GhidraScript)
INFO  FUN_001d3440 complexity: 37 (GhidraScript)
INFO  FUN_001d3930 complexity: 29 (GhidraScript)
INFO  FUN_001d3c40 complexity: 23 (GhidraScript)
INFO  FUN_001d3f50 complexity: 27 (GhidraScript)
INFO  FUN_001d4340 complexity: 191 (GhidraScript)
INFO  FUN_001d6c20 complexity: 16 (GhidraScript)
INFO  cairo_pdf_surface_create_for_stream complexity: 3 (GhidraScript)
INFO  cairo_pdf_surface_create complexity: 3 (GhidraScript)
INFO  cairo_pdf_surface_restrict_to_version complexity: 3 (GhidraScript)
INFO  cairo_pdf_get_versions complexity: 3 (GhidraScript)
INFO  cairo_pdf_version_to_string complexity: 2 (GhidraScript)
INFO  cairo_pdf_surface_set_size complexity: 4 (GhidraScript)
INFO  FUN_001d7070 complexity: 1 (GhidraScript)
INFO  FUN_001d7080 complexity: 1 (GhidraScript)
INFO  FUN_001d7090 complexity: 1 (GhidraScript)
INFO  FUN_001d70b0 complexity: 1 (GhidraScript)
INFO  FUN_001d70d0 complexity: 2 (GhidraScript)
INFO  FUN_001d71c0 complexity: 2 (GhidraScript)
INFO  FUN_001d7230 complexity: 2 (GhidraScript)
INFO  FUN_001d72a0 complexity: 6 (GhidraScript)
INFO  FUN_001d7370 complexity: 18 (GhidraScript)
INFO  FUN_001d76c0 complexity: 14 (GhidraScript)
INFO  FUN_001d7820 complexity: 1 (GhidraScript)
INFO  FUN_001d7870 complexity: 1 (GhidraScript)
INFO  FUN_001d78d0 complexity: 14 (GhidraScript)
INFO  FUN_001d7950 complexity: 1 (GhidraScript)
INFO  FUN_001d7980 complexity: 5 (GhidraScript)
INFO  FUN_001d79b0 complexity: 30 (GhidraScript)
INFO  FUN_001d8090 complexity: 3 (GhidraScript)
INFO  FUN_001d8140 complexity: 10 (GhidraScript)
INFO  FUN_001d8280 complexity: 2 (GhidraScript)
```

DEMO: Python Scripting

- Ghidra can run Python in a Jython environment, the Ghidra Java API is exposed to Python

- This script takes a user address selection and XORs the bytes in place with `0x41`

- `XorMemoryScript.py`

DEMO: Python Scripting

7 addresses selected)

100001ce8	00	??	00h	
100001ce9	00	??	00h	
100001cea	24	??	24h	$
100001ceb	2f	??	2Fh	/
100001cec	22	??	22h	"
100001ced	33	??	33h	3
100001cee	38	??	38h	8
100001cef	31	??	31h	1
100001cf0	35	??	35h	5
100001cf1	24	??	24h	$
100001cf2	25	??	25h	%
100001cf3	61	??	61h	a
100001cf4	2c	??	2Ch	,
100001cf5	24	??	24h	$
100001cf6	32	??	32h	2
100001cf7	32	??	32h	2
100001cf8	20	??	20h	
100001cf9	26	??	26h	&
100001cfa	24	??	24h	$
100001cfb	00	??	00h	
100001cfc	00	??	00h	

7 addresses selected)

100001ce8	00	??	00h	
100001ce9	00	??	00h	
100001cea	65	??	65h	e
100001ceb	6e	??	6Eh	n
100001cec	63	??	63h	c
100001ced	72	??	72h	r
100001cee	79	??	79h	y
100001cef	70	??	70h	p
100001cf0	74	??	74h	t
100001cf1	65	??	65h	e
100001cf2	64	??	64h	d
100001cf3	20	??	20h	
100001cf4	6d	??	6Dh	m
100001cf5	65	??	65h	e
100001cf6	73	??	73h	s
100001cf7	73	??	73h	s
100001cf8	61	??	61h	a
100001cf9	67	??	67h	g
100001cfa	65	??	65h	e
100001cfb	00	??	00h	
100001cfc	00	??	00h	

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P-Code

- Ghidra’s intermediate language
  - Dates back to at least 2005 according to documentation
- Code for different processors can be lifted into p-code, data-flow analysis and decompilation can then run over the p-code
- Pseudo-assembly, represents lifted instructions as small atomic operations without side-effects
- Built-in floating point support

```
MOVSXD       RAX,EDX
                        (register, 0x0, 8) = INT_SEXT (register, 0x10, 4)
LEA          RAX,[RAX + RAX*0x4]
                        (unique, 0x660, 8) = INT_MULT (register, 0x0, 8), (const, 0x4, 8)
                        (unique, 0x680, 8) = INT_ADD (register, 0x0, 8), (unique, 0x660, 8)
                        (register, 0x0, 8) = COPY (unique, 0x680, 8)
```

P-Code Design

- The language is machine independent.
- The language is designed to model general purpose processors.
- Instructions operate on user defined registers and address spaces.
- All data is manipulated explicitly. Instructions have no indirect effects.
- Individual p-code operations mirror typical processor tasks and concepts.

Quoted from `docs/languages/html/sleigh.html`

Processor to p-code modeling:

- RAM → *address space*
- Register → *varnode*
- Instruction → *operation*

```
SCASB.REPNE   RDI
                      $U22d0:1 = INT_EQUAL RCX, 0:8
                      CBRANCH *[ram]0x401548:8, $U22d0
                      RCX = INT_SUB RCX, 1:8
                      $U1d90:8 = COPY RDI
                      $U1da0:8 = INT_ADD RDI, 1:8
                      $U1db0:8 = INT_ZEXT DF
                      $U1dc0:8 = INT_MULT 2:8, $U1db0
                      RDI = INT_SUB $U1da0, $U1dc0
                      $U1de0:1 = LOAD ram($U1d90)
                      CF = INT_LESS AL, $U1de0
                      $U1de0:1 = LOAD ram($U1d90)
                      OF = INT_SBORROW AL, $U1de0
                      $U1de0:1 = LOAD ram($U1d90)
                      $Uac60:1 = INT_SUB AL, $U1de0
                      SF = INT_SLESS $Uac60, 0:1
                      ZF = INT_EQUAL $Uac60, 0:1
                      $U22f0:1 = BOOL_NEGATE ZF
                      CBRANCH *[ram]0x401546:8, $U22f0
NOT           RCX
                      RCX = INT_NEGATE RCX
```

Category	P-Code Operations
Data Moving	COPY, LOAD, STORE
Arithmetic	INT_ADD, INT_SUB, INT_CARRY, INT_SCARRY, INT_SBORROW, INT_2COMP, INT_MULT, INT_DIV, INT_SDIV, INT_REM, INT_SREM
Logical	INT_NEGATE, INT_XOR, INT_AND, INT_OR, INT_LEFT, INT_RIGHT, INT_SRIGHT
Int Comparison	INT_EQUAL, INT_NOTEQUAL, INT_SLESS, INT_SLESSEQUAL, INT_LESS, INT_LESSEQUAL
Boolean	BOOL_NEGATE, BOOL_XOR, BOOL_AND, BOOL_OR
Floating Point	FLOAT_ADD, FLOAT_SUB, FLOAT_MULT, FLOAT_DIV, FLOAT_NEG, FLOAT_ABS, FLOAT_SQRT, FLOAT_NAN
FP Compare	FLOAT_EQUAL, FLOAT_NOTEQUAL, FLOAT_LESS, FLOAT_LESSEQUAL
FP Conversion	INT2FLOAT, FLOAT2FLOAT, TRUNC, CEIL, FLOOR, ROUND
Branching	BRANCH, CBRANCH, BRANCHIND, CALL, CALLIND, RETURN
Extension / Truncation	INT_ZEXT, INT_SEXT, PIECE, SUBPIECE

DEMO: Source-Sink Analysis

- Use Ghidra p-code and the decompiler's analysis to identify the sources for values passed to function calls of interest (`malloc`), particularly function calls accepting user input
- *Solving* for the actual arguments requires a *solver*, this is a much simpler analysis that can empower a human analyst to hone in on interesting calls

- Start at the varnode for each argument to `malloc`, then trace back to the p-code operation that it's derived from
  - From there, recursively trace back the p-code operation(s) defining the varnode(s) that define that the inputs to those operations
- At function call sites, trace in, and find how the returned values are derived
- When a parameter is used, trace back to call sites which set the parameter

SLEIGH

- Ghidra’s language for describing instruction sets to facilitate RE
- **Disassembly:** translate bit-encoded machine instructions into human-readable assembly language statements
- **Semantics:** translate machine instructions into p-code instructions (one-to-many) for decompilation, analysis, and emulation
- Based off of SLED (Specification Language for Encoding and Decoding), a 1997 academic IL

SLEIGH Example - x86 `JMP rel8`

Raw bytes: `0xEB 0x03`

x86 instruction: `JMP $+5`

SLEIGH Example - x86 `JMP rel8`

Raw bytes: `0xEB 0x03`

x86 instruction: `JMP $+5`

```
00401f16 eb 03          JMP          LAB_00401f1b
                                       BRANCH *[ram]0x401f1b:8
```

SLEIGH Example - x86 `JMP rel8`

Raw bytes: `0xEB 0x03`

x86 instruction: `JMP $+5`

SLEIGH:

```
:JMP rel8 is vexMode=0 & byte=0xeb; rel8 {
    goto rel8;
}
```

```
00401f16 eb 03          JMP          LAB_00401f1b
                                          BRANCH *[ram]0x401f1b:8
```

SLEIGH Example - x86 `JMP rel8`

Raw bytes: `0xEB 0x03`

x86 instruction: `JMP $+5`

```
rel8: reloc is simm8 [ reloc=inst_next+simm8; ] {
    export *[ram]:$(SIZE) reloc;
}
```

SLEIGH:

```
:JMP rel8 is vexMode=0 & byte=0xeb; rel8 {
    goto rel8;
}
```

```
00401f16 eb 03          JMP          LAB_00401f1b
                                     BRANCH *[ram]0x401f1b:8
```

SLEIGH Example - x86 `JMP rel8`

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x86 instruction: `JMP $+5`

```
rel8: reloc is simm8 [ reloc=inst_next+simm8; ] {
    export *[ram]:$(SIZE) reloc;
}
```

SLEIGH:

```
:JMP rel8 is vexMode=0 & byte=0xeb; rel8 {
    goto rel8;
}
```

```
00401f16 eb 03          JMP          LAB_00401f1b
                                     BRANCH *[ram]0x401f1b:8
```

SLEIGH Example - x86 `JMP rel8`

Raw bytes: `0xEB 0x03`

x86 instruction: `JMP $+5`

```
rel8: reloc is simm8 [ reloc=inst_next+simm8; ] {
    export *[ram]:$(SIZE) reloc;
}
```

SLEIGH:

```
:JMP rel8 is vexMode=0 & byte=0xeb; rel8 {
    goto rel8;
}
```

```
00401f16 eb 03          JMP          LAB_00401f1b
                                     BRANCH *[ram]0x401f1b:8
```

SLEIGH Example - x86 `XOR AL, imm8`

Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

SLEIGH Example - x86 `XOR AL, imm8`

Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

```
34 57        XOR      AL,0x57
                       CF = COPY 0:1
                       OF = COPY 0:1
                       AL = INT_XOR AL, 0x57:1
                       SF = INT_SLESS AL, 0:1
                       ZF = INT_EQUAL AL, 0:1
```

SLEIGH Example - x86 `XOR AL, imm8`

Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

SLEIGH:

```
:XOR AL,imm8 is vexMode=0 & byte=0x34; AL & imm8 {
    logicalflags();
    AL = AL ^ imm8;
    resultflags( AL );
}
```

```
34 57        XOR      AL,0x57
                        CF = COPY 0:1
                        OF = COPY 0:1
                        AL = INT_XOR AL, 0x57:1
                        SF = INT_SLESS AL, 0:1
                        ZF = INT_EQUAL AL, 0:1
```

SLEIGH Example - x86 `XOR AL, imm8`

Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

```
macro logicalflags() {
 CF = 0;
 OF = 0;
}
```

SLEIGH:

```
:XOR AL,imm8 is vexMode=0 & byte=0x34; AL & imm8 {
    logicalflags();
    AL = AL ^ imm8;
    resultflags( AL );
}
```

```
macro resultflags(result) {
 SF = result s < 0;
 ZF = result == 0;
 # PF, AF not implemented
}
```

```
34 57        XOR        AL,0x57
                        CF = COPY 0:1
                        OF = COPY 0:1
                        AL = INT_XOR AL, 0x57:1
                        SF = INT_SLESS AL, 0:1
                        ZF = INT_EQUAL AL, 0:1
```

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Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

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macro logicalflags() {
 CF = 0;
 OF = 0;
}
```

SLEIGH:

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    logicalflags();
    AL = AL ^ imm8;
    resultflags( AL );
}
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```
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                       CF = COPY 0:1
                       OF = COPY 0:1
                       AL = INT_XOR AL, 0x57:1
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                       ZF = INT_EQUAL AL, 0:1
```

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x86 instruction: `XOR AL, 0x57`

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}
```

SLEIGH:

```
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    logicalflags();
    AL = AL ^ imm8;
    resultflags( AL );
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```

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 macro resultflags(result) {
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                     SF = INT_SLESS AL, 0:1
                     ZF = INT_EQUAL AL, 0:1
```

SLEIGH Example - x86 `XOR AL, imm8`

Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

```
macro logicalflags() {
 CF = 0;
 OF = 0;
}
```

SLEIGH:

```
:XOR AL,imm8 is vexMode=0 & byte=0x34; AL & imm8 {
    logicalflags();
    AL = AL ^ imm8;
    resultflags( AL );
}
```

```
macro resultflags(result) {
 SF = result s < 0;
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}
```

```
34 57        XOR      AL,0x57
                      CF = COPY 0:1
                      OF = COPY 0:1
                      AL = INT_XOR AL, 0x57:1
                      SF = INT_SLESS AL, 0:1
                      ZF = INT_EQUAL AL, 0:1
```

SLEIGH Example - x86 `XOR AL, imm8`

Raw bytes: `0x34 0x57`

x86 instruction: `XOR AL, 0x57`

```
macro logicalflags() {
 CF = 0;
 OF = 0;
}
```

SLEIGH:

```
:XOR AL,imm8 is vexMode=0 & byte=0x34; AL & imm8 {
    logicalflags();
    AL = AL ^ imm8;
    resultflags( AL );
}
```

```
macro resultflags(result) {
 SF = result s < 0;
 ZF = result == 0;
 # PF, AF not implemented
}
```

```
34 57      XOR     AL,0x57
                   CF = COPY 0:1
                   OF = COPY 0:1
                   AL = INT_XOR AL, 0x57:1
                   SF = INT_SLESS AL, 0:1
                   ZF = INT_EQUAL AL, 0:1
```

SLEIGH Example - x86 `RDTSC`

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

SLEIGH Example - x86 RDTSC

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

```
0f 31       RDTSC
                    $U9c60:8 = CALLOTHER "rdtsc"
                    EDX = SUBPIECE $U9c60, 4:4
                    EAX = SUBPIECE $U9c60, 0:4
```

SLEIGH Example - x86 `RDTSC`

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

SLEIGH:

```
:RDTSC is vexMode=0 & byte=0xf; byte=0x31 {
    tmp:8 = rdtsc();
    EDX = tmp(4);
    EAX = tmp(0);
}
```

```
0f 31       RDTSC
                   $U9c60:8 = CALLOTHER "rdtsc"
                   EDX = SUBPIECE $U9c60, 4:4
                   EAX = SUBPIECE $U9c60, 0:4
```

SLEIGH Example - x86 `RDTSC`

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

SLEIGH:

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:RDTSC is vexMode=0 & byte=0xf; byte=0x31 {
    tmp:8 = rdtsc();
    EDX = tmp(4);
    EAX = tmp(0);
}
```

```
define pcodeop rdtsc;
```

```
0f 31      RDTSC
                   $U9c60:8 = CALLOTHER "rdtsc"
                   EDX = SUBPIECE $U9c60, 4:4
                   EAX = SUBPIECE $U9c60, 0:4
```

SLEIGH Example - x86 `RDTSC`

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

SLEIGH:

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:RDTSC is vexMode=0 & byte=0xf; byte=0x31 {
    tmp:8 = rdtsc();
    EDX = tmp(4);
    EAX = tmp(0);
}
```

```
define pcodeop rdtsc;
```

```
0f 31       RDTSC
                    $U9c60:8 = CALLOTHER "rdtsc"
                    EDX = SUBPIECE $U9c60, 4:4
                    EAX = SUBPIECE $U9c60, 0:4
```

SLEIGH Example - x86 RDTSC

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

SLEIGH:

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:RDTSC is vexMode=0 & byte=0xf; byte=0x31 {
    tmp:8 = rdtsc();
    EDX = tmp(4);
    EAX = tmp(0);
}
```

```
define pcodeop rdtsc;
```

```
0f 31       RDTSC
            $U9c60:8 = CALLOTHER "rdtsc"
            EDX = SUBPIECE $U9c60, 4:4
            EAX = SUBPIECE $U9c60, 0:4
```

SLEIGH Example - x86 RDTSC

Raw bytes: `0x0F 0x31`

x86 instruction: `RDTSC`

SLEIGH:

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:RDTSC is vexMode=0 & byte=0xf; byte=0x31 {
    tmp:8 = rdtsc();
    EDX = tmp(4);
    EAX = tmp(0);
}
```

```
define pcodeop rdtsc;
```

```
0f 31       RDTSC
                    $U9c60:8 = CALLOTHER "rdtsc"
                    EDX = SUBPIECE $U9c60, 4:4
                    EAX = SUBPIECE $U9c60, 0:4
```

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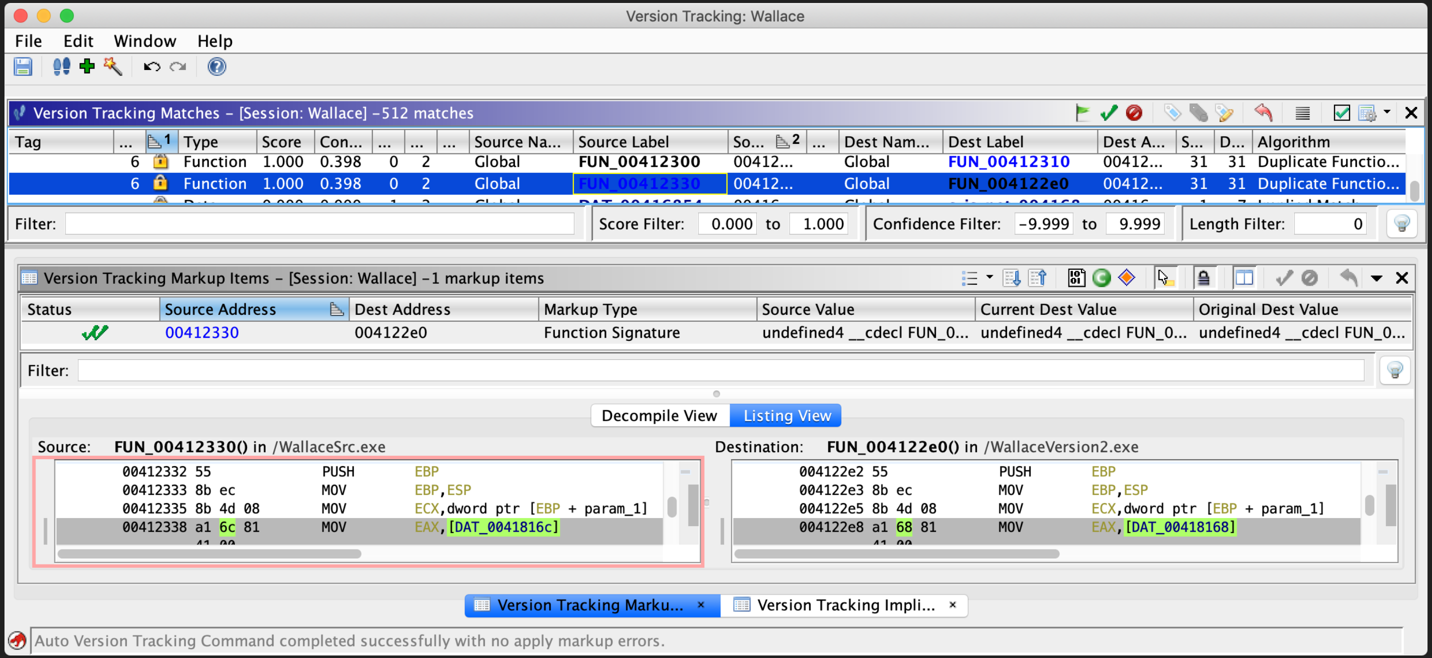
Other Major Features

- Multi-user collaboration
- Version tracking
- Extensibility for new binary loaders and architectures
- Headless mode
- GhidraDev Eclipse plugin
- Debugger promised at RSA
- Undocumented p-code emulator



IDA vs Binary Ninja vs Ghidra

IDA

- Maturity
- Windows support
- Decompiler
- Existing corpus of powerful plugins
- Debugger
- Support for paid customers
- Well tested
- Industry standard

Binary Ninja

- Innovation and modern design
- Program analysis features (SSA)
- Multi-level IL
- Rich API
- Embeddable
- Python-native scripting
- Clean modern UI
- Community

Ghidra

- Maturity
- Embedded support
- Decompiler
- Massive API
- Documentation
- Breath of features
- Collaboration
- Version tracking
- Price and open source extensibility

Decompiler - IDA Hex-Rays vs Ghidra

IDA Hex-Rays

- Optional add-on for IDA for IDA
- Microcode-based
- Supports limited architectures
- Better built-in support for Windows
- Variables, data, and functions can be xrefed from decompiler
- Variables can be mapped
- Variable representation can be changed in the decompiler (decimal, hex, char immediate, etc)
- Click to highlight

Ghidra Decompiler Decompiler

- Deeply integrated with Ghidra
- P-code based
- Supports all architectures
- No way to xref from decompiler
- Produces fewer `goto` statements and seemingly more idiomatic C
- Built in program analysis features, e.g., slicing and data flow
- Variables cannot be mapped
- Variable representation cannot be changed in the decompiler
- *Middle click* to highlight

ILs - Binary Ninja vs Ghidra

Binary Ninja

- Multi-level: LLIL, MLIL, forthcoming HLIL
- Machine consumable and human readable
- SSA form
- Designed in light of years of program analysis research
- Feels nicer to work with
- Deferred flag calculations

Ghidra

- Single level p-code, but can be enhanced by decompiler analysis
- Designed for machine consumption first, not human readability
- Uses SSA during decompilation, but raw p-code is not SSA
- Design origins based off of program analysis research from 20+ years ago

ILs - Binary Ninja vs Ghidra

```
phase_4:
rsp = rsp - 0x18
rcx = rsp + 0xc {var_c}
rdx = rsp + 8 {var_10}
esi = 0x4025cf  {"%d %d"}
eax = 0
call(__isoc99_sscanf)
if (eax != 2) then 7 @ 0x401035 else 9 @ 0x401033
```

LLIL

```
phase_4:
int32_t* rcx = &var_c
int32_t* rdx = &var_10
rax = __isoc99_sscanf(arg1, 0x4025cf, rdx, rcx)  {"%d %d"}
if (rax.eax != 2) then 4 @ 0x401035 else 6 @ 0x401033
```

MLIL

```
0040100c - phase_4
undefined phase_4()
        undefined         AL:1             <RETURN>
        undefined4        Stack[-0xc]:4    local_c
        undefined4        Stack[-0x10]:4   local_10
        CF = INT_LESS RSP, 24:8
        OF = INT_SBORROW RSP, 24:8
        RSP = INT_SUB RSP, 24:8
        SF = INT_SLESS RSP, 0:8
        ZF = INT_EQUAL RSP, 0:8
        $U770:8 = INT_ADD 12:8, RSP
        RCX = COPY $U770
        $U770:8 = INT_ADD 8:8, RSP
        RDX = COPY $U770
        RSI = COPY 0x4025cf:8
        RAX = COPY 0:8
        RSP = INT_SUB RSP, 8:8
        STORE ram(RSP), 0x401029:8
        CALL *[ram]0x400bf0:8
        CF = INT_LESS EAX, 2:4
        OF = INT_SBORROW EAX, 2:4
        $U58c0:4 = INT_SUB EAX, 2:4
        SF = INT_SLESS $U58c0, 0:4
        ZF = INT_EQUAL $U58c0, 0:4
        $U2080:1 = BOOL_NEGATE ZF
        CBRANCH *[ram]0x401035:8, $U2080
```

We Like Ghidra For...

- Scripting reverse engineering
- Firmware / embedded systems analysis
- Analysis of software that Hex-Rays can’t decompile
- Collaborative long-term professional RE
- Professional reversing at a computer workstation with multiple monitors, full keyboard with function keys, mouse with middle click and scroll wheel, etc...

Scripting - Java vs Python

- Java will catch errors at compile time, Ghidra’s API is highly object-oriented and benefits from this

- Complex Python scripts feel like binding together Java API calls with Python control flow and syntax

- **Recommended workflow:** prototype and experiment with APIs / objects in the Python interpreter, write final code in Java

For Reverse Engineers, By Reverse Engineers

- Built for multi-monitor use
- “Moving ants” highlight on control flow graphs
- Configurable “tool” views
- Hotkeys mappable to actions and scripts
- Right click > “extract and import”
- Processor manual integration
- Undo button
- Import directly from zip file
- Snapshot views
- Configurable listings
- Version tracker
- Project-based multi-binary RE
- `F1` to open help on whatever the mouse is pointing at
- File System browser
- Highly configurable assembly code listing
- Data flow analysis built into UI
- Embedded image detection
- Search for matching instructions
- Unique windows
    - Checksum Generator
    - Disassembled View
    - Data Type Preview
    - Function Tags
    - Symbol tree

Contributing to Ghidra

- Ghidra code is available on Github
    - Apache License 2.0
- NSA has been responsive to community questions and bug reports posted on Github
    - The agency has already published two minor-version updates

Official site: ghidra-sre.org
Open source: github.com/NationalSecurityAgency/ghidra
github.com/NationalSecurityAgency/ghidra-data

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Conclusion

@0xAlexei / @0xJeremy

Ghidra is a powerful binary reverse engineering tool built by the US National Security Agency

- For reverse engineers, by reverse engineers
- Interactive and headless scripting
- Built for program analysis
- We have yet to see what the community will do with Ghidra, this is just the beginning

Acknowledgements:

- NSA's Ghidra team
- Rob Joyce
- Rolf Rolles
- Evan Jensen
- Sophia d'Antoine
- Dave Aitel and the INFILTRATE team

Demo material: github.com/0xAlexei/INFILTRATE2019

IDA keybindings: github.com/JeremyBlackthorne/Ghidra-Keybindings

Official NSA sites:

github.com/NationalSecurityAgency/ghidra

ghidra-sre.org

Ghidra training: ringzer0.training

Appendix

Architecture Support

- Supports a variety of common desktop, embedded, and VM architectures
- Can handle unique compiler idioms and CPU modes
- Users can extend Ghidra with their own custom processor modules
- Ghidra can *decompile* anything it can disassemble

Language

Select Language and Compiler Specification

Proc...	Variant	Size	Endian	Compiler
x86	Real Mode	16	little	default
x86	System Management Mode	32	little	default
x86	default	32	little	Borland C++
x86	default	32	little	Delphi
x86	default	32	little	gcc
x86	default	32	little	Visual Studio
x86	default	64	little	gcc
x86	default	64	little	Visual Studio

Filter: x86

Description

☑ Show Only Recommended Language/Compiler Specs

Please select a language.

OK Cancel

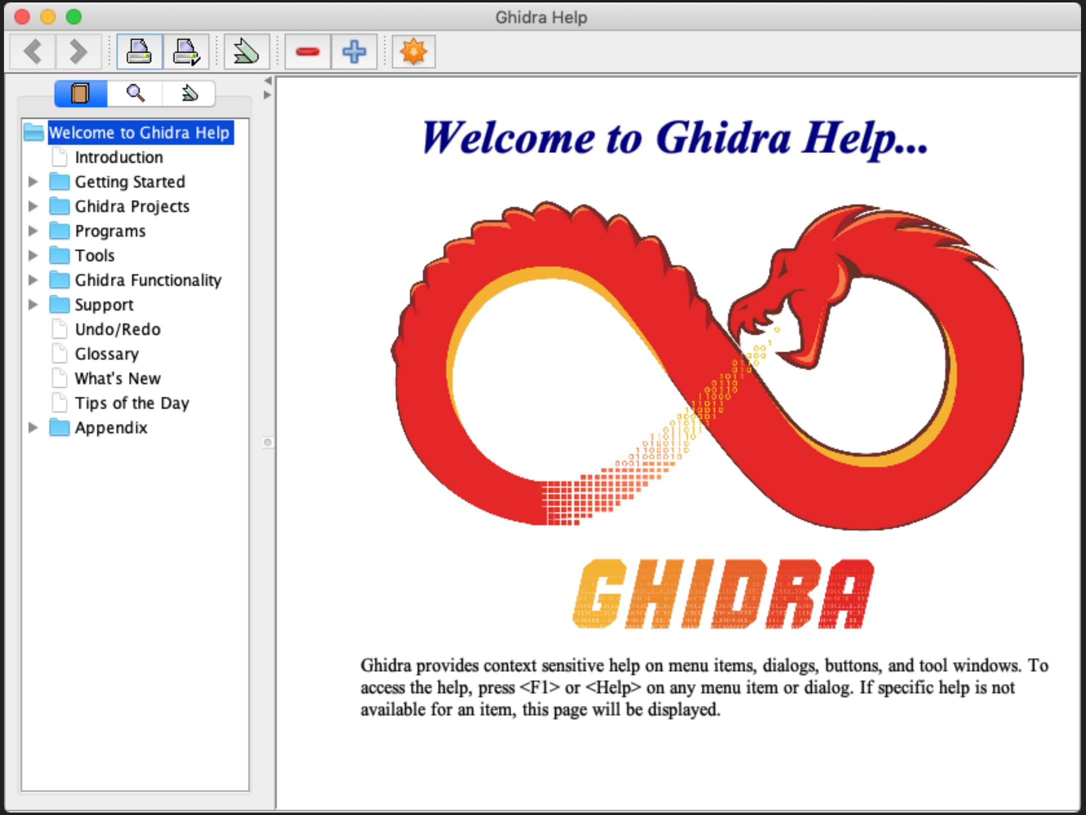
Installed Processor Modules

Processor
6502
68000
6805
80251
80390
8051
8085
AARCH64
ARM
AVR32
AVR8
CR16C
Dalvik
DATA
dsPIC30F
dsPIC33E
dsPIC33F
JVM
MIPS
PA-RISC
PIC-12
PIC-16
PIC-17
PIC-18
PIC-24
PowerPC
Sparc
TI_MSP430
TI_MSP430X
Toy
x86
Z180
Z80

Close

Documentation

- Help > Contents
- `F1` or `Help` key while pointing at any field or menu option
- `docs` directory
  - JavaDoc
  - Several classes
  - P-code and SLEIGH
- Doxygen in source files



Python Interpreter Window

- Unlike Java, which must be compiled in order to run, Python can be run inside Ghidra in an interactive REPL shell

- The shell can be helpful for exploring unfamiliar objects - Ghidra has great Python object `__str__` implementations

Python – Interpreter

```
>>> memcpy = getFunctionAt(currentAddress)
>>> refs = getReferencesTo(memcpy.getEntryPoint())
>>> refs
array(ghidra.program.model.symbol.Reference, [From: 004006ac To: 00400510 Type: UNCONDITIONAL_CALL Op: 0
DEFAULT, From: 004006d5 To: 00400510 Type: UNCONDITIONAL_CALL Op: 0 DEFAULT])

>>>
```

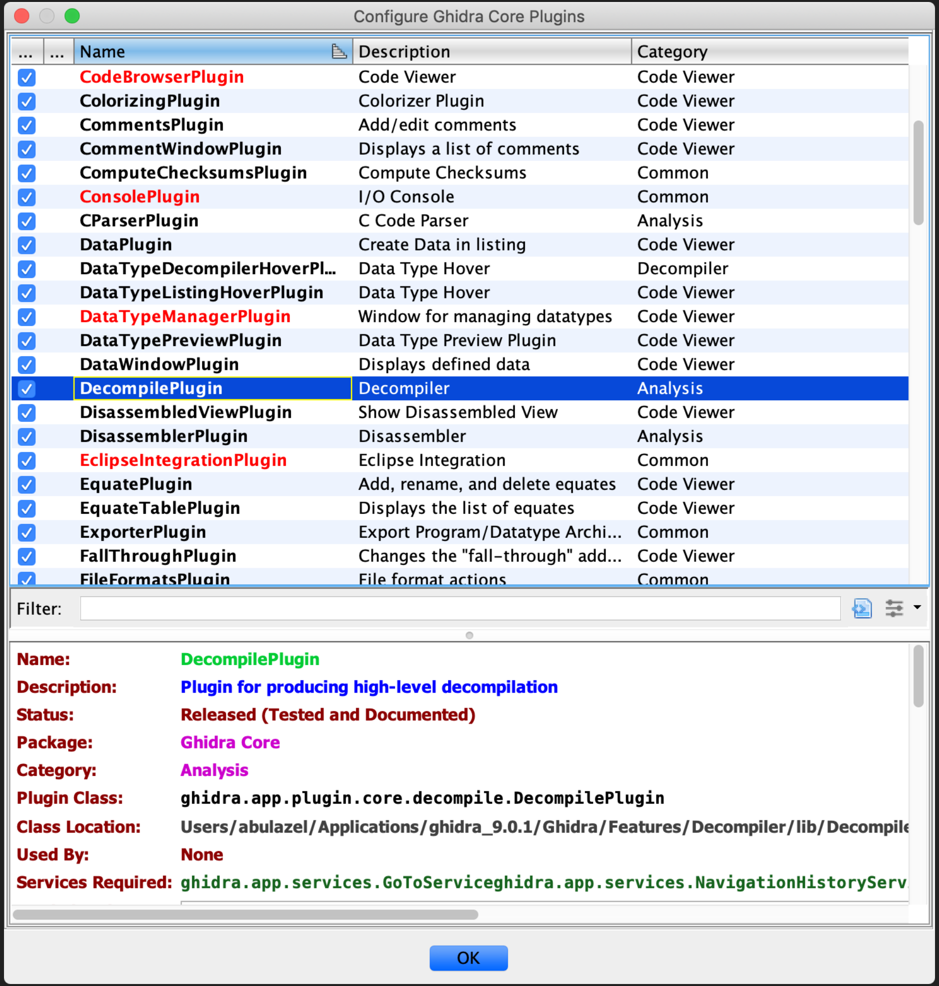
Script vs. Plugin vs. Extension

- **Scripts:** do a single thing with defined start and end point
- **Plugins:** base components for everything you interact with in Ghidra, such as UI panes
- **Extensions:** sets of plugins for extended functionality, e.g., custom binary format loaders, interfaces to external tools, libraries for use by other scripts
  - **Example:** Rolf Rolles' GhidraPAL
    `github.com/RolfRolles/GhidraPAL/releases`

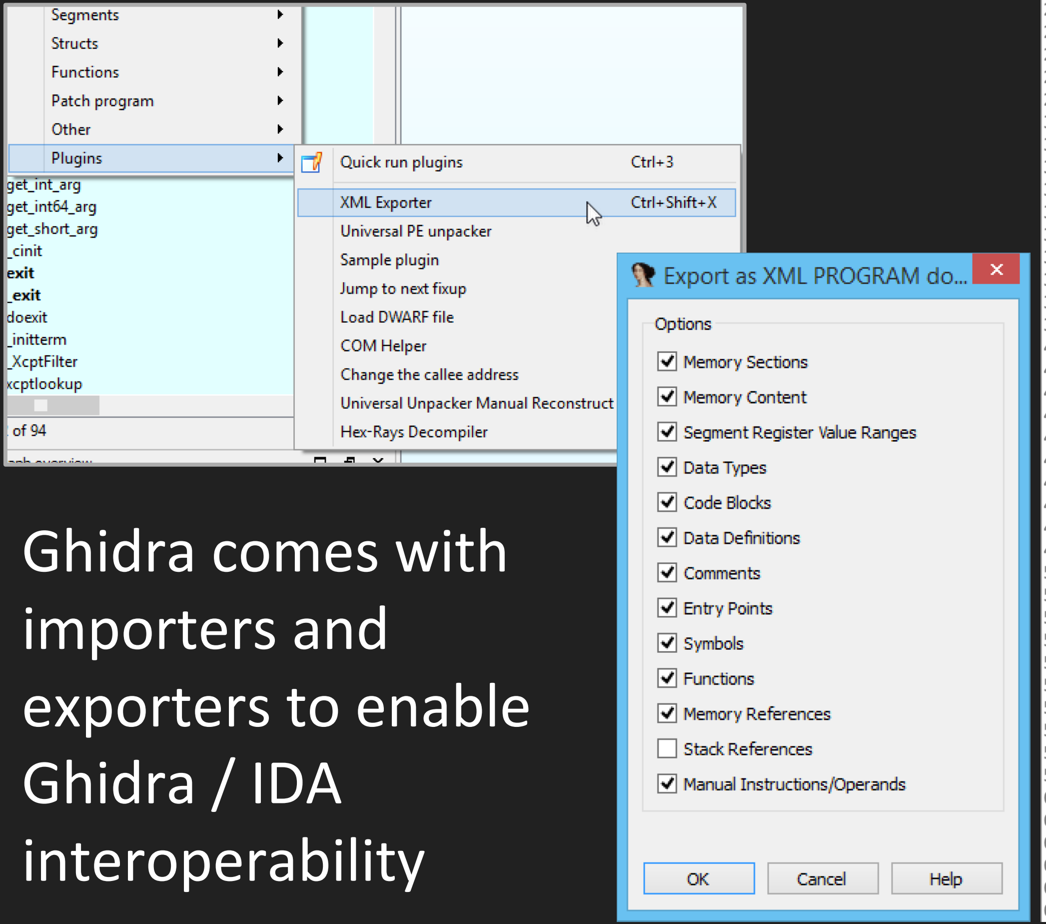
https://github.com/NationalSecurityAgency/ghidra/issues/243#issuecomment-475640292

Tools

- Ghidra tools are assemblies of plugins
- Ghidra comes with two tools: CodeBrowser and VersionTracker
- Tools can be configured and customized to suit unique RE needs - though currently there doesn’t seem to be much point



IDA Interoperability



Ghidra comes with importers and exporters to enable Ghidra / IDA interoperability

Decompiler Windows Structs - Hex-Rays vs Ghidra

```c
v12 = GetSystemMetrics(0);
cy = GetSystemMetrics(1);
hWnd = GetDesktopWindow();
hDC = GetDC(hWnd);
hdc = CreateCompatibleDC(hDC);
h = CreateCompatibleBitmap(hDC, v12, cy);
SelectObject(hdc, h);
BitBlt(hdc, 0, 0, v12, cy, hDC, 0, 0, 0xCC0020u);
GetObjectA(h, 24, &pv);
bmi.bmiHeader.biSize = 40;
bmi.bmiHeader.biWidth = v6;
bmi.bmiHeader.biHeight = cLines;
bmi.bmiHeader.biPlanes = 1;
bmi.bmiHeader.biBitCount = 32;
bmi.bmiHeader.biCompression = 0;
bmi.bmiHeader.biSizeImage = 0;
bmi.bmiHeader.biXPelsPerMeter = 0;
bmi.bmiHeader.biYPelsPerMeter = 0;
bmi.bmiHeader.biClrUsed = 0;
bmi.bmiHeader.biClrImportant = 0;
dwBytes = cLines * 4 * ((32 * v6 + 31) / 32);
hMem = GlobalAlloc(0x42u, cLines * 4 * ((32 * v6 + 31) / 32));
bmi.bmiColors[0] = (RGBQUAD)GlobalLock(hMem);
GetDIBits(hDC, (HBITMAP)h, 0, cLines, (LPVOID)bmi.bmiColors[0], &bmi, 0);
v16 = 54;
v15 = dwBytes + 54;
v14 = 19778;
v8 = GlobalAlloc(0x42u, dwBytes + 54);
v9 = GlobalLock(v8);
memcpy(v9, &v14, 0xEu);
memcpy((char *)v9 + 14, &bmi, 0x28u);
memcpy((char *)v9 + 54, (const void *)bmi.bmiColors[0], dwBytes);
GlobalUnlock(hMem);
GlobalFree(hMem);
ReleaseDC(hWnd, hDC);
DeleteDC(hdc);
DeleteObject(h);
result = v9;
*a1 = v9;
*a2 = dwBytes + 54;
return result;
```

```c
local_50 = (HDC)0x0;
local_20 = GetSystemMetrics(0);
local_8 = GetSystemMetrics(1);
DAT_004078cc = GetDesktopWindow();
DAT_004078c8 = GetDC(DAT_004078cc);
local_50 = CreateCompatibleDC(DAT_004078c8);
local_1c = CreateCompatibleBitmap(DAT_004078c8,local_20,local_8);
SelectObject(local_50,local_1c);
BitBlt(local_50,0,0,local_20,local_8,DAT_004078c8,0,0,0xcc0020);
GetObjectA(local_1c,0x18,local_70);
local_4c = 0x28;
local_48 = local_6c;
local_44 = local_68;
local_40 = 1;
local_3e = 0x20;
uStack60 = 0;
uStack58 = 0;
local_38 = 0;
local_34 = 0;
local_30 = 0;
local_2c = 0;
local_28 = 0;
iVar1 = local_6c * 0x20 + 0x1f;
dwBytes = ((int)(iVar1 + (iVar1 >> 0x1f & 0x1fU)) >> 5) * 4 * local_68;
hMem = GlobalAlloc(0x42,dwBytes);
local_24 = (undefined4 *)GlobalLock(hMem);
GetDIBits(DAT_004078c8,local_1c,0,local_68,local_24,(LPBITMAPINFO)&local_4c,0);
dwBytes_00 = dwBytes + 0x36;
local_e = 0x36;
local_18 = 0x4d42;
local_16 = dwBytes_00;
local_58 = GlobalAlloc(0x42,dwBytes_00);
local_54 = (undefined4 *)GlobalLock(local_58);
FUN_00401930(local_54,(undefined4 *)&local_18,0xe);
FUN_00401930((undefined4 *)((int)local_54 + 0xe),(undefined4 *)&local_4c,0x28);
FUN_00401930((undefined4 *)((int)local_54 + 0x36),local_24,dwBytes);
GlobalUnlock(hMem);
GlobalFree(hMem);
ReleaseDC(DAT_004078cc,DAT_004078c8);
DeleteDC(local_50);
DeleteObject(local_1c);
*(undefined4 **)param_1 = local_54;
*param_2 = dwBytes_00;
return;
```

P-Code Decompilation / Analysis

- “Raw p-code” = direct translation of one CPU instructions to p-code ops
- During decompilation, p-code is analyzed, and may be modified
  - Insertion of `MULTIEQUAL` instructions (SSA phi-nodes)
  - Association of parameters with `CALL` ops and return values with `RETURN` ops
  - Construction of abstract syntax tree
  - etc… - see linked documents
- The Decompiler is a C++ binary that runs on the host system

- When writing scripts interacting with p-code expect to experiment, read source code, and glean usage from example included scripts

`docs/languages/html/additionalpcode.html`
`Ghidra/Features/Decompiler/src/decompile/cpp/docmain.hh`

Links

Recommended Readings

Elias Bachaalany's quick overview: `0xeb.net/2019/03/ghidra-a-quick-overview`

Danny Quist on getting started with Ghidra: `github.com/dannyquist/re/blob/master/ghidra/ghidra-getting-started.md`

Rolf Rolles' GhidraPAL program analysis library:
`github.com/RolfRolles/GhidraPAL`
`msreverseengineering.com/blog/2019/4/17/an-abstract-interpretation-based-deobfuscation-plugin-for-ghidra`

Travis Goodspeed on reversing MD380 firmware with Ghidra: `github.com/travisgoodspeed/md380tools/wiki/GHIDRA`

Additional Recommended Readings

Links to many loaders and processor modules:
groups.google.com/forum/?utm_medium=email&utm_source=footer#!msg/sleigh/pD12wcoKUQM/rG8esJAVBAAJ

Writing a WASM Loader: habr.com/en/post/443318/

Sega Genesis loader: zznop.github.io/romhacking/2019/03/14/sega-genesis-rom-hacking-with-ghidra.html

Because Security's first impressions, with many Ghidra video links:
blog.because-security.com/t/ghidra-wiki/431#Firstimpress283

Elias Bachaalany's "Daenerys" IDA Pro / Ghidra interoperability framework:
0xeb.net/2019/03/daenerys-ida-pro-and-ghidra-interoperability-framework

Academic Work Related to SLEIGH / P-code

Norman Ramsey and Mary F. Fernández. 1997. Specifying representations of machine instructions. ACM Transactions on Programming Languages and Systems (TOPLAS) Vol. 19, Issue 3 (1997)
`citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.51.360&rep=rep1&type=pdf`

Cristina Cifuentes and Mike Van Emmerik. "UQBT: Adaptable binary translation at low cost." Computer 33.3 (2000)
`personales.ac.upc.edu/vmoya/docs/00825697.pdf`

The New Jersey Machine-Code Toolkit (1990s)
`www.cs.tufts.edu/~nr/toolkit/`

See `docs/languages/html/sleigh.html`