Introduction to Software Reverse Engineering with Ghidra Session 2: C to ASM

Hackaday U

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#Outline: C to ASM

- Class Admin
- Ghidra Exercise Tips
- Control Flow Review
- Function Calls
- Loops and Iterators
- Switch Statements
- Local and Global Variables
- Array Accesses and Manipulation

#Session Goals

- Learn how to identify basic C constructs in assembly language
- Review C constructs and their assembly representation
  - Heap memory
  - Function calls
  - Switch cases
  - Loops / iterations
  - Local and global variables
- How to view / modify these constructs with Ghidra

#Course Administration

- Office hours will be Thursday at 6:00 ET
- Questions for office hours can be submitted via zoom
- Questions can also be submitted through:
  - Hackaday.io chat room
  - Hackaday messaging

#Program Startup

- You may have noticed in our exercises, that there is additional code outside of our main functions!
  - These additional blocks of code are used to properly launch the binary
- Program startup and behavior is defined by the System V ABI
- Within the ELF header, there is an e_entry field, this field points to the _start() function
  - This is what eventually calls main!

#Program Startup

- All of the exercises in this course conform to the System V ABI
  - This determines how a program starts and is loaded!
  - Determines how information in the ELF header is parsed

- We can use the information from this ABI to help us when reverse engineering
  - `main()` is our entry point
  - The arguments to main are determined by the ABI!

#Ghidra Tip: Function Signatures

- Function signatures can be edited in Ghidra, altering:
  - Argument count
  - Argument types
  - Return values
- Fixing the function signature can greatly improve decompiler output
- Right click the function name -> Edit Function Signature

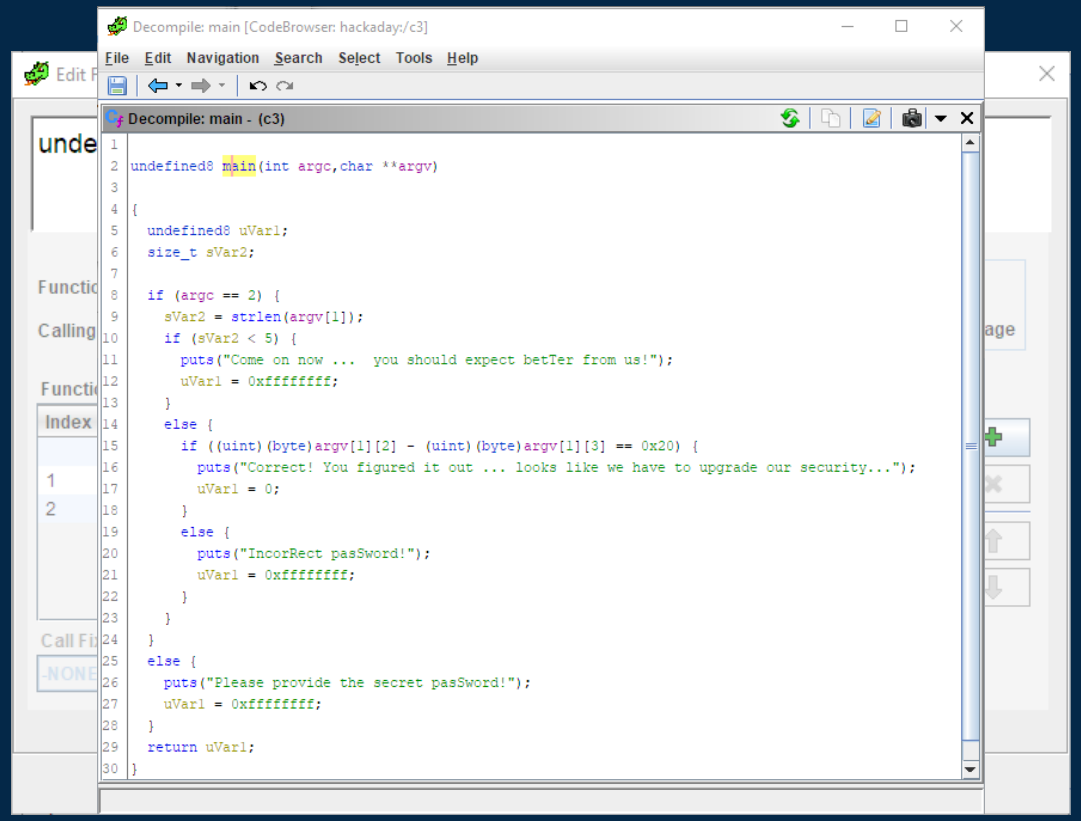
#Exercise Tip: argc/argv

- The C standard defines the arguments passed to a main function
  - `int argc` = Argument Count
  - `char **argv` = Argument vector

- We can apply these types to our function prototype in Ghidra
  - This makes the function more read-able

- The changes will also propagate to the assembly listing

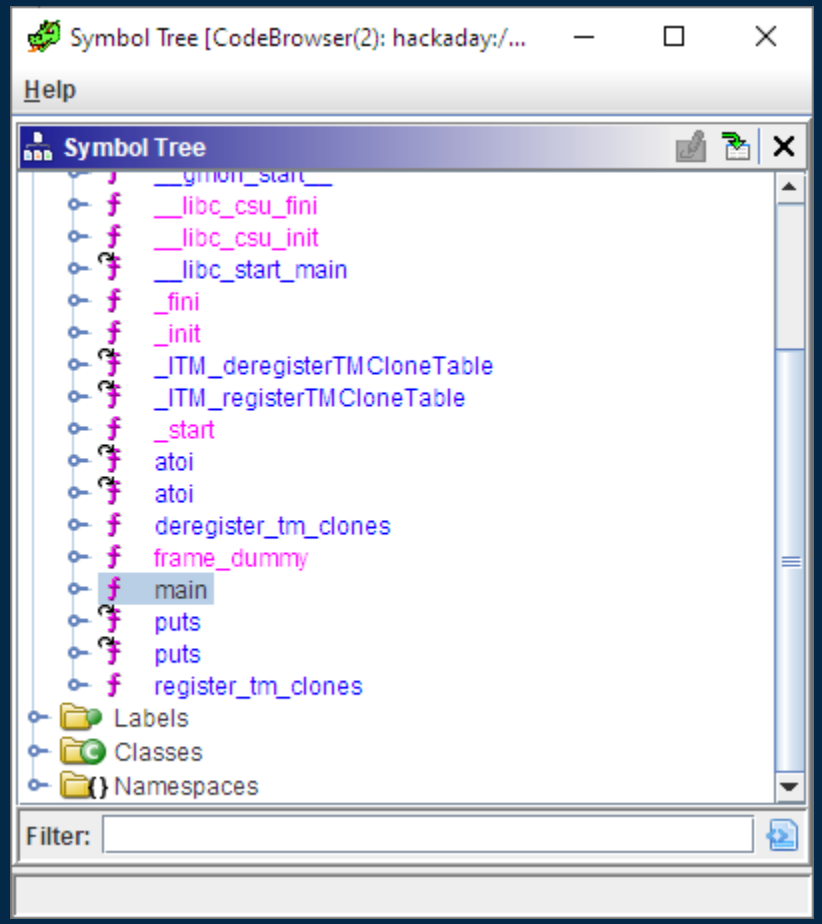
#Ghidra Tip: Function Signatures



#Ghidra Tip: Imports / Exports

- Imports and exports can be viewed from the Symbol tree
  - Imports: libraries that are utilized by your target binary
  - Exports: Exposed information about our binary for the operating system loader
- When importing a binary, users can also specify a path for libraries that are imported
- For our challenges, “main” is always a good starting point!
  - Defined by the ABI!
  - If you can’t find main, start with _start!

#Ghidra Tip: Imports / Exports



#Control Flow

- Control flow is the order in which instructions are executed
- Common statements used to manipulate control flow include:
  - if /else
  - goto
  - switch
  - while
- These statements can be reconstructed by analyzing the resulting assembly code

#Control Flow

- RIP contains the address of the next instruction to execute
- The JMP instruction (and others) can alter RIP
  - JMP ADDR
- JMP can also selectively execute based on the RFLAGS register
  - `JE:` Jump if equal/zero
  - `JNE:` Jump if not equal/nonzero
  - `JG:` Jump if greater (signed)
  - `JL:` Jump if less (signed)

#Control Flow: Example

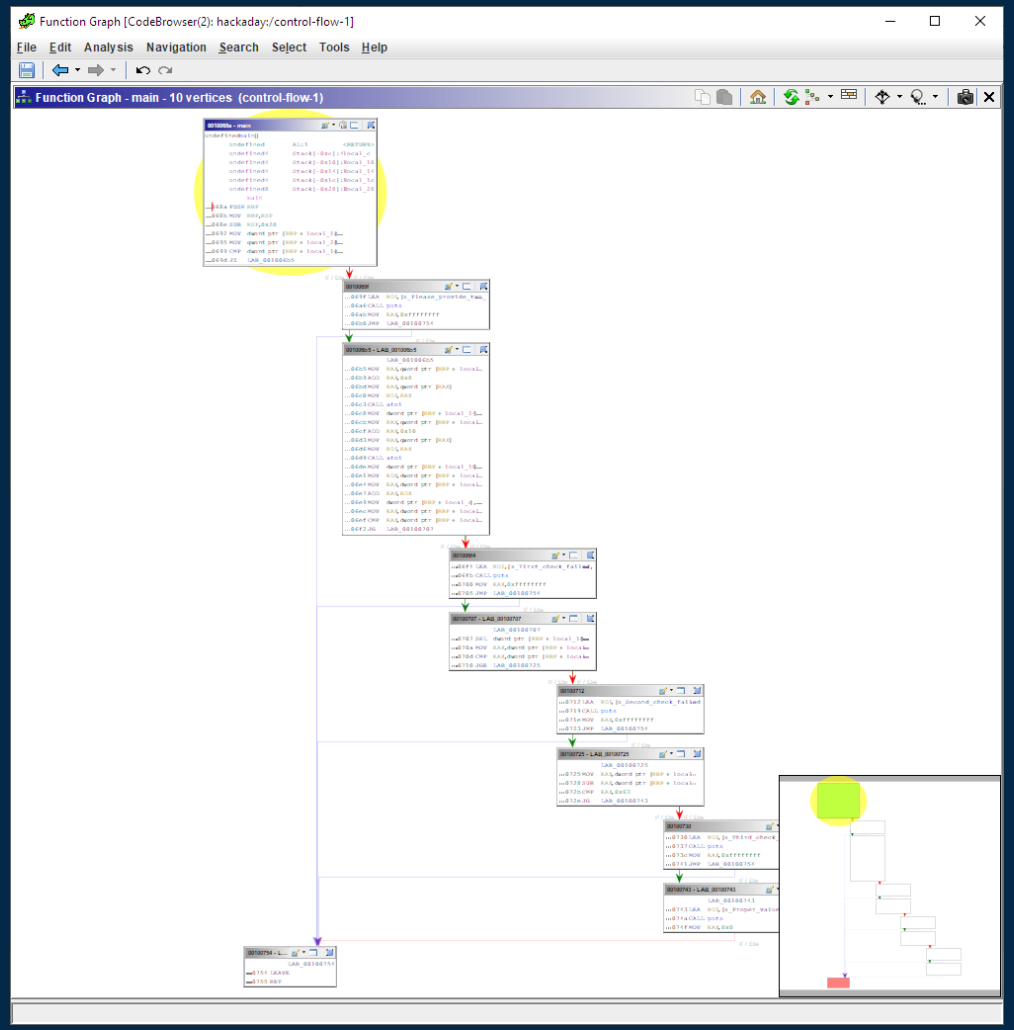
```
000000000040057d <main>:
  40057d:       55                      push   rbp
  40057e:       48 89 e5                mov    rbp,rsp
  400581:       48 83 ec 20             sub    rsp,0x20
  400585:       89 7d ec                mov    DWORD PTR [rbp-0x14],edi
  400588:       48 89 75 e0             mov    QWORD PTR [rbp-0x20],rsi
  40058c:       48 8b 45 e0             mov    rax,QWORD PTR [rbp-0x20]
  400590:       48 83 c0 08             add    rax,0x8
  400594:       48 8b 00                mov    rax,QWORD PTR [rax]
  400597:       ba 0a 00 00 00          mov    edx,0xa
  40059c:       be 00 00 00 00          mov    esi,0x0
  4005a1:       48 89 c7                mov    rdi,rax
  4005a4:       b8 00 00 00 00          mov    eax,0x0
  4005a9:       e8 d2 fe ff ff          call   400480 <strtol@plt>
  4005ae:       48 98                   cdqe
  4005b0:       48 89 45 f8             mov    QWORD PTR [rbp-0x8],rax
  4005b4:       48 83 7d f8 64          cmp    QWORD PTR [rbp-0x8],0x64
  4005b9:       7e 0c                   jle    4005c7 <main+0x4a>
  4005bb:       bf 64 06 40 00          mov    edi,0x400664
  4005c0:       e8 8b fe ff ff          call   400450 <puts@plt>
  4005c5:       eb 0a                   jmp    4005d1 <main+0x54>
  4005c7:       bf 76 06 40 00          mov    edi,0x400676
  4005cc:       e8 7f fe ff ff          call   400450 <puts@plt>
  4005d1:       b8 00 00 00 00          mov    eax,0x0
  4005d6:       c9                      leave
  4005d7:       c3                      ret
  4005d8:       0f 1f 84 00 00 00 00    nop    DWORD PTR [rax+rax*1+0x0]
  4005df:       00
```

If it was less than 100 we jump to 0x4005C7, otherwise we continue to 0x4005BB

#Ghidra Tip: Graph View

- When looking at multiple branches, graph view can be helpful
  - Displays multiple blocks of code representing each branch
- Graph view can be useful when determining control flow
- This can be entered through the following:
  - Highlight a function name
  - Window -> Function Graph

#Ghidra Tip: Graph View



#Control Flow: Exercise 1

- Load the exercise session-two/exercises/control-flow-1
- How many compare statements are in main?
- What are the three values that are being compared?
- Can you pass all three checks?

#Switch Cases

- Switch cases allow a variable to be compared against a list of values
  - Each value being compared against is a case
- Switch statements can contain any number of cases
- The expression for the case must have the same data type as the variable in the switch
- The switch statement terminates on a break statement

#Switch Cases: C to ASM

- C Code

```
int a = atoi(argv[1]);
switch((char)a){
   case 'a':
      a = 1;
      break;
   case 'b':
      a = 2;
      break;
default:
      a = 3;
      break;
}
return 0;
```

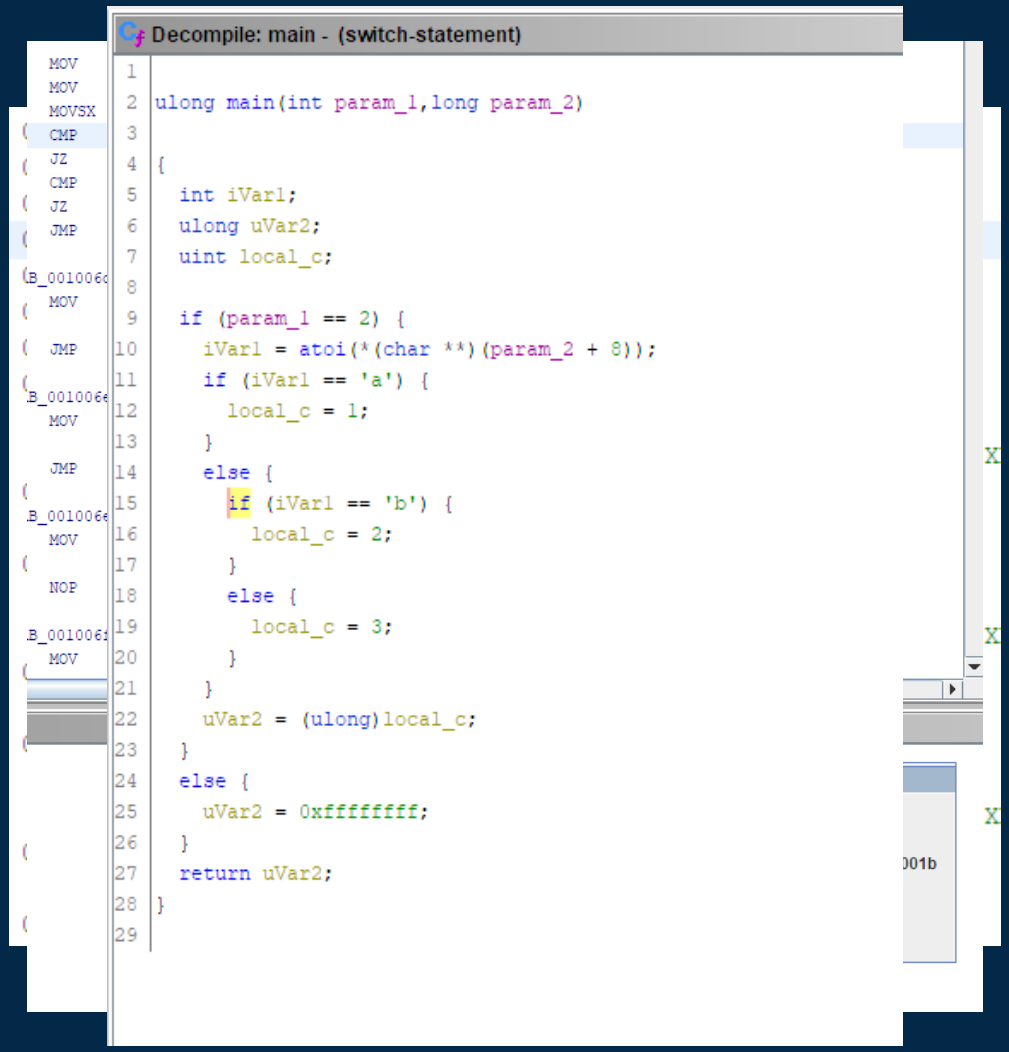
- Assembly Code

```
6c0: call  560 <atoi@plt>
6c5: mov   DWORD PTR [rbp-0x4],eax
6c8: mov   eax,DWORD PTR [rbp-0x4]
6cb: movsx eax,al
6ce: cmp   eax,0x61
6d1: je    6da <main+0x50>
6d3: cmp   eax,0x62
6d6: je    6e3 <main+0x59>
6d8: jmp   6ec <main+0x62>
6da: mov   DWORD PTR [rbp-0x4],0x1
6e1: jmp   6f4 <main+0x6a>
6e3: mov   DWORD PTR [rbp-0x4],0x2
6ea: jmp   6f4 <main+0x6a>
6ec: mov   DWORD PTR [rbp-0x4],0x3
```

#Ghidra Tip: Converting Data

- In the listing view, data types can be converted
  - Hexadecimal, decimal, char, etc
- Right click an immediate value and select: “Convert”
  - Multiple representations can be applied
- This can be used to make the decompiler output more readable

#Ghidra Tip: Converting Data



#Loops

- Loops allow repeated execution of a block of code
  - One of the most common programming structures
  - Statements in the loop are executed sequentially
- Loops can be implemented in assembly in multiple ways
  - CMP -> JMP
  - LOOP
  - REP
- Loop typically operate under a conditional code
  - This code is used to determine whether the loop should execute

#Loops: C to ASM – for

- C Code

```
int count = atoi(argv[1]);
int sum =0;
int x = 0;
for(x = 0;x<count;x++){
    sum += x;
}
```

- Assembly Code

```
6ac: call 560 <atoi@plt>
6b1: mov  DWORD PTR [rbp-0x4],eax
6b4: mov  DWORD PTR [rbp-0xc],0x0
6bb: mov  DWORD PTR [rbp-0x8],0x0
6c2: mov  DWORD PTR [rbp-0x8],0x0
6c9: jmp  6d5 <main+0x4b>
6cb: mov  eax,DWORD PTR [rbp-0x8]
6ce: add  DWORD PTR [rbp-0xc],eax
6d1: add  DWORD PTR [rbp-0x8],0x1
6d5: mov  eax,DWORD PTR [rbp-0x8]
6d8: cmp  eax,DWORD PTR [rbp-0x4]
6db: jl   6cb <main+0x41>
```

#Loops: C to ASM – while

- C Code

```
int count = atoi(argv[1]);
int sum =0;
int x = 0;
while(x<count){
   sum += x;
   x += 1;
}
```

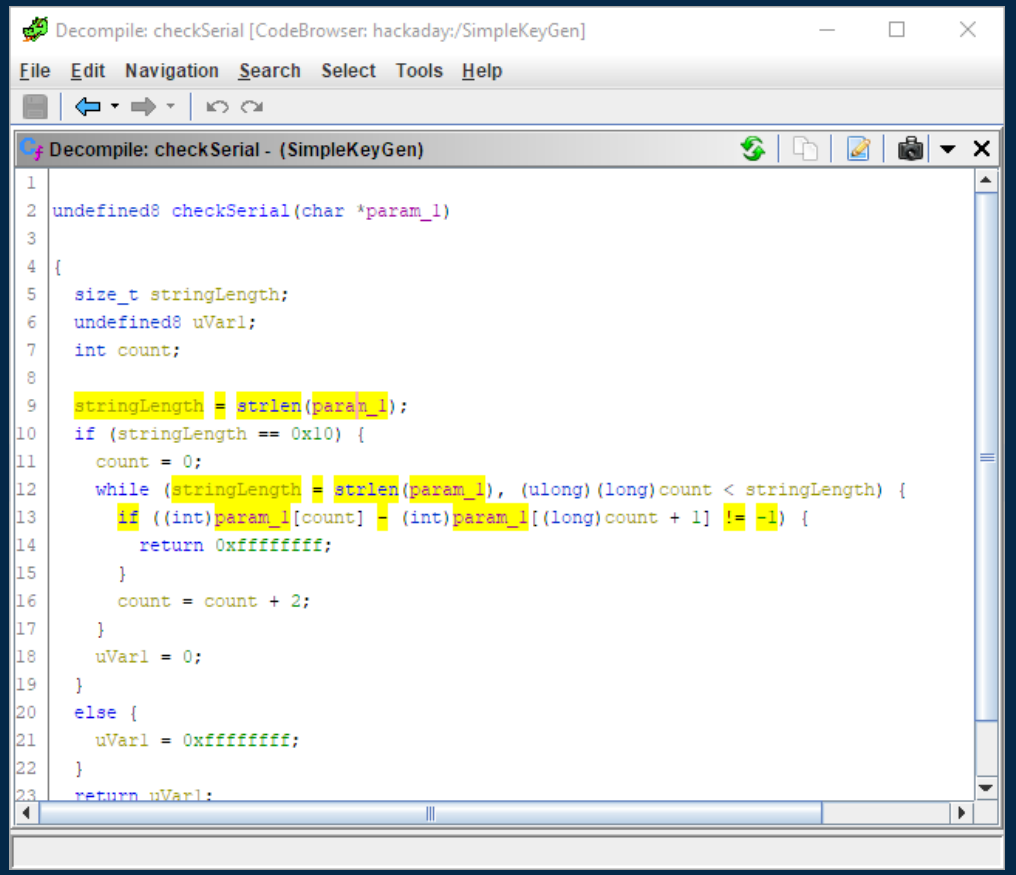
- Assembly Code

```
6ac: call 560 <atoi@plt>
6b1: mov  DWORD PTR [rbp-0x4],eax
6b4: mov  DWORD PTR [rbp-0xc],0x0
6bb: mov  DWORD PTR [rbp-0x8],0x0
6c2: jmp  6ce <main+0x44>
6c4: mov  eax,DWORD PTR [rbp-0x8]
6c7: add  DWORD PTR [rbp-0xc],eax
6ca: add  DWORD PTR [rbp-0x8],0x1
6ce: mov  eax,DWORD PTR [rbp-0x8]
6d1: cmp  eax,DWORD PTR [rbp-0x4]
6d4: jl   6c4 <main+0x3a>
```

#Ghidra Tip: Highlighting / Slicing

- When viewing the assembly listing or decompiler view, items can be highlighted
  - Useful for tracking register usage in larger functions
- Slicing can be applied in the decompiler window
  - This will display usage of the selected variable
- Ghidra will attempt to synchronize highlights between disassembly / decompiler views

#Ghidra Tip: Highlighting / Slicing



Forward Inst Slice highlights usages moving forward in the function

#Loops and Iterations: Exercise

- Load the exercise session-two/exercises/loop-example-1
- How many times does this loop run?
- What is this loop looking for?
  - Do the values used represent anything?
- Can you get access?

#Variables

- When a variable is declared, it is declared within a particular scope
  - The scope defines how accessible a variable is
  - We will define two types of scope for this course: Local and Global
- Local Variables
  - Defined within a function
  - Only accessible within the function
- Global Variables
  - Declared outside of a function
  - Can be used in all functions

#Variables: C to ASM

- C Code

```
int globalVar = 0x15;

int main(int argc, char *argv[]){
        int localVar = 0x10;
        int localVarTwo = 0x11;
        globalVar += localVar;
        localVarTwo += globalVar;
        globalVar = 0;
        return 0;
}
```

- Assembly Code

```
5fa: push   rbp
5fb: mov    rbp,rsp
5fe: mov    DWORD PTR [rbp-0x14],edi
601: mov    QWORD PTR [rbp-0x20],rsi
605: mov    DWORD PTR [rbp-0x8],0x10
60c: mov    DWORD PTR [rbp-0x4],0x11
613: mov    edx,DWORD PTR [rip+0x2009f7]   # 201010 <globalVar>
619: mov    eax,DWORD PTR [rbp-0x8]
61c: add    eax,edx
61e: mov    DWORD PTR [rip+0x2009ec],eax   # 201010 <globalVar>
624: mov    eax,DWORD PTR [rip+0x2009e6]   # 201010 <globalVar>
62a: add    DWORD PTR [rbp-0x4],eax
62d: mov    DWORD PTR [rip+0x2009d9],0x0   # 201010 <globalVar>
637: mov    eax,0x0
63c: pop    rbp
63d: ret
63e: xchg   ax,ax
```

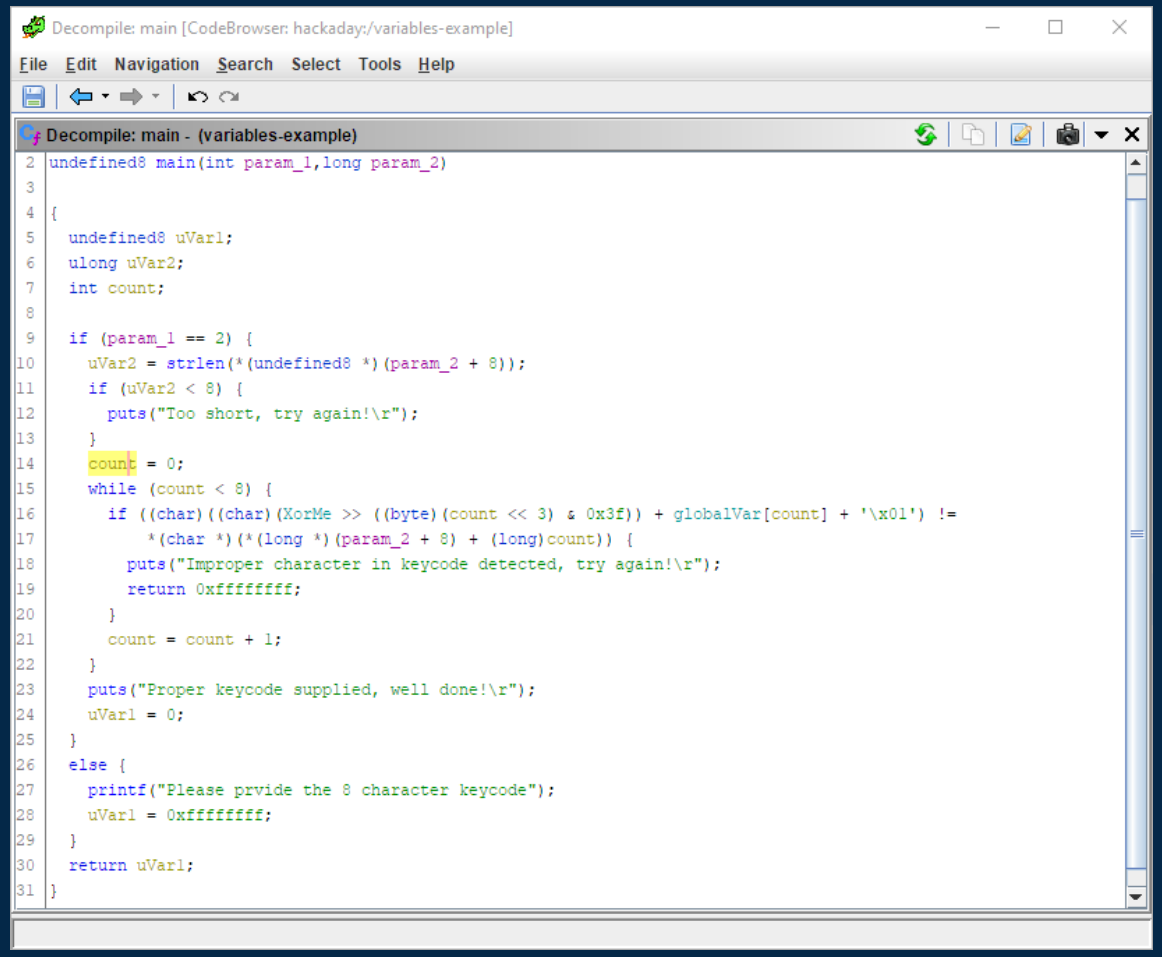
Stored in .data section!

#Ghidra Tip: Labelling/Renaming

- Variables and offsets can be labelled in Ghidra
  - Useful for labelling memory regions
  - Makes pseudo code more understandable

- Ghidra will attempt to synchronize the variable names between the listing view and decompiler view

#Ghidra Tip: Labelling/Renaming



#Variables: Example

- Load the exercise session-two/exercises/variables-example
- How many global variables are being used?
- How many local variables are in use?
- Can you find the proper keycode?

#Functions

- Functions are called using the `call` instruction
  - `call` pushes the return address to the stack when called
- The first 6 function parameters are passed in through registers
  - RDI,RSI,RDX,RCX,R8,R9
  - After this parameters are passed through the stack
  - Large parameters /structures passed by value are passed through the stack
- `ret` is used to return from a function
  - The return address is popped off the stack and placed into RIP

#Functions: Stack Usage

```
0000000000400517 <main>:
  400517:       55                      push   rbp
  400518:       48 89 e5                mov    rbp,rsp
  40051b:       48 83 ec 10             sub    rsp,0x10
  40051f:       89 7d fc                mov    DWORD PTR [rbp-0x4],edi
  400522:       48 89 75 f0             mov    QWORD PTR [rbp-0x10],rsi
  400526:       bf 0f 00 00 00          mov    edi,0xf
  40052b:       e8 bd ff ff ff          call   4004ed <add_and_print>
  400530:       b8 00 00 00 00          mov    eax,0x0
  400535:       c9                      leave
  400536:       c3                      ret
  400537:       66 0f 1f 84 00 00 00    nop    WORD PTR [rax+rax*1+0x0]
  40053e:       00 00
```

#Functions: Calling Conventions

- Calling conventions define how function calls are implemented
  - How arguments are passed to functions
  - How return values are pass back from functions
  - Stack management and register cleanup
- GNU/Linux uses the System V AMD64 ABI
  - ABI = Application Binary Interface
- Calling convention defined the epilogue / prologue for functions

#Functions: Prologue/Epilogue

- Functions can be thought of as three components:
  - Prologue
  - Body
  - Epilogue
- The prologue reserves space for variables on the stack
- The epilogue cleans up the stack frame and returns it to it's original state

#Function: C to ASM

C Code

```
void add_and_print(int x)
{
    int local_var = 10;
    int local_var_two = 14;
    int sum = 0;
    sum += x;
    sum += local_var;
}
```

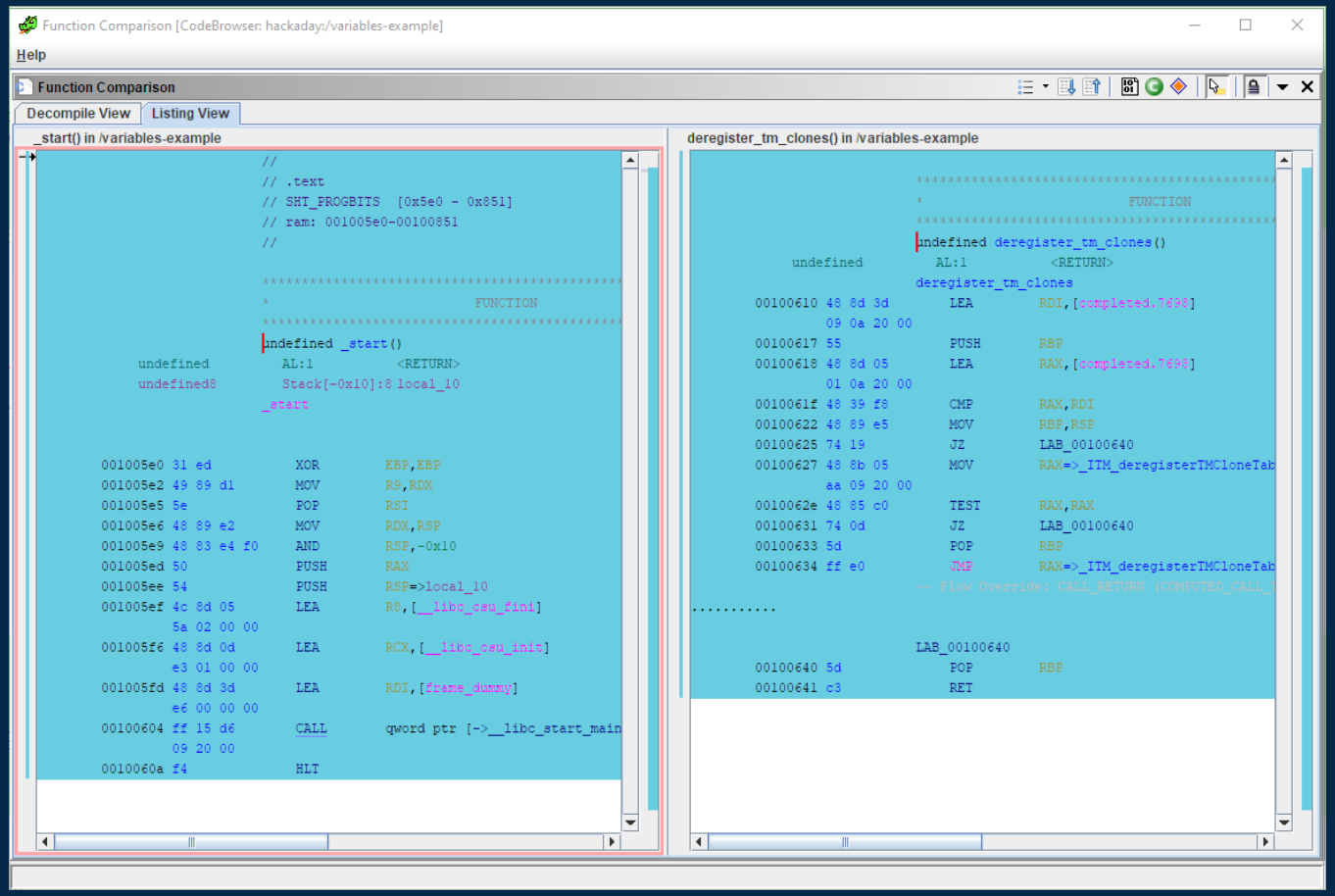
Assembly Code

```
4004ed: push rbp
4004ee: mov  rbp,rsp
4004f1: mov  DWORD PTR [rbp-0x14],edi
4004f4: mov  DWORD PTR [rbp-0xc],0xa
4004fb: mov  DWORD PTR [rbp-0x8],0xe
400502: mov  DWORD PTR [rbp-0x4],0x0
400509: mov  eax,DWORD PTR [rbp-0x14]
40050c: add  DWORD PTR [rbp-0x4],eax
40050f: mov  eax,DWORD PTR [rbp-0xc]
400512: add  DWORD PTR [rbp-0x4],eax
400515: pop  rbp
400516: ret
```


#Ghidra Tip: Functions

- Ghidra can perform function comparisons
  - This can be useful for doing side by side comparisons of similar functions
- Ghidra will display the two functions side by side
  - Listing view
  - Decompiler view
- To view the function comparison window, highlight two functions, then right click -> Compare Selected Functions

#Ghidra Tip: Functions



#Functions: Exercise 1

- Load the exercise `session-two/exercises/func-example-1`
- How many functions does the auto analysis discover?
- How many local variables are present in the each function?
  - What are their values?
- Do any of these functions take arguments?
  - If so, what are the arguments?

#Heap Memory

- The heap is used for dynamic memory allocations
  - Used when the size of a variable can be varied
  - `malloc/calloc` – Used to allocate
- Heap memory is not managed automatically
  - Developers must manage it manually
  - `free(var)` – used to free memory
  - Failure to do so results in “memory leaks”
- Heap variables can be accessed globally

#Heap Memory: Stack Vs. Heap

- Stack Memory
  - No need to de-allocate
  - Local variables only
  - Limited by stack size (OS dependent)
  - Statically sized variables
- Heap Memory
  - Variables can be accessed globally
  - No limit on size (within reason)
  - Must be managed by user

#Heap Memory: Exercise 1

- Load the exercise session-two/exercises/heap-example-1
- How much memory is being allocated via malloc?
- How is this program different than the loop example?

#Array Accesses

- Array accesses often utilize the LEA instruction

- LEA = Load Effective Address
  - Loads the address of the memory calculation into the register
  - Does not dereference the value as MOV would

- LEA EAX, [EAX + EBX + 1234567]
  - Stores the value of EAX+EBX+1234567 into EAX
  - Does not dereference!

#Array Accesses: C to ASM

C Code

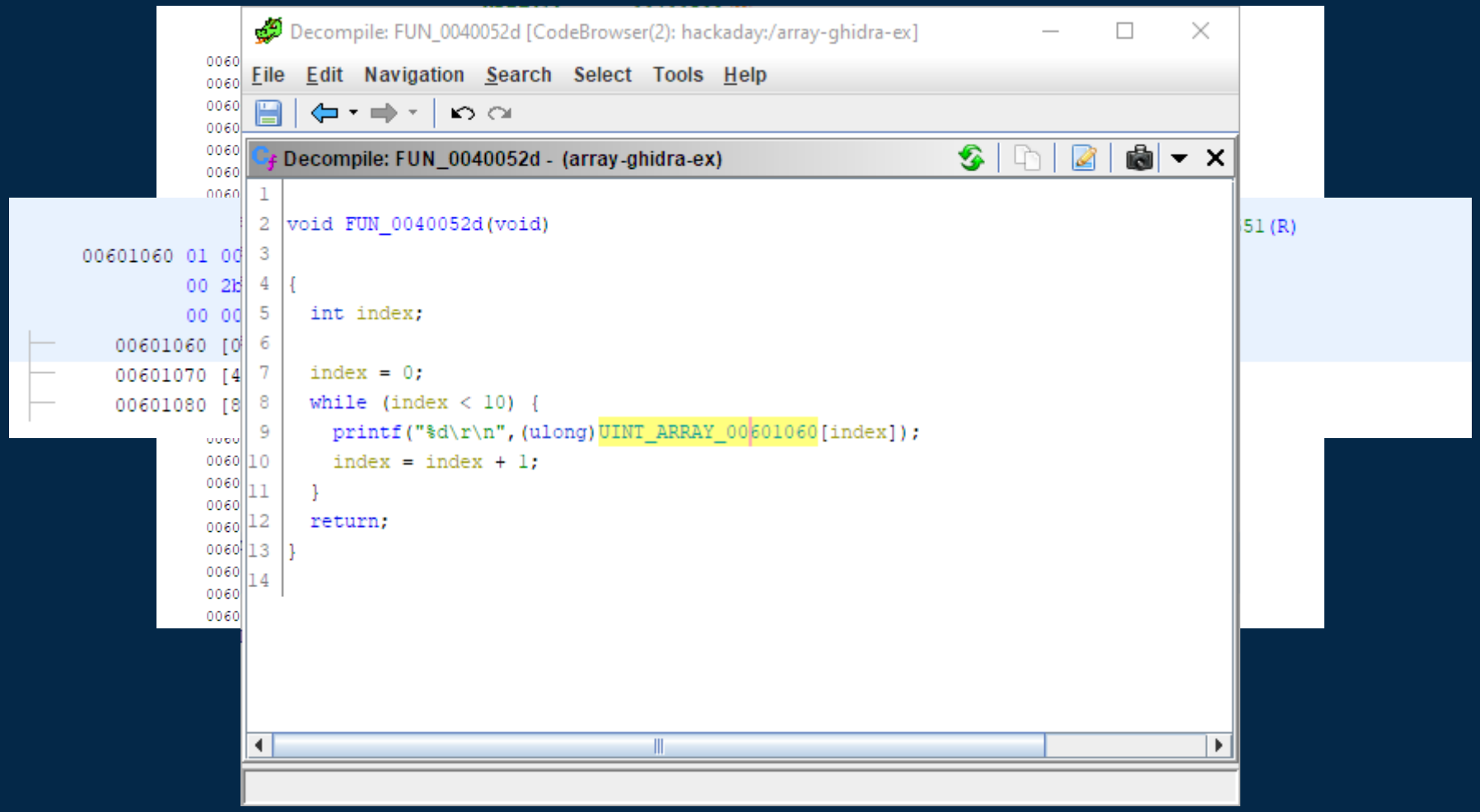
```
int nums[10];

int main(int argc, char *argv[]){
    int x;
    for(x=0;x<10;x++){
        nums[x] = x;
    }
    return 0;
}
```

Assembly Code

```
0000000000000633 <main>:
633: push   rbp
634: mov    rbp,rsp
637: mov    DWORD PTR [rbp-0x14],edi
63a: mov    QWORD PTR [rbp-0x20],rsi
63e: mov    DWORD PTR [rbp-0x4],0x0
645: jmp    665 <main+0x32>
647: mov    eax,DWORD PTR [rbp-0x4]
64a: cdqe
64c: lea    rcx,[rax*4+0x0]
653: 00
654: lea    rax,[rip+0x2009e5]        # 201040 <nums>
65b: mov    edx,DWORD PTR [rbp-0x4]
65e: mov    DWORD PTR [rcx+rax*1],edx
661: add    DWORD PTR [rbp-0x4],0x1
665: cmp    DWORD PTR [rbp-0x4],0x9
669: jle    647 <main+0x14>
66b: mov    eax,0x0
670: pop    rbp
671: ret
672: nop    WORD PTR cs:[rax+rax*1+0x0]
679: 00 00 00
67c: 0f 1f 40 00            nop    DWORD PTR [rax+0x0]
```

#Ghidra Tip: Creating Arrays



#Array Accesses: Exercise

- Load the exercise session-two/exercises /array-example
- How many different arrays are in use?
  - What is their scope, are they global?
- Cal you solve the password for all 4 index values?

#Wrap Up

- Today we reviewed how to identify various C constructs in C
  - Even though you have a decompiler, it is important to be able to recognize these constructs!
- We also reviewed multiple Ghidra tips to make the reversing process more streamlined
- The exercises for this course are available on the GitHub page!

#Questions

?