END-SEMESTER PROJECT REPORT 2025

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NASM Mini-Project Report

I-Reverse Array :

1. Objective:

The goal of this project is to implement and optimize low-level array operations using NASM x86-64 assembly. Through this exercise, we aim to enhance our understanding of memory manipulation, register usage, and system-level programming.

2. Project Description:

This project includes the development of two fundamental routines in NASM:

1. reverse_array_asm

- **Description:** Reverses the contents of a 32-bit integer array in place.
- **Inputs:**
  - RDI: pointer to the array
  - RSI: number of elements
- **Behavior:**
  The function swaps elements from both ends moving toward the center. It handles edge cases where the array is empty or has only one element.

2. find_second_largest_asm

- **Description:** Identifies the second largest value in an integer array.
- **Inputs:**
  - RDI: pointer to the array
  - RSI: number of elements
- **Output:**
  - EAX: second largest value, or -1 if invalid input
- **Behavior:**
  Traverses the array while tracking the largest and second largest values. It handles the case of insufficient array length by returning -1.

All functions are implemented using the System V AMD64 calling convention, making them callable from C programs.

3. Environment Setup:

- **Operating System:** Kali Linux
- **Assembler:** NASM
- **Compiler/Linker:** GCC
- **Text Editor:** nano/vim
- **Build Automation:** Optional use of Makefile

4. Testing and Validation:

Each function was tested using a dedicated C test file. Test inputs included both normal and edge cases, such as:

- Arrays of size 0 and 1
- Arrays with repeated elements
- Negative values

Example test in C:

int arr[] = {7, 2, 10, 5};

reverse_array_asm(arr, 4);

// arr becomes {5, 10, 2, 7}

int result = find_second_largest_asm(arr, 4);

// result = 10

5. Challenges Encountered:

- **Memory Addressing:** Computing offsets correctly using rdi + rcx*4
- **Edge Case Handling:** Avoiding invalid memory access on small arrays
- **Register Management:** Preserving necessary registers as per the calling convention
- **Flow Control:** Designing clean conditional logic with cmp, jge, je, etc.

6. Optimizations and Design Decisions:

- Efficient swapping using mov and xchg instructions
- Pointer arithmetic to reduce memory access overhead
- Use of manual loop control for clarity and predictability
- Return values via eax to match C function expectations

7. Conclusion:

This project offered a hands-on opportunity to work at the hardware-near level using assembly language. It allowed us to practice low-level debugging, understand data layout in memory, and manage performance-critical control flow.

Key Achievements:

- Wrote and tested two NASM routines
- Ensured compliance with Linux calling conventions
- Validated correctness through integration with C

II-Find second largest element in array

1. Project Objective

The goal of this project is to implement and optimize low-level array operations using NASM x86-64 assembly language. This exercise provides hands-on experience with:

- Memory manipulation at the system level
- Efficient register usage
- System-level programming concepts

- Integration with high-level languages (C)

2. Project Description

The project implements two core array operations in x86-64 assembly:

reverse_array_asm

Purpose: Reverses a 32-bit integer array in place
Inputs:

- RDI: Pointer to array
- RSI: Number of elements

Behavior:

- Swaps elements from both ends moving toward center
- Handles edge cases (empty/single-element arrays)
- Performs in-place modification

find_second_largest_asm

Purpose: Finds the second largest value in an integer array
Inputs:

- RDI: Pointer to array
- RSI: Number of elements

Output:

- EAX: Second largest value (-1 for invalid input)

Behavior:

- Tracks largest and second largest during traversal
- Returns -1 if array has fewer than 2 elements
- Handles duplicate values

3. Development Environment

- **OS:** Kali Linux
- **Assembler:** NASM (Netwide Assembler)
- **Compiler/Linker:** GCC
- **Editor:** nano/vim
- **Build:** Makefile for automation

4. Testing Methodology

Test Cases Included:

- Empty arrays and single-element arrays
- Arrays with duplicate values
- Arrays containing negative numbers
- Typical use cases

Sample Test (C Driver Program):

- int arr[] = {7, 2, 10, 5};
- reverse_array_asm(arr, 4); // Result: {5, 10, 2, 7}
- int result = find_second_largest_asm(arr, 4); // Returns 10

5. Technical Challenges

1. **Memory Addressing:**
   - Correct calculation of element offsets using rdi + rcx*4
   - Ensuring proper alignment for 32-bit operations
2. **Edge Case Handling:**
   - Preventing invalid memory access on small arrays
   - Special handling for arrays with <2 elements
3. **Register Management:**
   - Compliance with System V AMD64 calling convention
   - Efficient use of available registers
4. **Flow Control:**
   - Clean conditional logic using cmp, jge, je
   - Optimized loop structures

6. Optimizations & Design Choices

- **Efficient Swapping:** Used mov and xchg instructions
- **Pointer Arithmetic:** Minimized memory access overhead
- **Manual Loop Control:** Improved predictability
- **Register Usage:** Maximized register-based operations
- **Return Values:** Used EAX for C compatibility

7. Key Learnings & Outcomes

- Gained practical experience with low-level memory manipulation
- Developed understanding of x86-64 calling conventions
- Learned to integrate assembly with high-level languages
- Improved debugging skills at the assembly level

III-Factorial

Purpose:

To compute the **factorial** of a non-negative integer using x86-64 assembly (n! = n × (n−1) × … × 1).

Input:

- EDI: an integer n whose factorial is to be calculated.

Output:

- RAX: the result of n! (as a 64-bit integer).

Logic Overview:

1. The function initializes the result in EAX to 1, assuming 0! = 1 by definition.
2. It checks if the input number is **less than or equal to 0**:
    - If so, it skips the loop and directly returns 1.
3. If the input is greater than 0:
    - It copies the input value into the counter register ECX.
4. The function enters a loop:
    - On each iteration, it multiplies the current result (RAX) by the counter (RCX).
    - It then decrements the counter.
    - The loop continues until the counter becomes zero.
5. Once finished, the function returns with RAX holding the computed factorial value.

Example:

Input:

int n = 5;

Calculations:

RAX = 1 × 5 × 4 × 3 × 2 × 1 = 120

Output:

RAX = 120

IV-Magic Number:

Objective

The purpose of this project is to implement a low-level number-processing routine in NASM x86-64 assembly that determines whether a given integer is a **magic number**. This project aims to deepen understanding of digit manipulation, loop design, conditional branching, and register usage within the System V AMD64 calling convention.

2. **Project Description**

This project includes the development of one primary function:

1. isMagic

- **Description**:
  Determines whether a number is a *magic number*, defined as a number whose **recursive digit sum** eventually results in 1.
- **Input**:
  - RDI: A 64-bit positive integer
- **Output**:
  - RAX: Returns 1 if the number is magic, or 0 otherwise
- **Behavior**:
  - The function repeatedly sums the digits of the number.
  - If the final one-digit result is 1, the number is considered magic.
  - Handles special edge cases like zero or negative input by returning 0.

3. **Environment Setup**

- **Operating System**: Kali Linux
- **Assembler**: NASM
- **Compiler/Linker**: GCC
- **Text Editor**: nano / vim
- **Build Automation**: Optional (Makefile can be used)

5. **Testing and Validation**

The function was tested using a dedicated C file. Test cases included:

- Valid magic numbers like 1, 10, 19, 123
- Non-magic numbers like 4, 7, 88
- Edge cases: input = 0, negative numbers (expected to return 0)

7. **Optimizations and Design Decisions**

- Used div instead of modulus to avoid extra calculations
- Used rsi as an accumulator for summing digits
- Implemented clear loop labels for readability and debugging
- Avoided recursion to maintain linear performance and better control flow

V- Reverse a string in placef

Purpose:

To reverse a null-terminated string **in place**—i.e., modify the original string so that the characters appear in reverse order.

Input:

- RDI: a pointer to the input string (char*)

Output:

- The original string is modified directly in memory to become reversed.
- The function does not return a value; the change happens in place.

Logic Overview:

1. **Calculate the length of the string** by calling a helper function (strlen_asm). The length does not include the null terminator.
2. If the string is **empty** or has **only one character**, there's nothing to reverse, so the function exits immediately.
3. Two pointers are initialized:
   - One pointing to the **first character** of the string.
   - One pointing to the **last character** (just before the null terminator).
4. The function performs **in-place swapping**:
   - It swaps the character at the beginning with the one at the end.
   - Then it moves the start pointer forward and the end pointer backward.
   - This process repeats until both pointers meet or cross, which means the reversal is complete.
5. The function ends, and the string is now reversed in memory.

Example:

Input:

char str[] = "hello";

Output (after strrev_asm(str)):

str → "olleh"

VIII- Calculate length of null-terminated string

Purpose:

To compute the length of a null-terminated string (just like the C standard function strlen), without including the null terminator (\0).

Input:

- RDI: A pointer to the start of the null-terminated string.

Output:

- RAX: The number of characters in the string (excluding the null terminator).

Logic Overview:

1. The function starts by clearing RAX, which will serve as a **counter** for the string length.
2. It then enters a loop that:
   - Checks the byte at the current position ([RDI + RAX]).

    - If this byte is **not zero**, it increments the counter (RAX) and continues.
    - If the byte **is zero** (i.e., the null terminator \0 is reached), the loop ends.
3. When the loop finishes, RAX holds the length of the string (number of characters before the null terminator).
4. The function returns with the length in RAX.

Example:

Input:

char* str = "NASM";

Memory layout:

Address → Content

[0] = 'N'

[1] = 'A'

[2] = 'S'

[3] = 'M'

[4] = '\0'

Output:

RAX = 4

VI-debuging

step:

1️⃣ Understand the Problem

- Read the error message, log, or unexpected output.
- Reproduce the bug consistently (if possible).
- Identify **where** and **when** the error occurs.

2️⃣ Set Up the Debugging Environment

- Use tools like:
    - gdb for C/C++
    - Built-in debuggers in IDEs (e.g., Visual Studio, Eclipse, VSCode)
    - Logging (e.g., printf, console.log)
- If you're using Assembly, tools like **GDB** or **objdump** are useful.

3️⃣ Use Breakpoints

- Place breakpoints to **pause** the program at specific lines.
- Inspect variable values and program flow step by step.

4️⃣ Trace and Analyze

- Step through the code **line by line**.
- Watch variable changes, register values (in assembly), or memory content.
- Check if logic and control flow behave as expected.

5️⃣ Isolate the Bug

- Narrow down the part of code where the issue originates.
- Remove or comment out unrelated sections to focus on the bug.

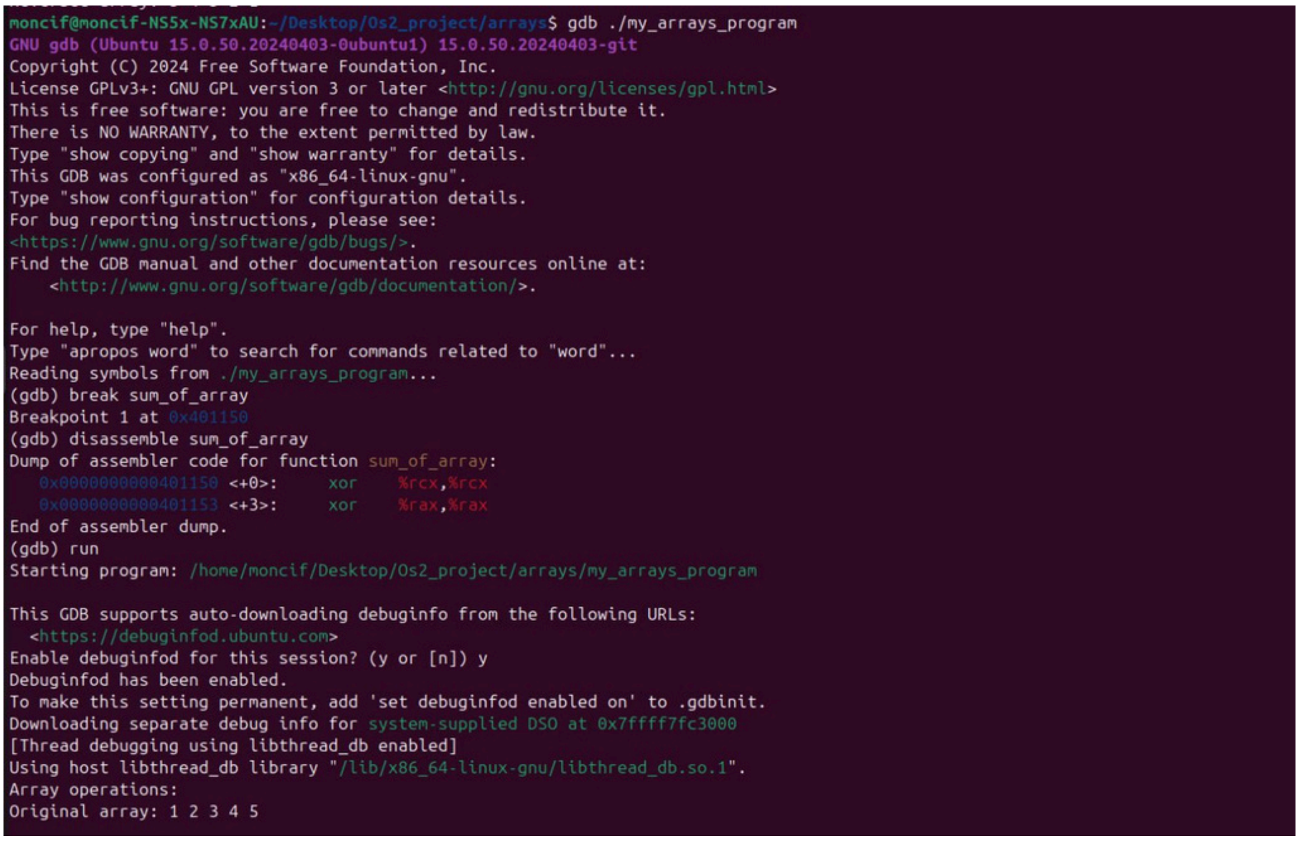
6️⃣ Fix the Bug

- Correct the logic, syntax, or algorithm causing the error.
- Ensure that the fix doesn't break other parts of the code

window.__oai_logHTML?window.__oai_logHTML():window.__oai_SSR_HTML=window.__oai_SSR_HTML||Date.now();requestAnimationFrame((function(){window.__oai_logTTI?window.__oai_logTTI():window.__oai_SSR_TTI=window.__oai_SSR_TTI||Date.now()}))

debugin of array function

- **step1: Assemble and Link the Code and start GDB**

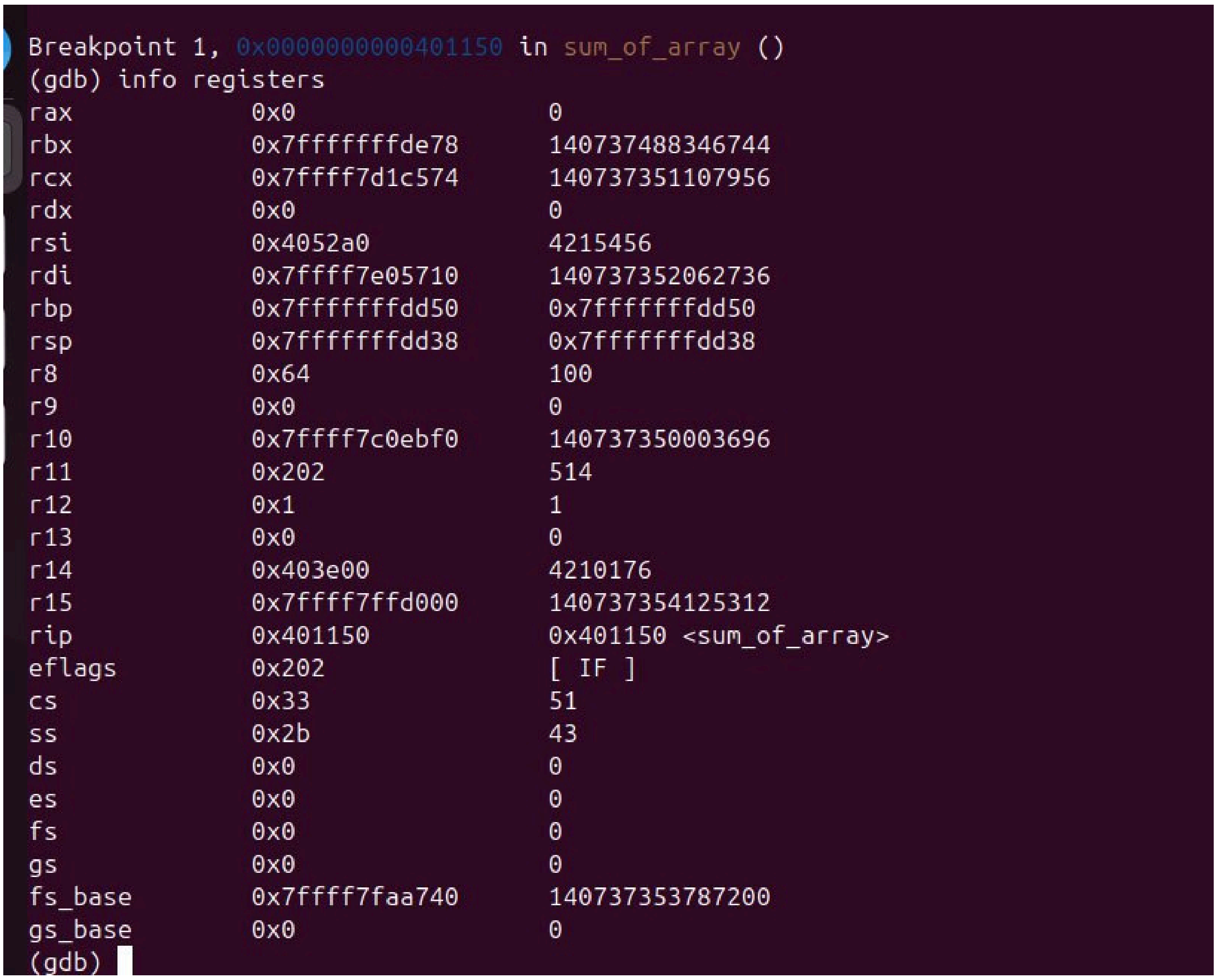


```
moncif@moncif-NS5x-NS7xAU:~/Desktop/Os2_project/arrays$ gdb ./my_arrays_program
GNU gdb (Ubuntu 15.0.50.20240403-0ubuntu1) 15.0.50.20240403-git
Copyright (C) 2024 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from ./my_arrays_program...
(gdb) break sum_of_array
Breakpoint 1 at 0x401150
(gdb) disassemble sum_of_array
Dump of assembler code for function sum_of_array:
   0x0000000000401150 <+0>:     xor    %rcx,%rcx
   0x0000000000401153 <+3>:     xor    %rax,%rax
End of assembler dump.
(gdb) run
Starting program: /home/moncif/Desktop/Os2_project/arrays/my_arrays_program

This GDB supports auto-downloading debuginfo from the following URLs:
  <https://debuginfod.ubuntu.com>
Enable debuginfod for this session? (y or [n]) y
Debuginfod has been enabled.
To make this setting permanent, add 'set debuginfod enabled on' to .gdbinit.
Downloading separate debug info for system-supplied DSO at 0x7ffff7fc3000
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
Array operations:
Original array: 1 2 3 4 5
```

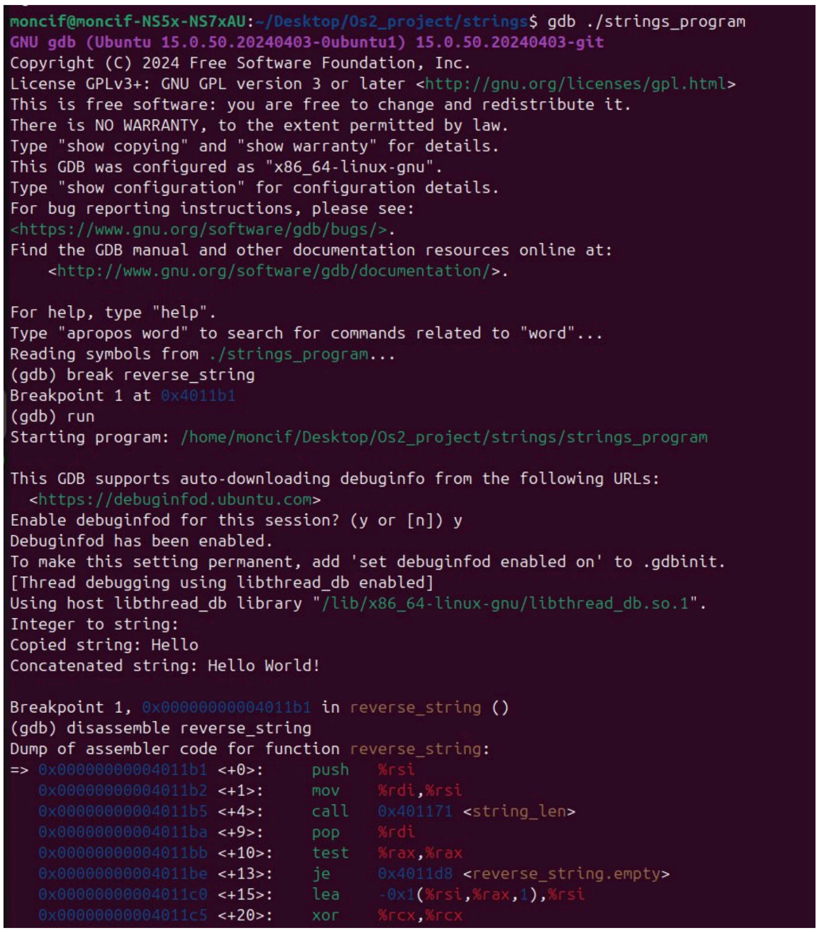
- **step2: Set a Breakpoint**



```
Breakpoint 1, 0x0000000000401150 in sum_of_array ()
(gdb) info registers
rax            0x0                 0
rbx            0x7fffffffde78      140737488346744
rcx            0x7ffff7d1c574      140737351107956
rdx            0x0                 0
rsi            0x4052a0            4215456
rdi            0x7ffff7e05710      140737352062736
rbp            0x7fffffffdd50      0x7fffffffdd50
rsp            0x7fffffffdd38      0x7fffffffdd38
r8             0x64                100
r9             0x0                 0
r10            0x7ffff7c0ebf0      140737350003696
r11            0x202               514
r12            0x1                 1
r13            0x0                 0
r14            0x403e00            4210176
r15            0x7ffff7ffd000      140737354125312
rip            0x401150            0x401150 <sum_of_array>
eflags         0x202               [ IF ]
cs             0x33                51
ss             0x2b                43
ds             0x0                 0
es             0x0                 0
fs             0x0                 0
gs             0x0                 0
fs_base        0x7ffff7faa740      140737353787200
gs_base        0x0                 0
(gdb) 
```

debugin of string function

- **step1: Assemble and Link the Code and start GDB**



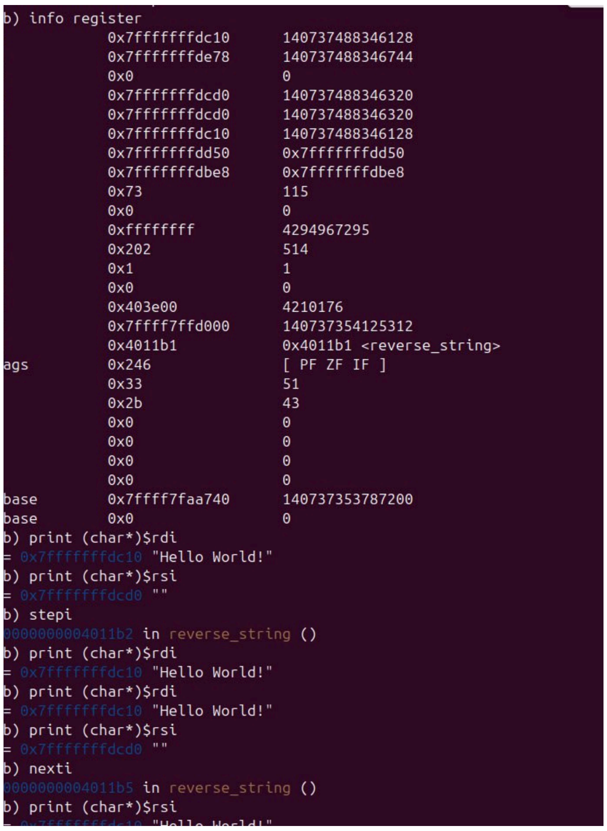
```
moncif@moncif-NS5x-NS7xAU:~/Desktop/Os2_project/strings$ gdb ./strings_program
GNU gdb (Ubuntu 15.0.50.20240403-0ubuntu1) 15.0.50.20240403-git
Copyright (C) 2024 Free Software Foundation, Inc.
License GPLv3+: GNU GPL version 3 or later <http://gnu.org/licenses/gpl.html>
This is free software: you are free to change and redistribute it.
There is NO WARRANTY, to the extent permitted by law.
Type "show copying" and "show warranty" for details.
This GDB was configured as "x86_64-linux-gnu".
Type "show configuration" for configuration details.
For bug reporting instructions, please see:
<https://www.gnu.org/software/gdb/bugs/>.
Find the GDB manual and other documentation resources online at:
    <http://www.gnu.org/software/gdb/documentation/>.

For help, type "help".
Type "apropos word" to search for commands related to "word"...
Reading symbols from ./strings_program...
(gdb) break reverse_string
Breakpoint 1 at 0x4011b1
(gdb) run
Starting program: /home/moncif/Desktop/Os2_project/strings/strings_program

This GDB supports auto-downloading debuginfo from the following URLs:
  <https://debuginfod.ubuntu.com>
Enable debuginfod for this session? (y or [n]) y
Debuginfod has been enabled.
To make this setting permanent, add 'set debuginfod enabled on' to .gdbinit.
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
Integer to string:
Copied string: Hello
Concatenated string: Hello World!

Breakpoint 1, 0x00000000004011b1 in reverse_string ()
(gdb) disassemble reverse_string
Dump of assembler code for function reverse_string:
=> 0x00000000004011b1 <+0>:     push   %rsi
   0x00000000004011b2 <+1>:     mov    %rdi,%rsi
   0x00000000004011b5 <+4>:     call   0x401171 <string_len>
   0x00000000004011ba <+9>:     pop    %rdi
   0x00000000004011bb <+10>:    test   %rax,%rax
   0x00000000004011be <+13>:    je     0x4011d8 <reverse_string.empty>
   0x00000000004011c0 <+15>:    lea    -0x1(%rsi,%rax,1),%rsi
   0x00000000004011c5 <+20>:    xor    %rcx,%rcx
```

- **step2: Set a Breakpoint**



```
b) info register
            0x7fffffffdc10      140737488346128
            0x7fffffffde78      140737488346744
            0x0                 0
            0x7fffffffdcd0      140737488346320
            0x7fffffffdcd0      140737488346320
            0x7fffffffdc10      140737488346128
            0x7fffffffdd50      0x7fffffffdd50
            0x7fffffffdbe8      0x7fffffffdbe8
            0x73                115
            0x0                 0
            0xffffffff          4294967295
            0x202               514
            0x1                 1
            0x0                 0
            0x403e00            4210176
            0x7ffff7ffd000      140737354125312
            0x4011b1            0x4011b1 <reverse_string>
ags         0x246               [ PF ZF IF ]
            0x33                51
            0x2b                43
            0x0                 0
            0x0                 0
            0x0                 0
            0x0                 0
base        0x7ffff7faa740      140737353787200
base        0x0                 0
b) print (char*)$rdi
= 0x7fffffffdc10 "Hello World!"
b) print (char*)$rsi
= 0x7fffffffdcd0 ""
b) stepi
00000000004011b2 in reverse_string ()
b) print (char*)$rdi
= 0x7fffffffdc10 "Hello World!"
b) print (char*)$rdi
= 0x7fffffffdc10 "Hello World!"
b) print (char*)$rsi
= 0x7fffffffdcd0 ""
b) nexti
00000000004011b5 in reverse_string ()
b) print (char*)$rsi
= 0x7fffffffdc10 "Hello World!"
```

IX- Steps to link the .c and .asm programs

1-Compile with GCC:

gcc -c main.c -o main.o

2. Assemble NASM File to Object File

nasm -f elf64 factorial.asm -o factorial.o

3. Link C and ASM Object Files Together

gcc main.o factorial.o -o program

4. Run the Final Program

./program

X-Developing the Makefile

Role of the Makefile: The Makefile automates the entire build process, making it efficient and reproducible. It defines rules for how different types of files are compiled, assembled, and linked. This is essential for managing dependencies and ensuring that only changed files are reprocessed.

How functions are built and linked *instead of* manually doing it:

- **Defining Sources:** The Makefile would list all your C source files (.c) and NASM assembly source files (.asm).
- **Compilation Rules (C to Object Files):** It would have a rule (e.g., %.o: %.c) that tells make how to compile each .c file into a .o (object) file using gcc. For example:
- Makefile
- %.o: %.c
-         gcc -c $< -o $@ -Wall -g # -g for debugging info
- **Assembly Rules (NASM to Object Files):** It would have a similar rule (e.g., %.o: %.asm) for assembling each .asm file into a .o file using nasm:
- Makefile
- %.o: %.asm
-         nasm -f elf64 $< -o $@ # -f elf64 for 64-bit Linux object files
- **Linking Rule (Object Files to Executable):** The final rule would combine all the generated .o files (from both C and NASM) into the final executable using gcc as the linker front-end:
- Makefile

- my_program: c_file1.o c_file2.o asm_function1.o asm_function2.o
- gcc $^ -o $@
  - $^ expands to all prerequisites (all .o files).
  - $@ expands to the target name (my_program).
  - **Seamless Linking:** gcc handles the complexities of linking, including resolving symbol references between C and assembly code, ensuring the correct calling conventions are respected (if the assembly functions were written according to them), and pulling in necessary system libraries. The Makefile orchestrates this by providing gcc with all the required object files.
- **Clean Rule:** A Makefile usually includes a clean rule to remove all generated files, facilitating a fresh build.
- **Debugging Integration:** The Makefile can also have rules to build with debugging symbols (-g for gcc and nasm).

XI-Benchmarks

Purpose

Benchmarks are used to **measure and evaluate the performance** of a program or function under specific conditions. In the context of your NASM x86-64 assembly routines, benchmarks serve several key purposes:

1. **Performance Evaluation**

- **Goal**: Determine how fast or efficient a routine is when executing.
- Example: How many CPU cycles does reverse_array_asm take compared to a C implementation?

2. **Comparison Between Implementations**

- Allows you to compare:
  - Your NASM implementation vs. a high-level C version
  - Different versions of your own assembly function (e.g., with/without optimizations)

3. **Detecting Bottlenecks**

- Benchmarks can help **identify slow sections** in your code.
- You can profile individual loops or instructions to spot performance issues.

4. **Validation of Optimizations**

- After applying optimizations (e.g., using xchg, minimizing memory access), benchmarking lets you **verify if performance actually improved**.

- Without a benchmark, you may assume the code is faster without proof.

5. **System Behavior Under Load**

- You can benchmark functions using **large data sets** (e.g., reversing a 10,000-element array) to see how they behave under **stress**.

6. **Documentation and Reporting**

- Including benchmarks in a project report provides **quantitative evidence** of efficiency.
- It shows you care about both correctness and **performance**, a key skill in systems programming.