Debugging and Design

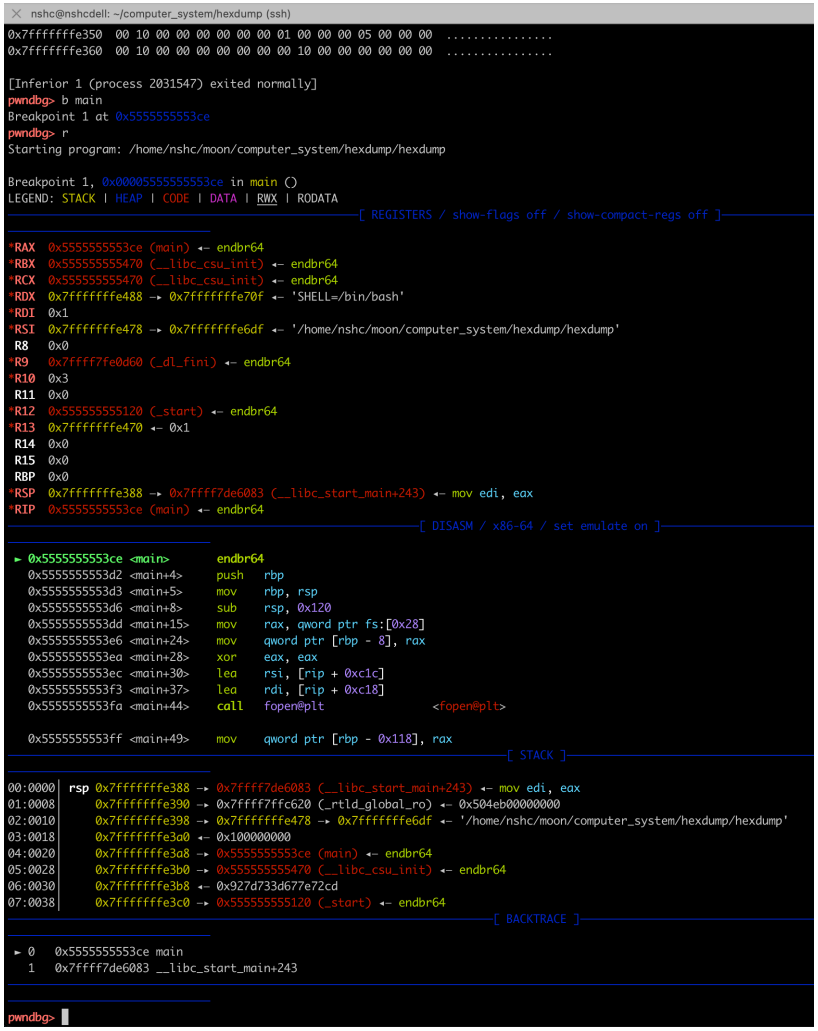
Computer Systems
Friday, November 01, 2024

Outline

- **Debugging**
  - Tools
  - Code with a Bug
- Design
  - Managing complexity
  - Communication
  - Naming
  - Comments

GDB

- **No longer stepping through assembly!**
  - Use the step/next commands
  - break on line numbers, functions
  - Use list to display code at line-numbers and functions
  - Use print with variables
- **Use pwndbg**
  - Nice display for viewing source/executing commands



https://darkdust.net/files/GDB%20Cheat%20Sheet.pdf

Valgrind

- **Find memory errors, detect memory leaks**
- **Common errors:**
  - Illegal read/write errors
  - Use of uninitialized values
  - Illegal frees
  - Overlapping source/destination addresses
- **Typical solutions**
  - Did you allocate enough memory?
  - Did you accidentally free stack variables/something twice?
  - Did you initialize all your variables?
  - Did use something that you just free'd?
- **--leak-check=full**
  - Memcheck gives details for each definitely/possibly lost memory block (where it was allocated

Code with a Bug

```
#include <stdio.h>

int fact(int n) {
    if(n == 1)
        return n;
    else
        return n * fact(n-1);
}

int main() {
    int n;
    for (n=0; n<20; n++)
    {
        printf("factorial of %d: \t %d\n" , n, fact(n));
    }
    return 0;
}
```

$ ./fact
Segmentation fault (core dumped)

Code with a Bug

```
pwndbg> r
Starting program: /home/nshc/moon/computer_system/07_debugging/fact

Program received signal SIGSEGV, Segmentation fault.
0x080491bf in fact ()
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA
──────────────────────────[ REGISTERS / show-flags off / show-compact-regs off ]──
*EAX  0xfffc005a ◂— 0x91c4fffc
*EBX  0x804c000 (_GLOBAL_OFFSET_TABLE_) —▸ 0x804bf14 (_DYNAMIC) ◂— 0x1
*ECX  0xffffd500 ◂— 0x1
*EDX  0xffffd524 ◂— 0x0
*EDI  0xf7fb1000 (_GLOBAL_OFFSET_TABLE_) ◂— 0x1ead6c
*ESI  0xf7fb1000 (_GLOBAL_OFFSET_TABLE_) ◂— 0x1ead6c
*EBP  0xff7fe018 —▸ 0xff7fe038 —▸ 0xff7fe058 —▸ 0xff7fe078 —▸ 0xff7fe098 ◂— ...
*ESP  0xff7fe000 —▸ 0xfffc005a ◂— 0x91c4fffc
*EIP  0x80491bf (fact+41) —▸ 0xffffd2e8 ◂— 0x3
──────────────────────────[ DISASM / i386 / set emulate on ]──────────────────────
 ► 0x80491bf <fact+41>    call   fact                    <fact>
        arg[0]: 0xfffc005a ◂— 0x91c4fffc
        arg[1]: 0x0
        arg[2]: 0x0
        arg[3]: 0x80491a5 (fact+15) ◂— add eax, 0x2e5b

   0x80491c4 <fact+46>    add    esp, 0x10
   0x80491c7 <fact+49>    imul   eax, dword ptr [ebp + 8]
   0x80491cb <fact+53>    leave
   0x80491cc <fact+54>    ret

   0x80491cd <main>       endbr32
   0x80491d1 <main+4>     lea    ecx, [esp + 4]
   0x80491d5 <main+8>     and    esp, 0xfffffff0
   0x80491d8 <main+11>    push   dword ptr [ecx - 4]
   0x80491db <main+14>    push   ebp
   0x80491dc <main+15>    mov    ebp, esp
──────────────────────────[ STACK ]──────────────────────────────────────────────
00:0000 │ esp 0xff7fe000 —▸ 0xfffc005a ◂— 0x91c4fffc
01:0004 │     0xff7fe004 ◂— 0x0
02:0008 │     0xff7fe008 ◂— 0x0
03:000c │     0xff7fe00c —▸ 0x80491a5 (fact+15) ◂— add eax, 0x2e5b
04:0010 │     0xff7fe010 ◂— 0x0
05:0014 │     0xff7fe014 ◂— 0x0
06:0018 │ ebp 0xff7fe018 —▸ 0xff7fe038 —▸ 0xff7fe058 —▸ 0xff7fe078 —▸ 0xff7fe098 ◂— ...
07:001c │     0xff7fe01c —▸ 0x80491c4 (fact+46) ◂— add esp, 0x10
──────────────────────────[ BACKTRACE ]──────────────────────────────────────────
 ► 0 0x80491bf fact+41
   1 0x80491c4 fact+46
   2 0x80491c4 fact+46
   3 0x80491c4 fact+46
   4 0x80491c4 fact+46
   5 0x80491c4 fact+46
   6 0x80491c4 fact+46
   7 0x80491c4 fact+46
──────────────────────────────────────────────────────────────────────────────────
pwndbg>
```

Code with a Bug

```
pwndbg> info thread
  Id   Target Id             Frame
* 1    process 3280933 "fact" 0x080491bf in fact ()
pwndbg> cat /proc/3280933/maps
08048000-08049000 r--p 00000000 fd:00 4463972                            /home/nshc/moon/computer_system/07_debugging/fact
08049000-0804a000 r-xp 00001000 fd:00 4463972                            /home/nshc/moon/computer_system/07_debugging/fact
0804a000-0804b000 r--p 00002000 fd:00 4463972                            /home/nshc/moon/computer_system/07_debugging/fact
0804b000-0804c000 r--p 00002000 fd:00 4463972                            /home/nshc/moon/computer_system/07_debugging/fact
0804c000-0804d000 rw-p 00003000 fd:00 4463972                            /home/nshc/moon/computer_system/07_debugging/fact
f7dc6000-f7ddf000 r--p 00000000 fd:00 6041625                            /usr/lib/i386-linux-gnu/libc-2.31.so
f7ddf000-f7f3a000 r-xp 00019000 fd:00 6041625                            /usr/lib/i386-linux-gnu/libc-2.31.so
f7f3a000-f7fae000 r--p 00174000 fd:00 6041625                            /usr/lib/i386-linux-gnu/libc-2.31.so
f7fae000-f7faf000 ---p 001e8000 fd:00 6041625                            /usr/lib/i386-linux-gnu/libc-2.31.so
f7faf000-f7fb1000 r--p 001e8000 fd:00 6041625                            /usr/lib/i386-linux-gnu/libc-2.31.so
f7fb1000-f7fb2000 rw-p 001ea000 fd:00 6041625                            /usr/lib/i386-linux-gnu/libc-2.31.so
f7fb2000-f7fb5000 rw-p 00000000 00:00 0
f7fca000-f7fcc000 rw-p 00000000 00:00 0
f7fcc000-f7fcf000 r--p 00000000 00:00 0                                  [vvar]
f7fcf000-f7fd1000 r-xp 00000000 00:00 0                                  [vdso]
f7fd1000-f7fd2000 r--p 00000000 fd:00 6041336                            /usr/lib/i386-linux-gnu/ld-2.31.so
f7fd2000-f7ff0000 r-xp 00001000 fd:00 6041336                            /usr/lib/i386-linux-gnu/ld-2.31.so
f7ff0000-f7ffb000 r--p 0001f000 fd:00 6041336                            /usr/lib/i386-linux-gnu/ld-2.31.so
f7ffc000-f7ffd000 r--p 0002a000 fd:00 6041336                            /usr/lib/i386-linux-gnu/ld-2.31.so
f7ffd000-f7ffe000 rw-p 0002b000 fd:00 6041336                            /usr/lib/i386-linux-gnu/ld-2.31.so
ff7fe000-ffffe000 rw-p 00000000 00:00 0                                  [stack]
This command is deprecated in Pwndbg. Please use the GDB's built-in syntax for running shell commands instead: !cat <args>
pwndbg>
```

Code with a Bug

```
pwndbg> vmmap
LEGEND: STACK | HEAP | CODE | DATA | RWX | RODATA
     Start        End Perm     Size Offset File
 0x8048000  0x8049000 r--p     1000      0 /home/nshc/moon/computer_system/07_debugging/fact
 0x8049000  0x804a000 r-xp     1000   1000 /home/nshc/moon/computer_system/07_debugging/fact
 0x804a000  0x804b000 r--p     1000   2000 /home/nshc/moon/computer_system/07_debugging/fact
 0x804b000  0x804c000 r--p     1000   2000 /home/nshc/moon/computer_system/07_debugging/fact
 0x804c000  0x804d000 rw-p     1000   3000 /home/nshc/moon/computer_system/07_debugging/fact
0xf7dc6000 0xf7ddf000 r--p    19000      0 /usr/lib/i386-linux-gnu/libc-2.31.so
0xf7ddf000 0xf7f3a000 r-xp   15b000  19000 /usr/lib/i386-linux-gnu/libc-2.31.so
0xf7f3a000 0xf7fae000 r--p    74000 174000 /usr/lib/i386-linux-gnu/libc-2.31.so
0xf7fae000 0xf7faf000 ---p     1000 1e8000 /usr/lib/i386-linux-gnu/libc-2.31.so
0xf7faf000 0xf7fb1000 r--p     2000 1e8000 /usr/lib/i386-linux-gnu/libc-2.31.so
0xf7fb1000 0xf7fb2000 rw-p     1000 1ea000 /usr/lib/i386-linux-gnu/libc-2.31.so
0xf7fb2000 0xf7fb5000 rw-p     3000      0 [anon_f7fb2]
0xf7fca000 0xf7fcc000 rw-p     2000      0 [anon_f7fca]
0xf7fcc000 0xf7fcf000 r--p     3000      0 [vvar]
0xf7fcf000 0xf7fd1000 r-xp     2000      0 [vdso]
0xf7fd1000 0xf7fd2000 r--p     1000      0 /usr/lib/i386-linux-gnu/ld-2.31.so
0xf7fd2000 0xf7ff0000 r-xp    1e000   1000 /usr/lib/i386-linux-gnu/ld-2.31.so
0xf7ff0000 0xf7ffb000 r--p     b000  1f000 /usr/lib/i386-linux-gnu/ld-2.31.so
0xf7ffc000 0xf7ffd000 r--p     1000  2a000 /usr/lib/i386-linux-gnu/ld-2.31.so
0xf7ffd000 0xf7ffe000 rw-p     1000  2b000 /usr/lib/i386-linux-gnu/ld-2.31.so
0xff7fe000 0xffffe000 rw-p   800000      0 [stack]
pwndbg>
```

Code with a Bug

```
nshc@nshcdell:~/computer_system/07_debugging$ valgrind ./fact
==3281737== Memcheck, a memory error detector
==3281737== Copyright (C) 2002-2017, and GNU GPL'd, by Julian Seward et al.
==3281737== Using Valgrind-3.15.0 and LibVEX; rerun with -h for copyright info
==3281737== Command: ./fact
==3281737==
==3281737== Stack overflow in thread #1: can't grow stack to 0xfe522000
==3281737==
==3281737== Process terminating with default action of signal 11 (SIGSEGV)
==3281737==  Access not within mapped region at address 0xFE522FFC
==3281737== Stack overflow in thread #1: can't grow stack to 0xfe522000
==3281737==    at 0x80491A0: fact (in /home/nshc/moon/computer_system/07_debugging/fact)
==3281737==  If you believe this happened as a result of a stack
==3281737==  overflow in your program's main thread (unlikely but
==3281737==  possible), you can try to increase the size of the
==3281737==  main thread stack using the --main-stacksize= flag.
==3281737==  The main thread stack size used in this run was 8388608.
==3281737== Stack overflow in thread #1: can't grow stack to 0xfe522000
--3281737-- VALGRIND INTERNAL ERROR: Valgrind received a signal 11 (SIGSEGV) - exiting
--3281737-- si_code=1;  Faulting address: 0xFE522FFC;  sp: 0x82c36f20

valgrind: the 'impossible' happened:
   Killed by fatal signal

host stacktrace:
==3281737==    at 0x580B5272: ??? (in /usr/lib/x86_64-linux-gnu/valgrind/memcheck-x86-linux)

sched status:
  running_tid=1

Thread 1: status = VgTs_Runnable (lwpid 3281737)
Segmentation fault (core dumped)
nshc@nshcdell:~/computer_system/07_debugging$
```

Practice : rec_main.c

- rec_main

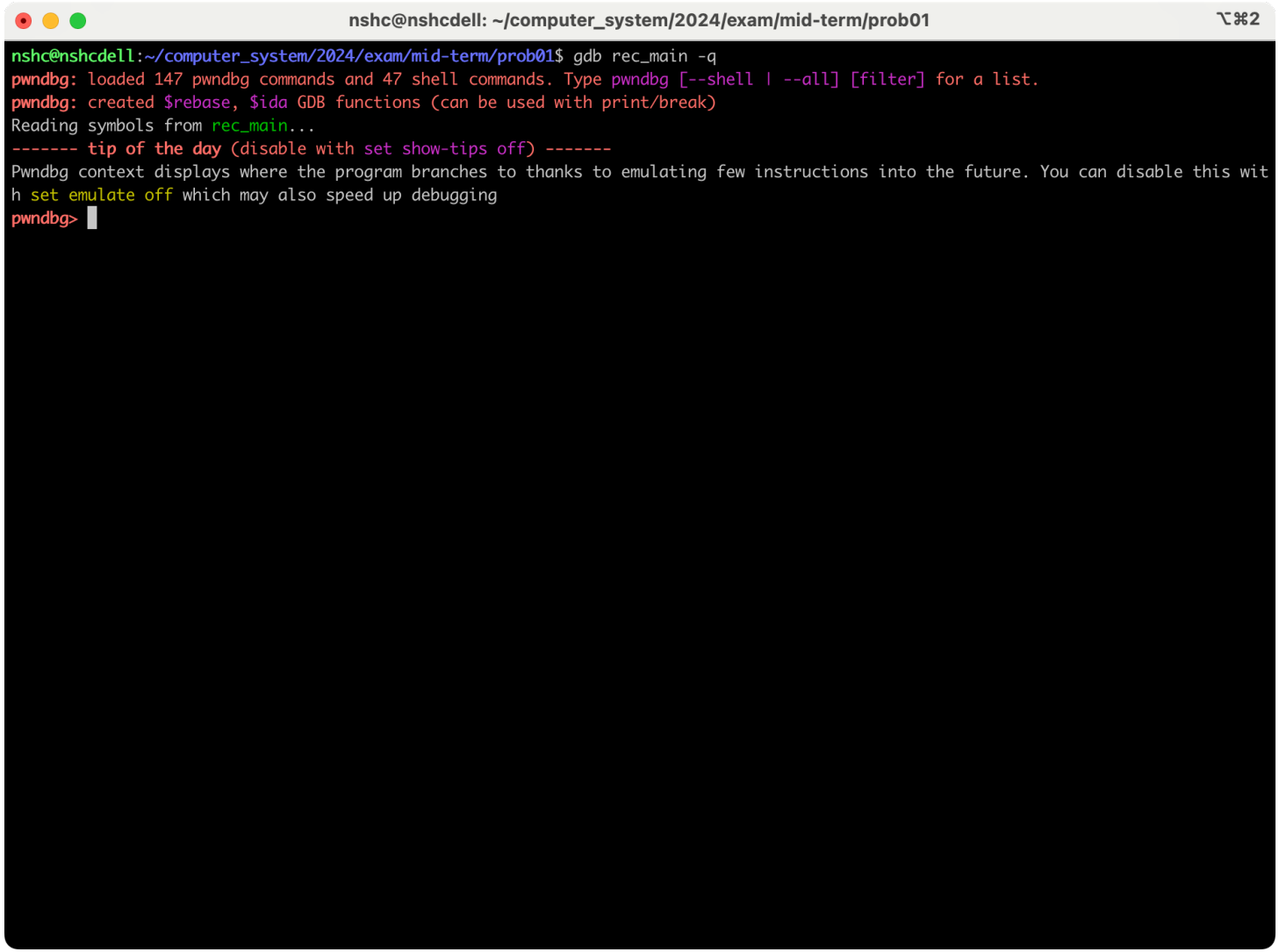
```c
#include <stdio.h>

int main(int argc)
{
        if (argc > 0x800)
                printf("The result is %d\n", argc);
        else
                return main(argc<<1);
}
```

```
>>> while argc <= 0x800 :
...     argc = argc<<1
...
>>> argc
4096
```

```
nshc@nshcdell:~/computer_system/2024/exam/mid-term/prob01$ ./rec_main
The result is 4096
```

rec_main.c

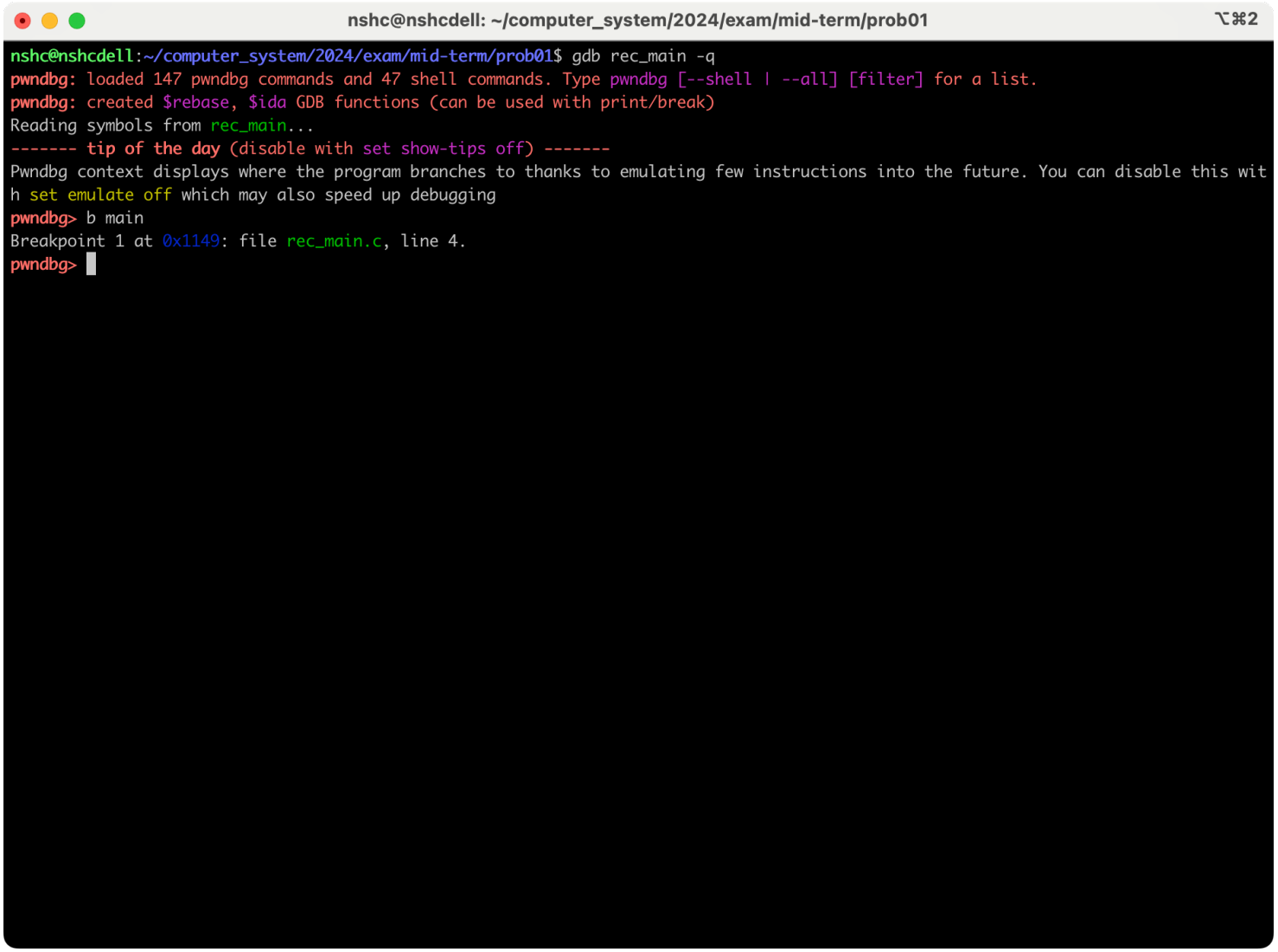
- rec_main (debugging)




```
$gdb rec_main -q
```

rec_main.c

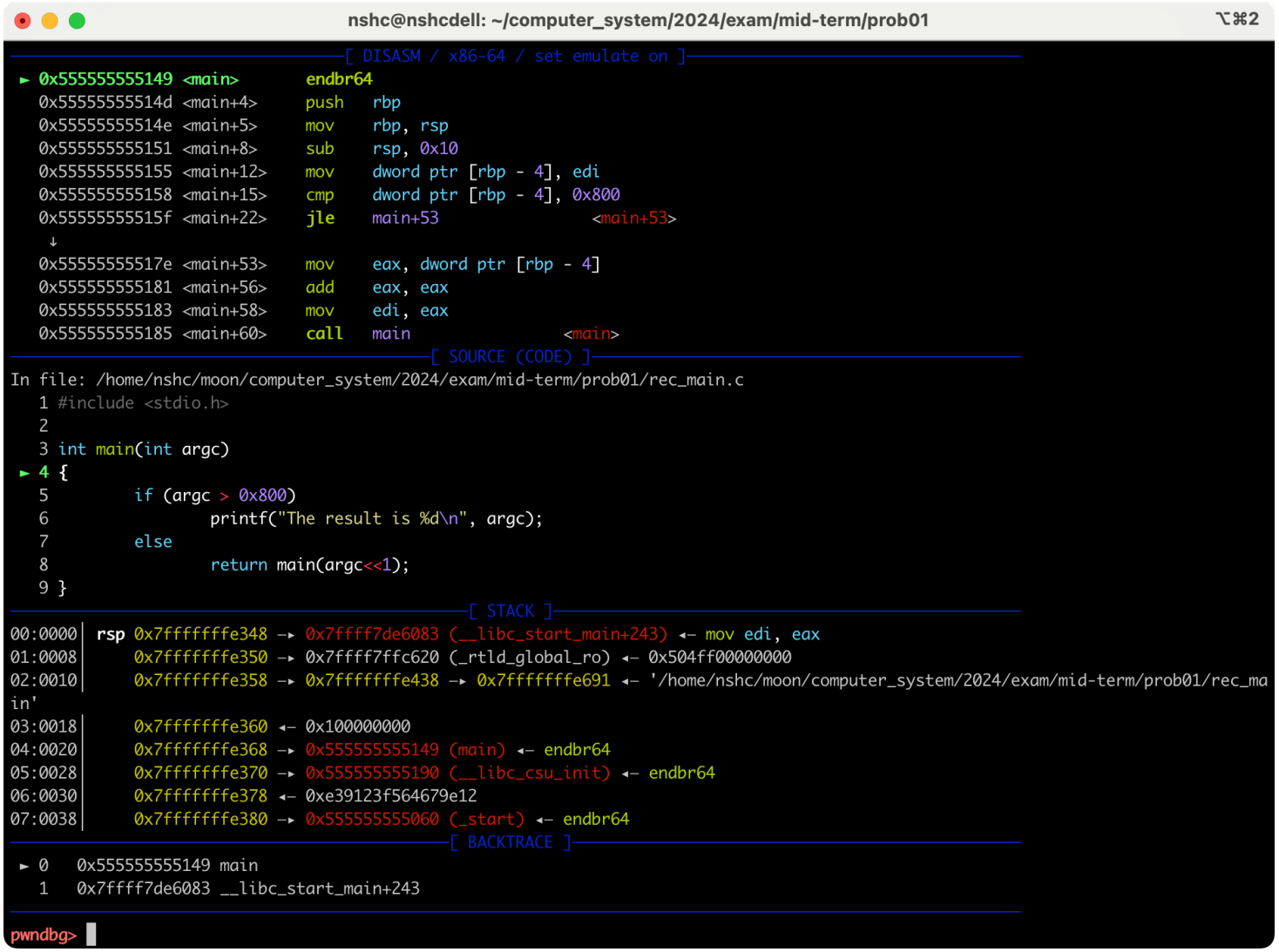
- rec_main (debugging)




```
$gdb rec_main -q
> break main
```

rec_main.c

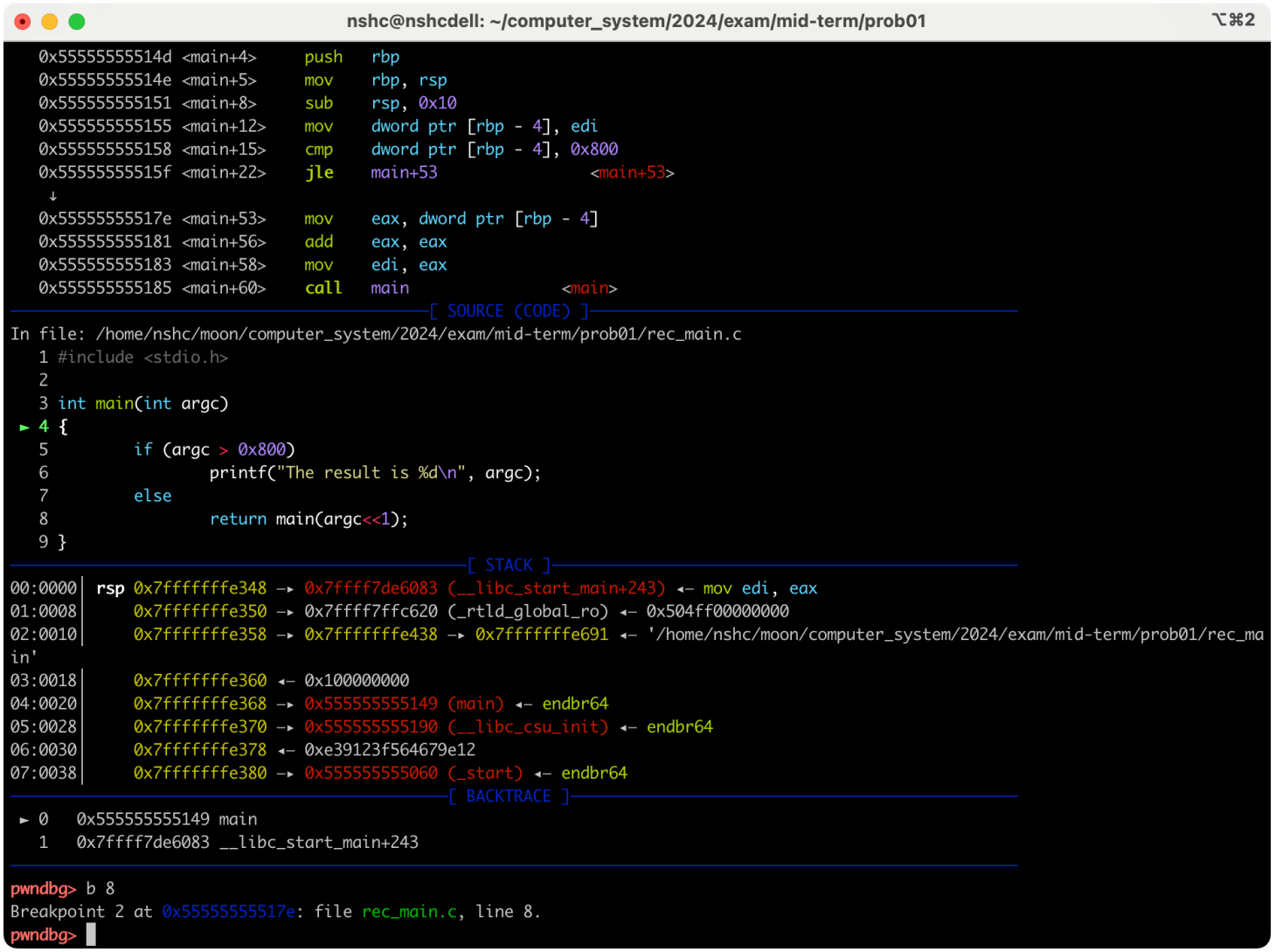
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
```

rec_main.c

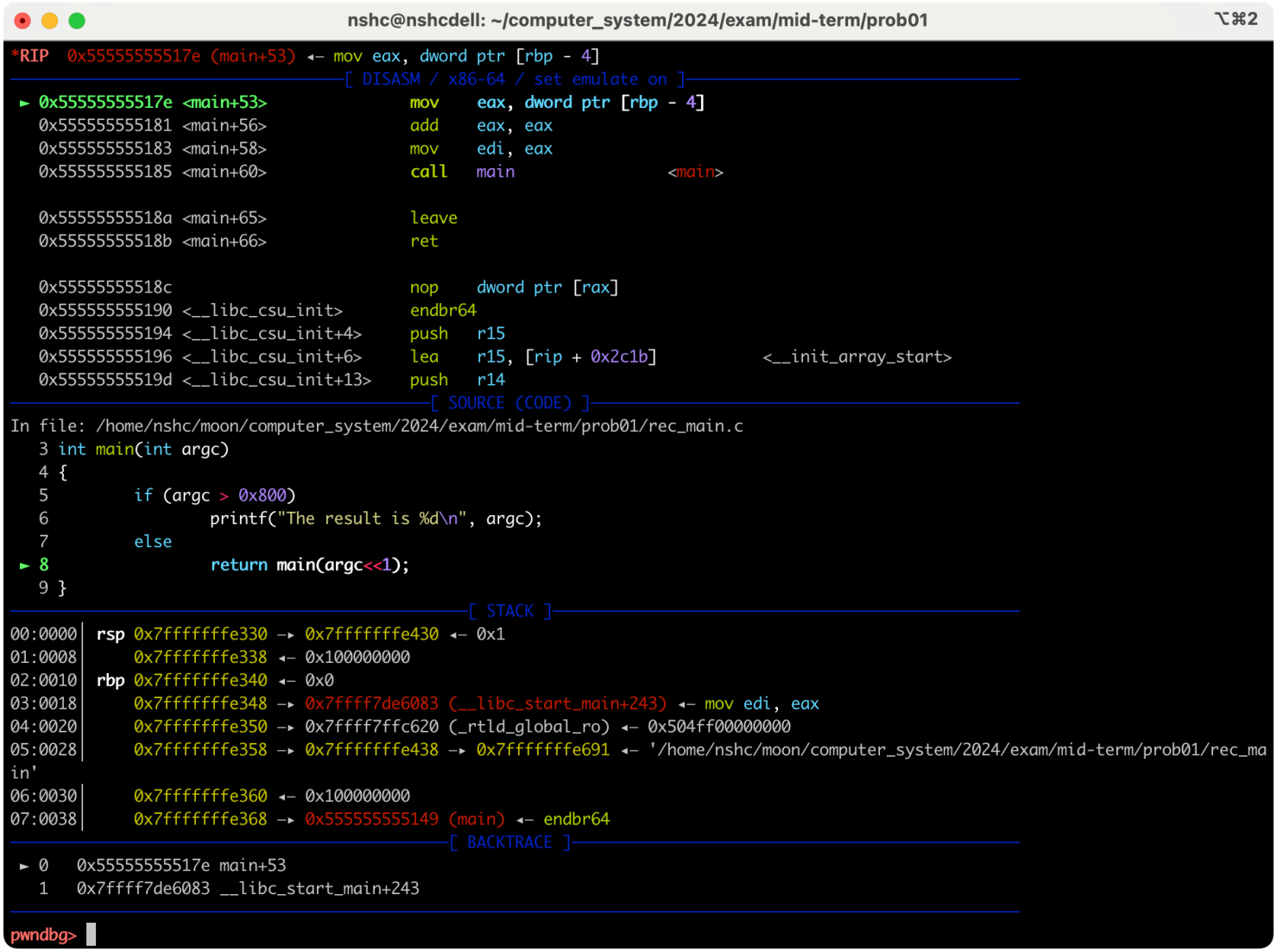
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
```

rec_main.c

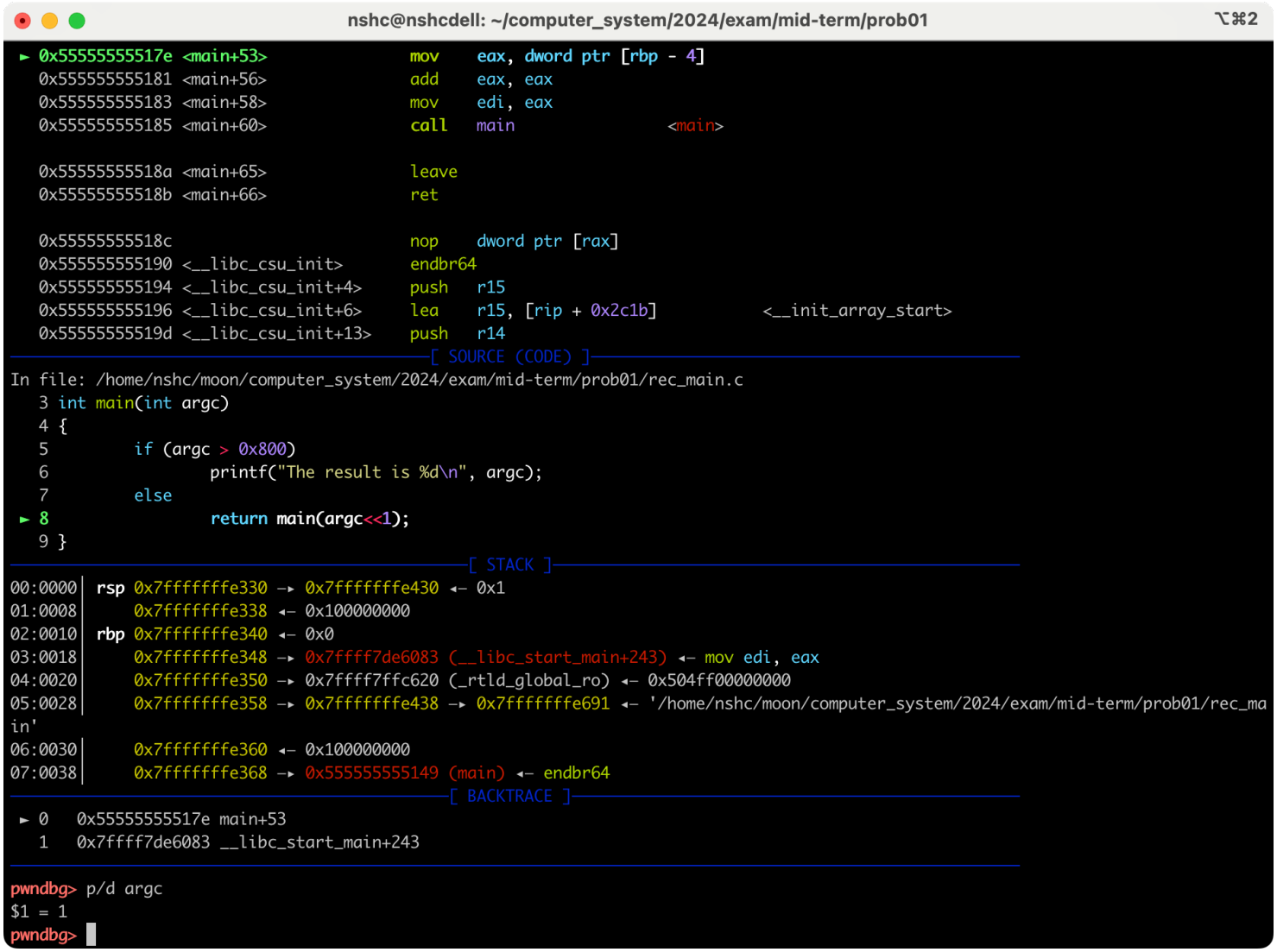
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
```

rec_main.c

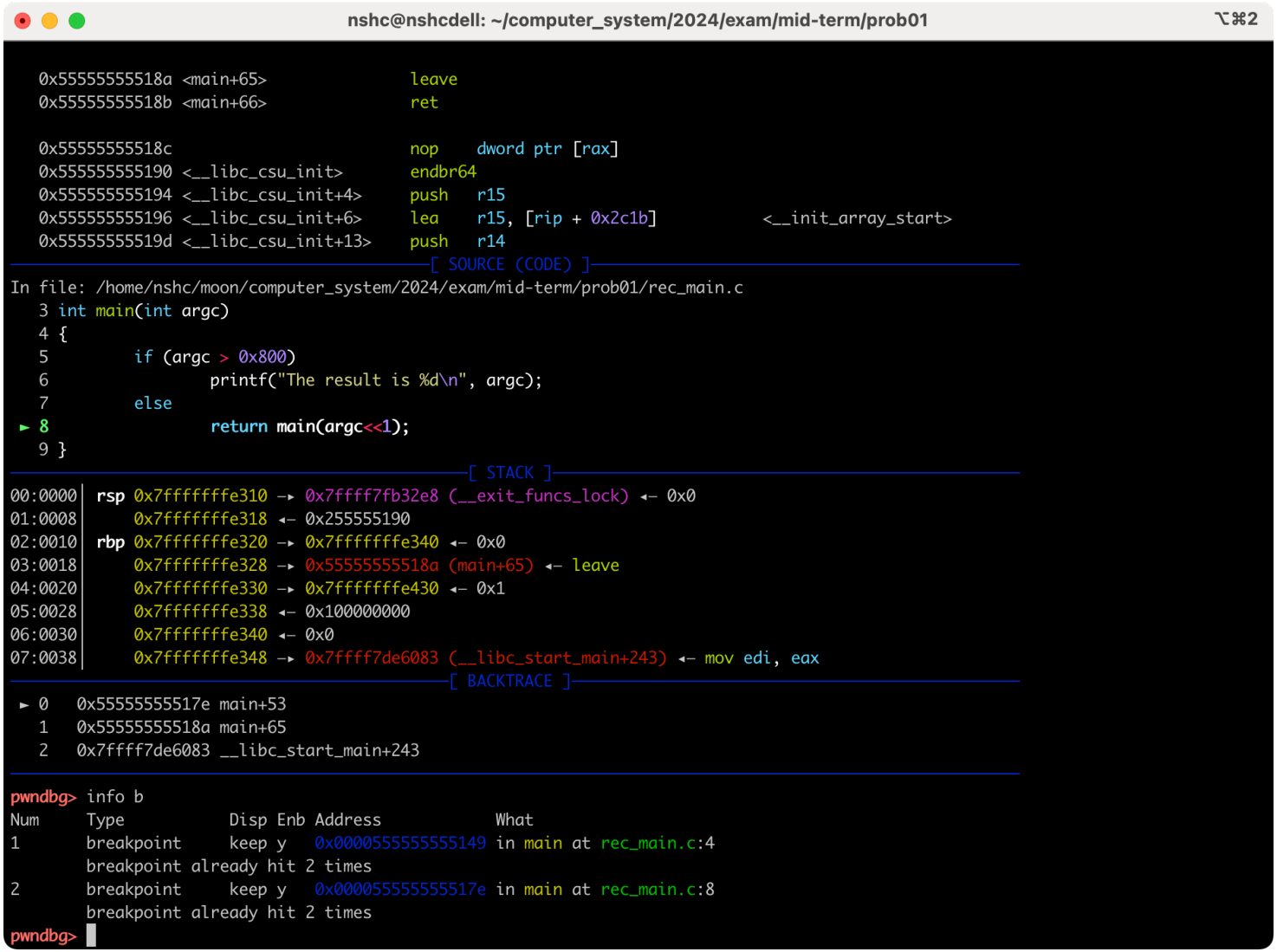
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
```

rec_main.c

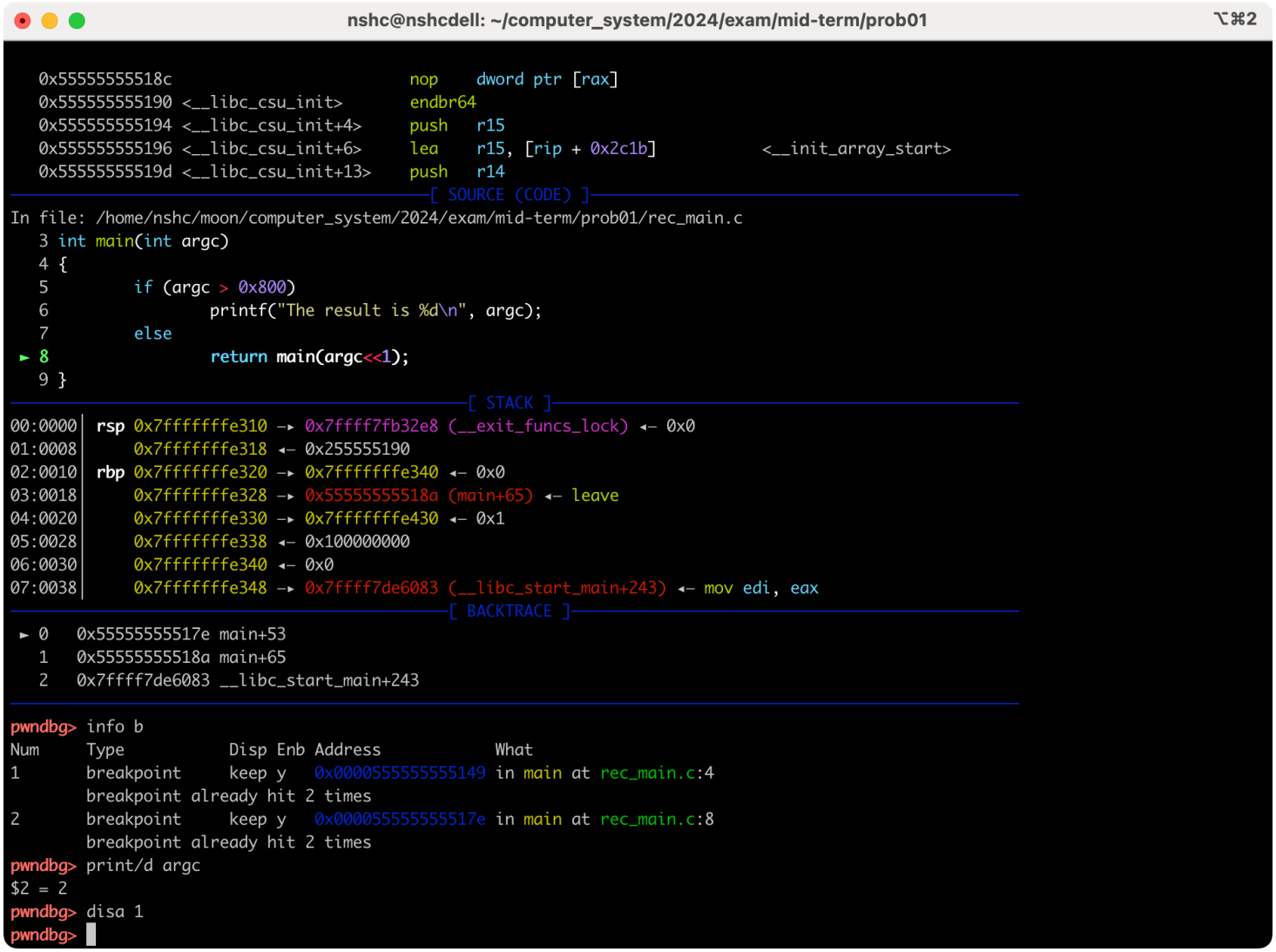
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
```

rec_main.c

- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
```

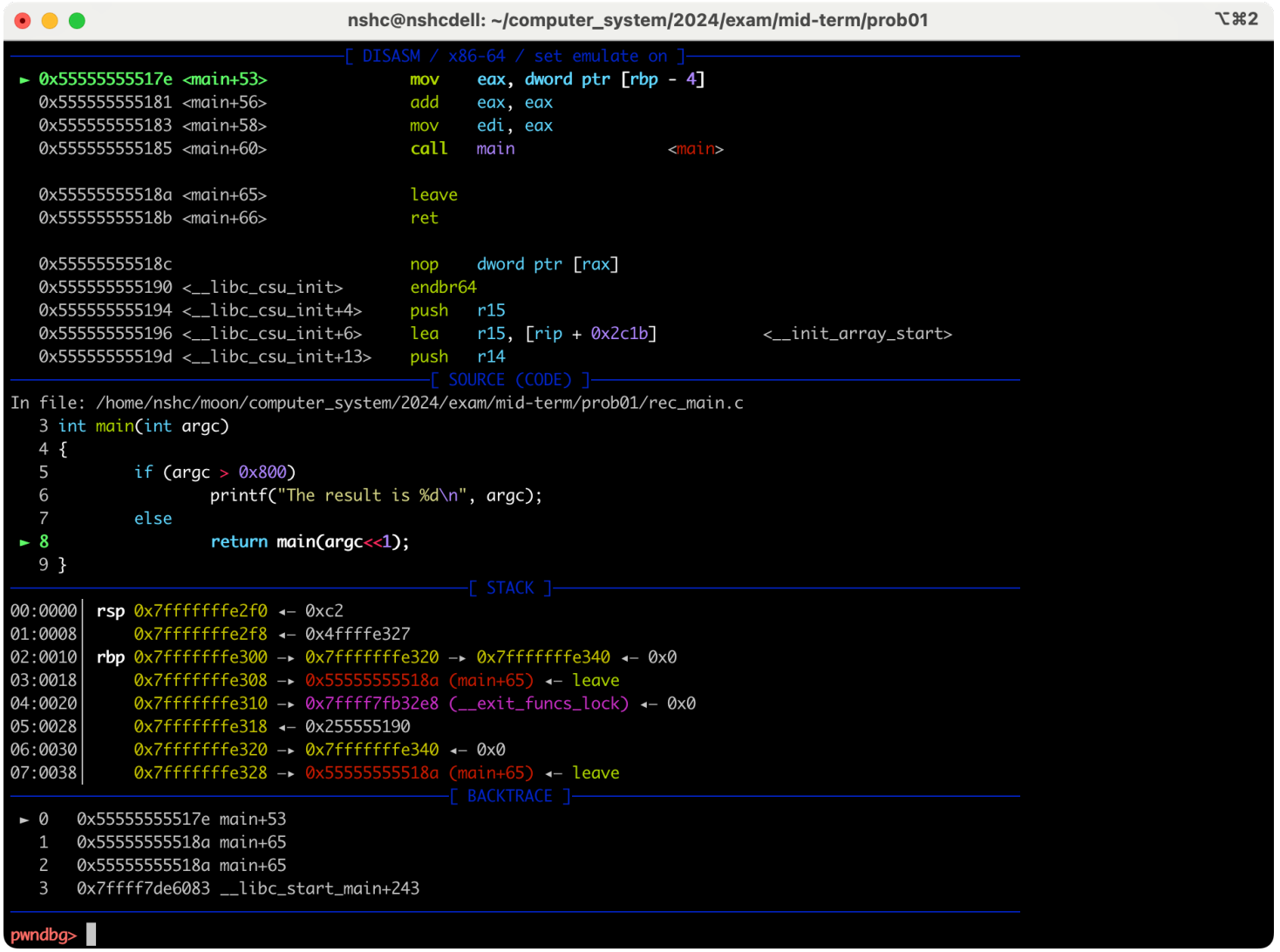
rec_main.c

- rec_main (debugging)


```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
```

rec_main.c

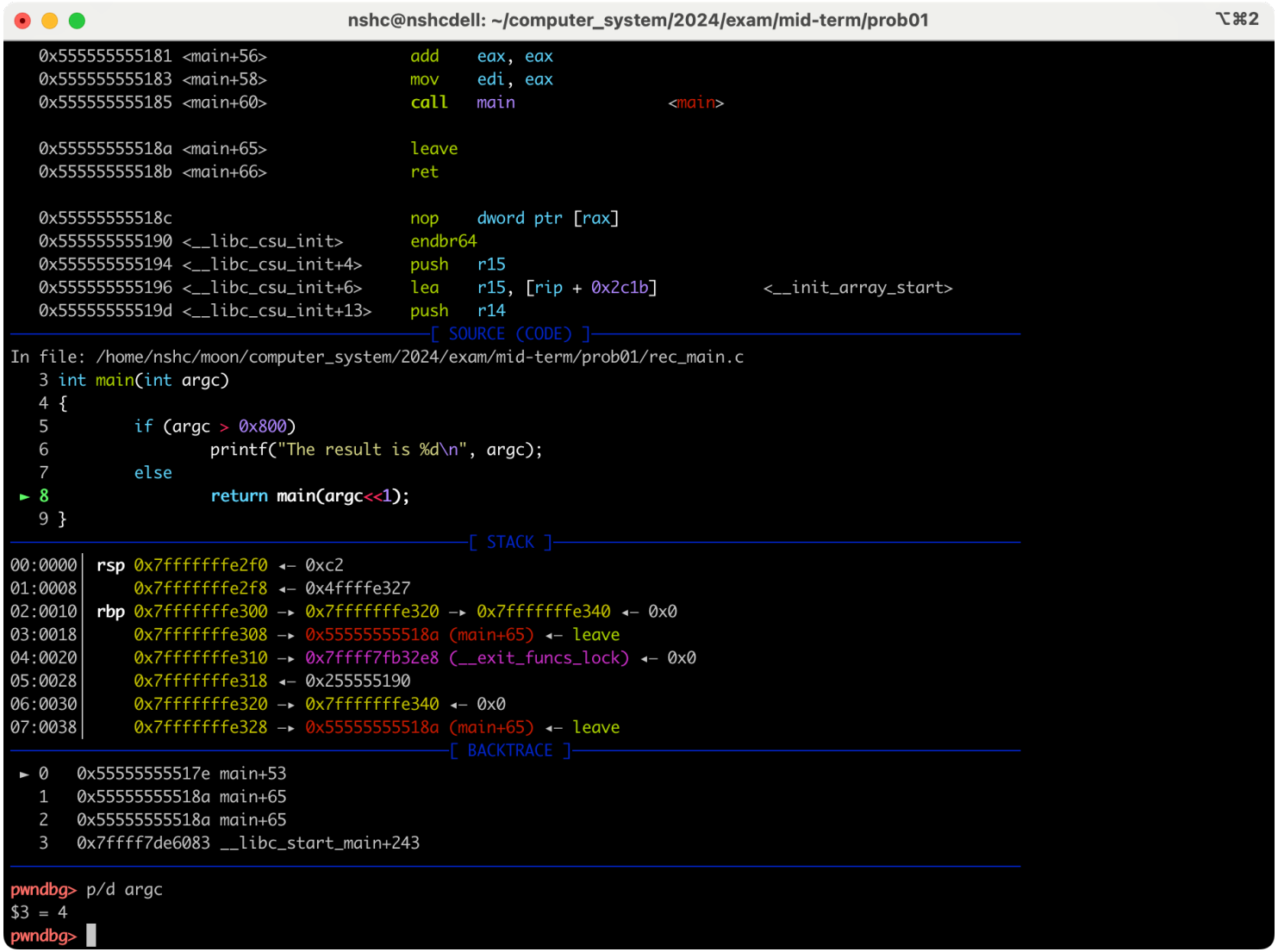
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
```

rec_main.c

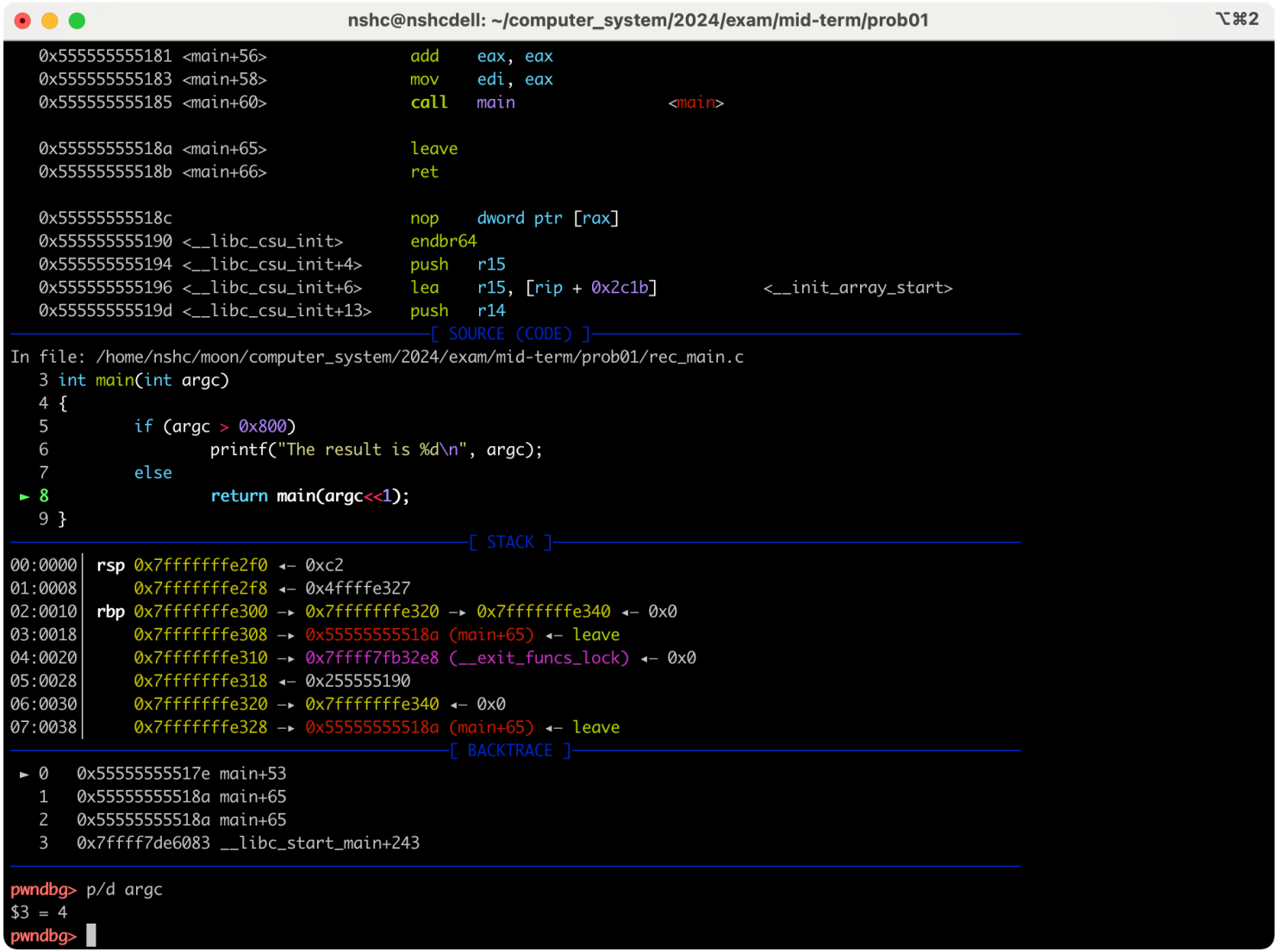
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
```

rec_main.c

- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
```

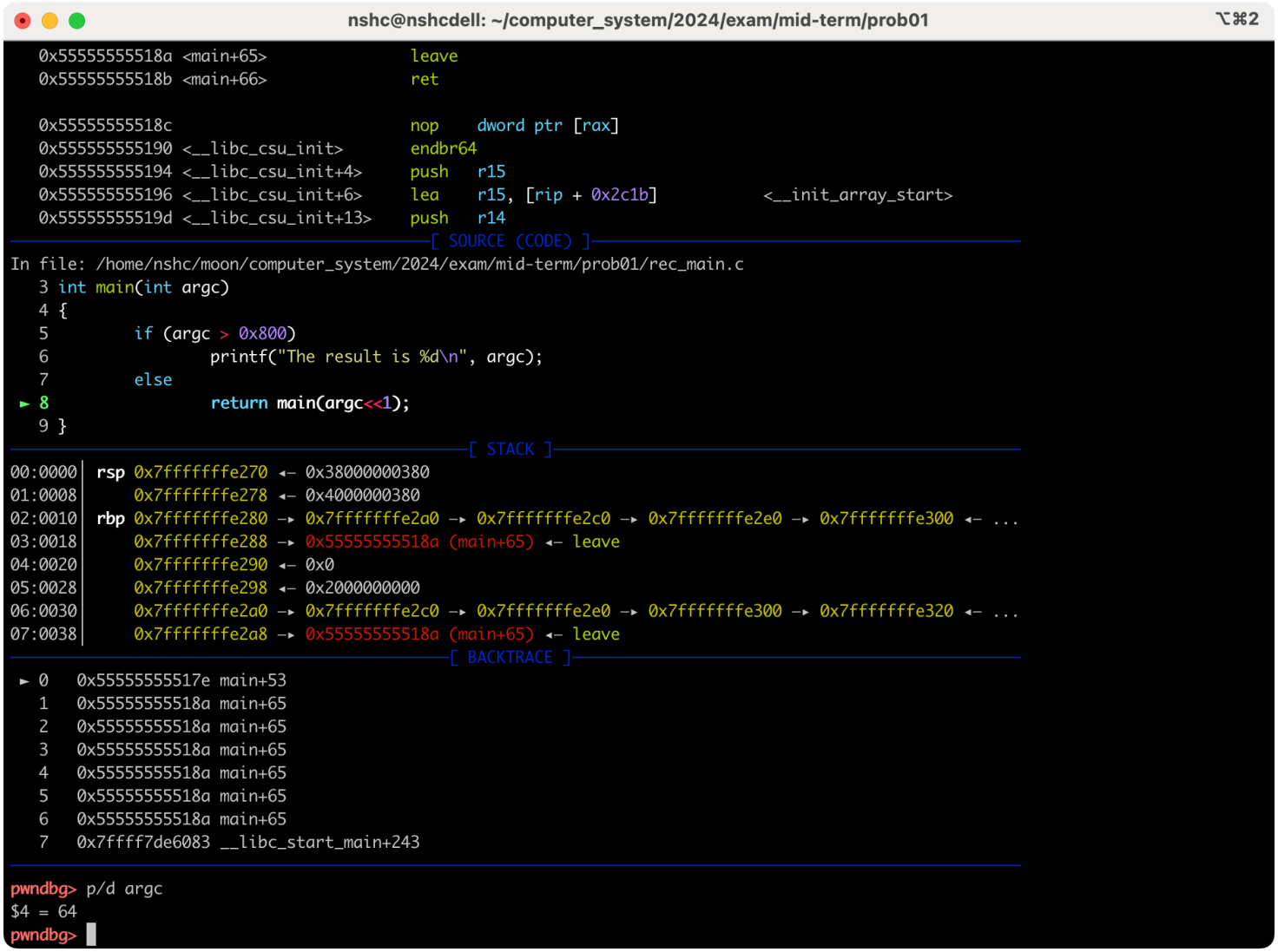
rec_main.c

- rec_main (debugging)


```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
> continue 4
```

rec_main.c

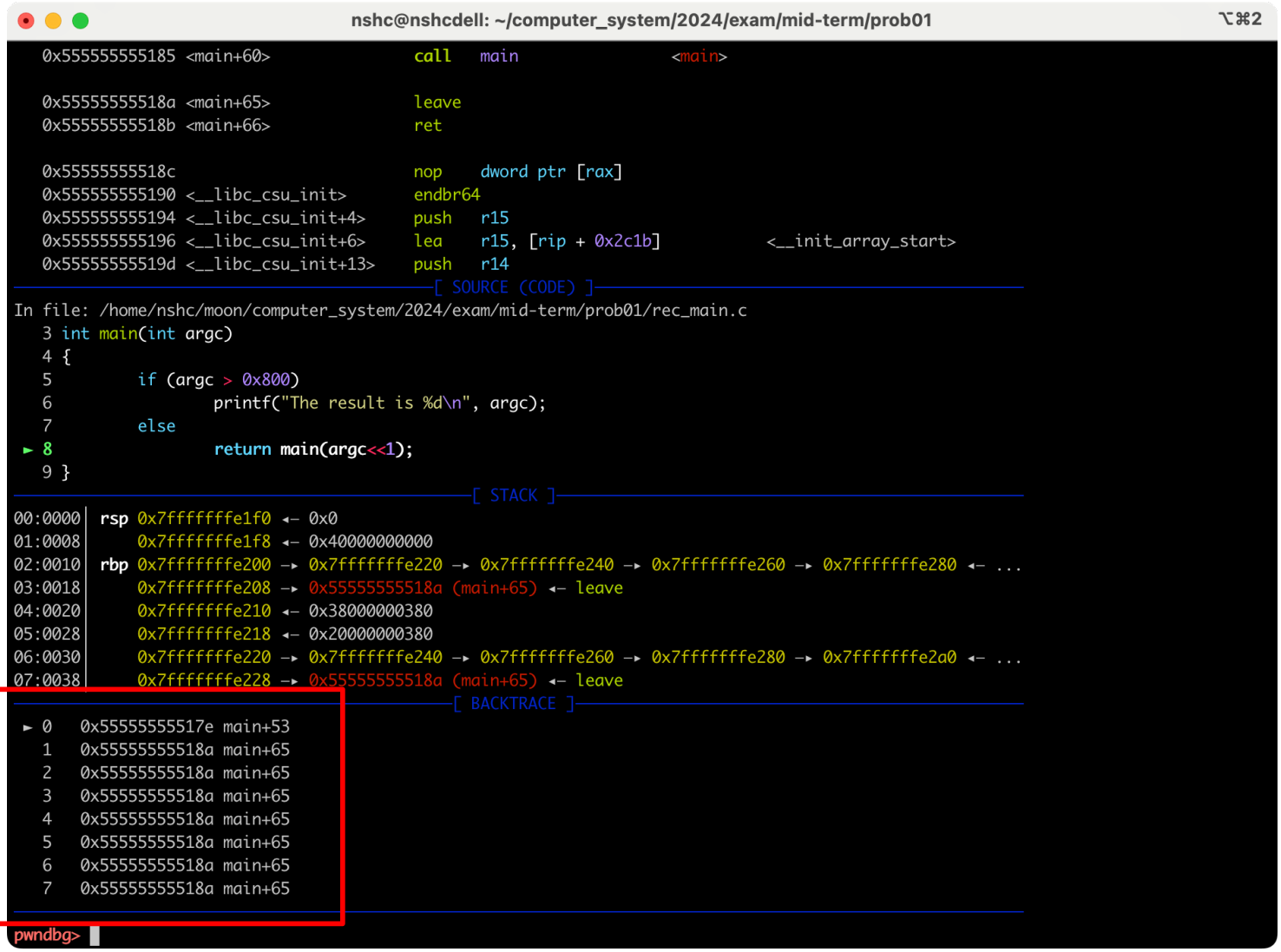
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
> continue 4
> p/d argc
```

rec_main.c

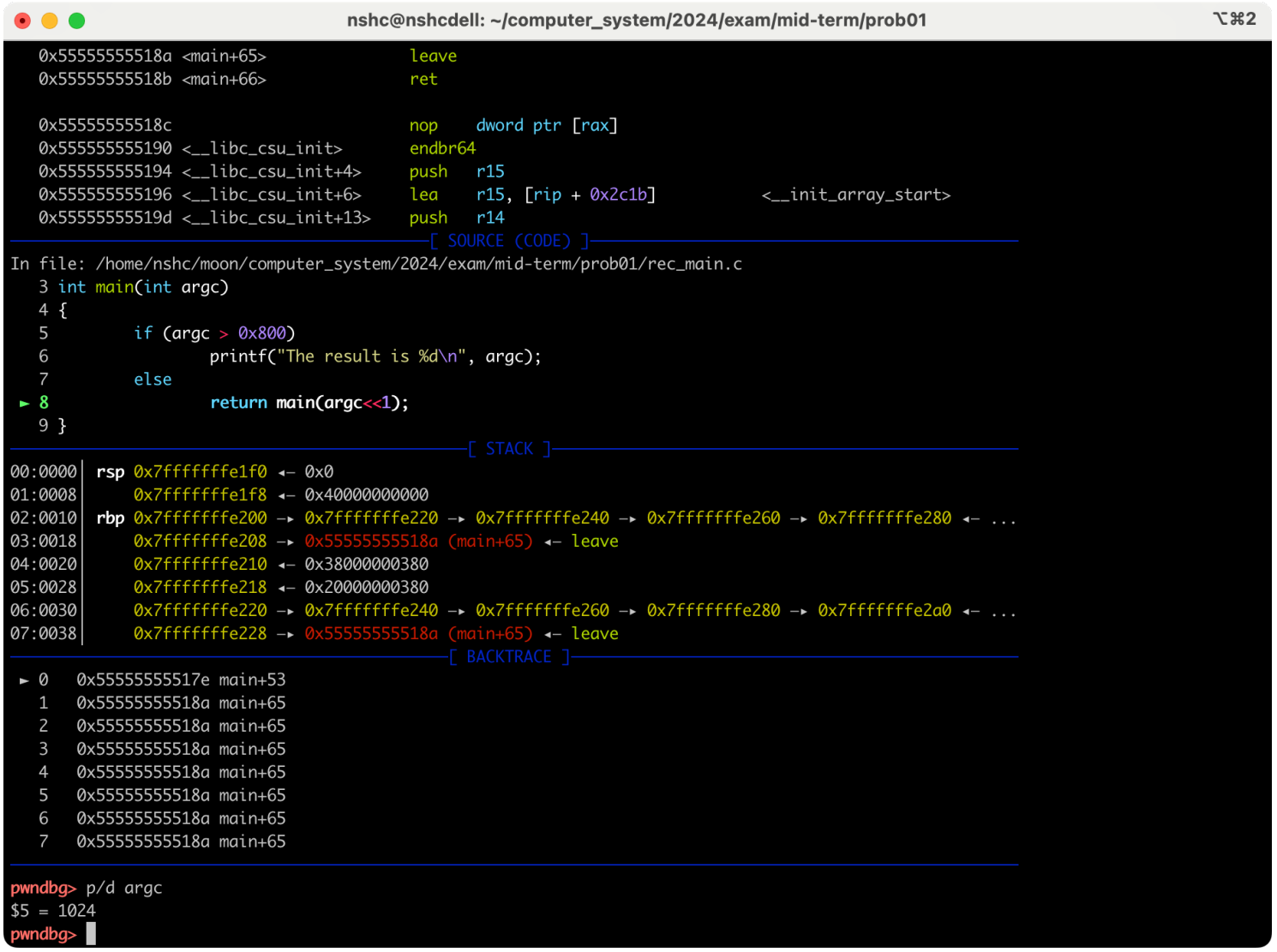
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
> continue 4
> p/d argc
> continue 4
```

rec_main.c

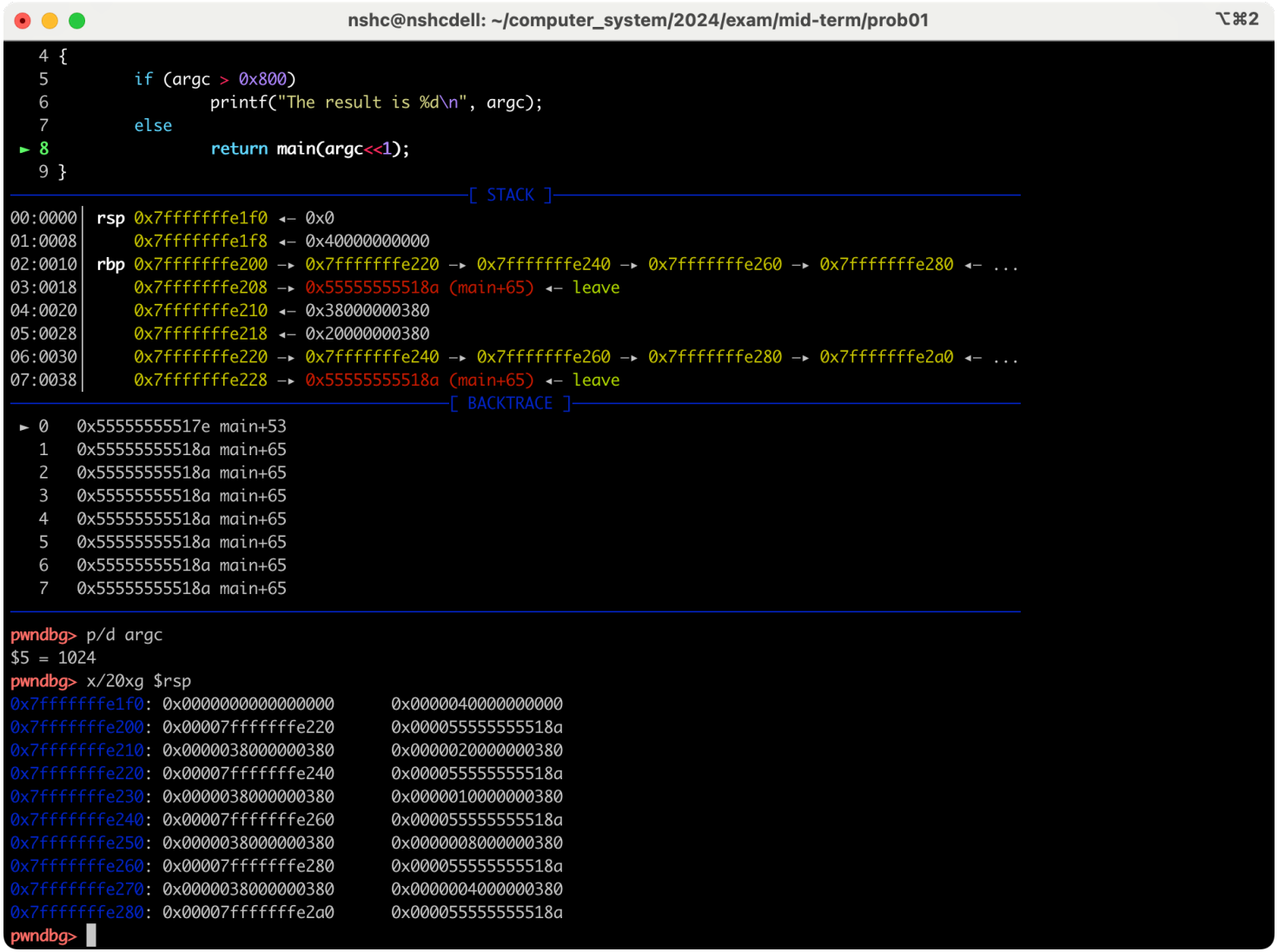
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
> continue 4
> p/d argc
> continue 4
> p/d argc
```

rec_main.c

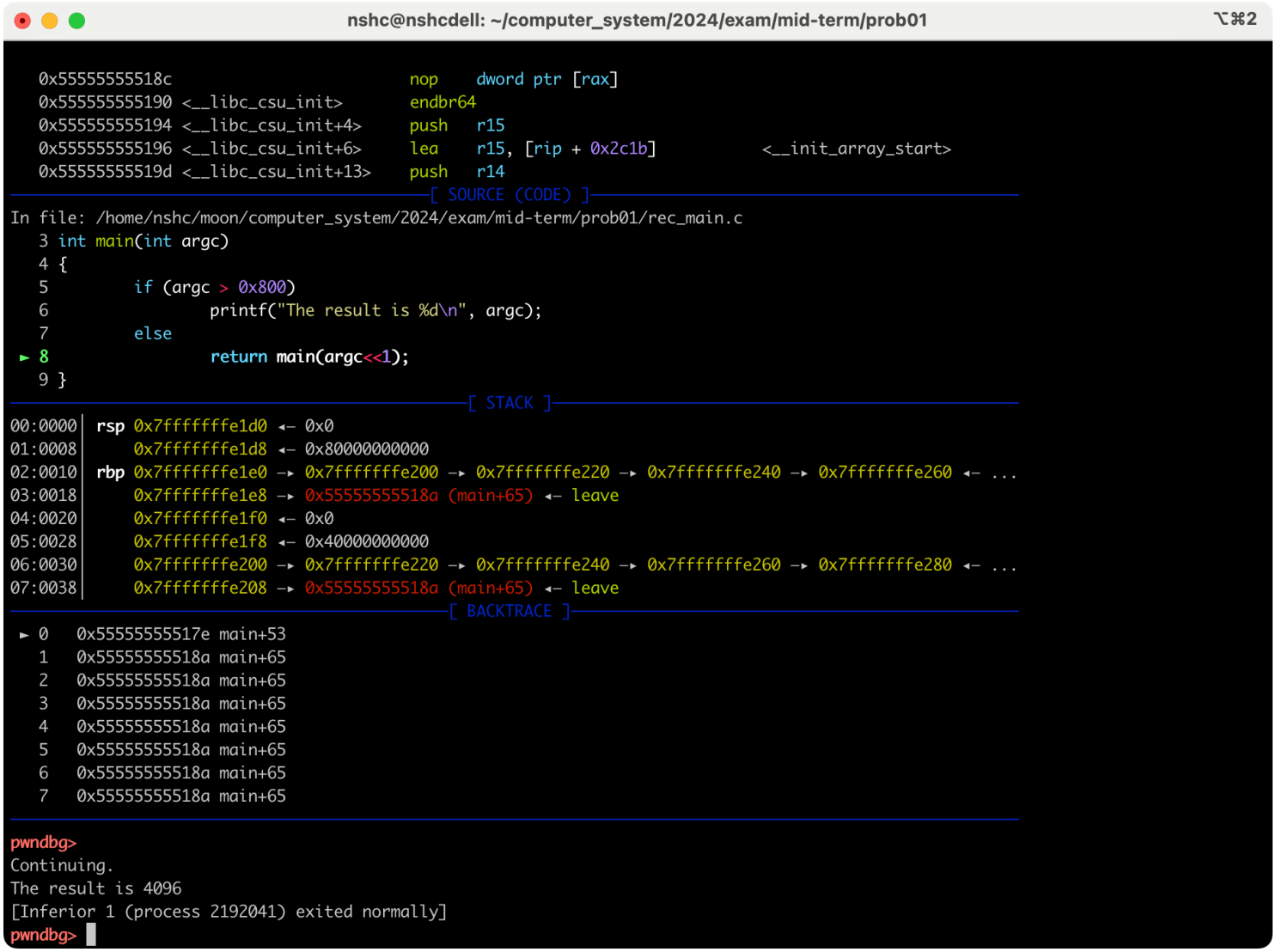
- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
> continue 4
> p/d argc
> continue 4
> p/d argc
> x/20xg $rsp
```

rec_main.c

- rec_main (debugging)




```
$gdb rec_main -q
> break main
> run
> break 8
> continue
> p/d argc
> info break
> disa 1
> info break
> continue
> p/d argc
> continue 4
> p/d argc
> continue 4
> p/d argc
> x/20xg $rsp
> continue
```

Practice : prob6

- C code

```
(a) newData->start = 0x

(b) newData->raw[0] = 0

(c) newData->raw[2] = 0

(d) newData->raw[4] = 0

(e) newData->sense = 0x
```

```
In file: /home/nshc/moon/computer_system/2024/exam/mid-term/prob06/prob6.c
   30     oldData->data = 1.5;
   31
   32     newData = (NewSensorData *) oldData;
   33
   34     printf("newData->code %x\n", newData->code);
► 35     printf("newData->start %x\n", newData->start);
   36     printf("newData->raw[0] %x\n", newData->raw[0]);
   37     printf("newData->raw[1] %x\n", newData->raw[1]);
   38     printf("newData->raw[2] %x\n", newData->raw[2]);
   39     printf("newData->raw[3] %x\n", newData->raw[3]);
   40     printf("newData->raw[4] %x\n", newData->raw[4]);
──────────────────────────────────────────[ STACK ]──────────────────────────────────────────
00:0000| esp 0xffffd450 —▸ 0x56557008 ◂— 'newData->code %x\n'
01:0004|     0xffffd454 ◂— 0x104f
02:0008|     0xffffd458 ◂— 0x9e
03:000c|     0xffffd45c —▸ 0xf7faf224 (__elf_set___libc_subfreeres_element_free_mem__) -
_mem) ◂— endbr32
04:0010|     0xffffd460 ◂— 0x0
05:0014|     0xffffd464 ◂— 0x14
06:0018|     0xffffd468 —▸ 0xf7fb1000 (_GLOBAL_OFFSET_TABLE_) ◂— 0x1ead6c
07:001c|     0xffffd46c —▸ 0x56556314 (main+44) ◂— add esp, 0x10
─────────────────────────────────────────[ BACKTRACE ]─────────────────────────────────────────
► 0 0x56556241 foo+84
  1 0x56556314 main+44
  2 0xf7de0ed5 __libc_start_main+245
──────────────────────────────────────────────────────────────────────────────────────────────

pwndbg> p *newData
$1 = {
  code = 4175,
  start = -256,
  raw = "\270\032P\200", <incomplete sequence \341>,
  sense = 143,
  ext = 0,
  data = -3.1566918117587027e+78
}
pwndbg>
```

Homework 5

- Homework #05
  - Overview

  - **Released date**: 11/1 (Fri.)
  - **Due date**: 11/8 (Fri.)
  - **Where to submit**: to e-class (http://eclass.seoultech.ac.kr)
    - Late submission is not allowed.
  - **Assigned score**: 1 points

1. Refer to the following source code.

```
#include <stdio.h>

unsigned long long fibonacci(unsigned long long n) {
   if(n == 0){
      return 0;
   } else if(n == 1) {
      return 1;
   } else {
      return (fibonacci(n-1) + fibonacci(n-2));
   }
}

int main() {
   unsigned long long i;
   unsigned long long n = 90;

   printf("Fibonacci of %lld: \n" , n);

   for(i = 0;i<n;i++) {
      printf("%lld ",fibonacci(i));
   }
   printf("\n");
   return 0;
}
```

Outline

- Debugging
  - Tools
- **Design**
  - **Managing complexity**
  - **Communication**
  - **Naming**
  - **Comments**

Design

- **A good design needs to achieve many things:**
  - Performance
  - Availability
  - Modifiability, portability
  - Scalability
  - Security
  - Testability
  - Usability
  - Cost to build, cost to operate

Design

- **A good design needs to achieve many things:**
  - Performance
  - Availability
  - Modifiability, portability
  - Scalability
  - Security
  - Testability
  - Usability
  - Cost to build, cost to operate

But above all else: it must be readable

Design

Good Design does:

Complexity Management &

Communication

Complexity

- There are well known limits to how much complexity a human can manage easily.

VOL. 63, NO. 2 MARCH, 1956

THE PSYCHOLOGICAL REVIEW

THE MAGICAL NUMBER SEVEN, PLUS OR MINUS TWO: SOME LIMITS ON OUR CAPACITY FOR PROCESSING INFORMATION [1]

GEORGE A. MILLER

Harvard University

Complexity Management

- However, patterns can be very helpful...

COGNITIVE PSYCHOLOGY 4, 55–81 (1973)

Perception in Chess[1]

WILLIAM G. CHASE AND HERBERT A. SIMON
Carnegie–Mellon University

This paper develops a technique for isolating and studying the perceptual structures that chess players perceive. Three chess players of varying strength — from master to novice — were confronted with two tasks: (1) A perception task, where the player reproduces a chess position in plain view, and (2) de Groot's (1965) short-term recall task, where the player reproduces a chess position after viewing it for 5 sec. The successive glances at the position in the perceptual task and long pauses in the memory task were used to segment the structures in the reconstruction protocol. The size and nature of these structures were then analyzed as a function of chess skill.

Complexity Management

Many techniques have been developed to help manage complexity:

- Separation of concerns
- Modularity
- Reusability
- Extensibility
- DRY
- Abstraction
- Information Hiding
- ...

Managing Complexity

- **Given the many ways to manage complexity**
  - Design code to be testable
  - Try to reuse testable chunks

Complexity Example

- **Split a cache access into three+ testable components**
  - State all of the steps that a cache access requires
  - Which steps depend on the operation being a load or a store?

Complexity Example

- **Split a cache access into three+ testable components**
  - State all of the steps that a cache access requires

    Convert address into tag, set index, block offset

    Look up the set using the set index

    Check if the tag matches any line in the set

    If so, hit

    If not a match, miss, then

        Find the LRU block

        Evict the LRU block

        Read in the new line from memory

    Update LRU

    Update dirty if the access was a store

  - Which steps depend on the operation being a load or a store?

Designs need to be testable

- **Testable design**
  - Testing versus Contracts
  - These are complementary techniques

- **Testing and Contracts are**
  - Acts of design more than verification
  - Acts of documentation

Designs need to be testable

- **Testable design**
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- **Testing and Contracts are**
  - Acts of design more than verification
  - Acts of documentation: executable documentation!

Testing Example

- **For your cache simulator, you can write your own traces**
  - Write a trace to test for a cache hit

    L 50, 1
    L 50, 1

  - Write a trace to test dirty bytes in cache

    S 100, 1

Testable design is modular

- **Modular code has: separation of concerns, encapsulation, abstraction**
  - Leads to: reusability, extensibility, readability, testability
- **Separation of concerns**
  - Create helper functions so each function does “one thing”
  - Functions should neither do too much nor too little
  - Avoid duplicated code
- **Encapsulation, abstraction, and respecting the interface**
  - Each module is responsible for its own internals
  - No outside code “intrudes” on the inner workings of another module

Trust the Compiler!

- Use plenty of temporary variables
- Use plenty of functions
- Let compiler do the math

Communication

When writing code, the author is communicating with:

- **The machine**
- **Other developers of the system**
- **Code reviewers**
- **Their future self**

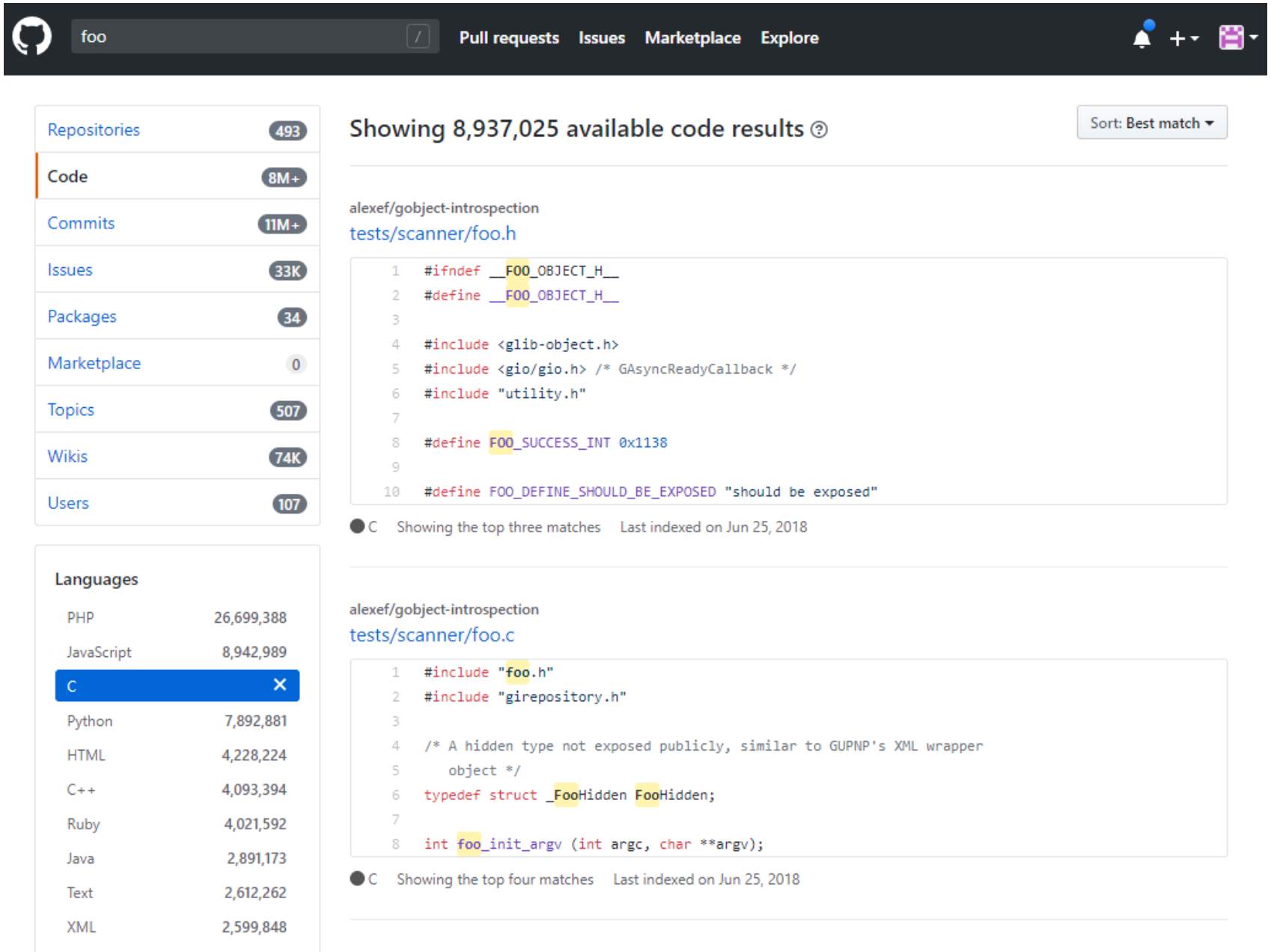
Communication

There are many techniques that have been developed around code communication:

- Tests
- Naming
- Comments
- Commit Messages
- Code Review
- Design Patterns
- ...

Naming

Avoid deliberately meaningless names:



Naming is understanding

"If you don't know what a thing should be called, you cannot know what it is.

If you don't know what it is, you cannot sit down and write the code." - Sam Gardiner

Better naming practices

1. Start with meaning and intention
2. Use words with precise meanings (avoid “data”, “info”, “perform”)
3. Prefer fewer words in names
4. Avoid abbreviations in names
5. Use code review to improve names
6. Read the code out loud to check that it sounds okay
7. Actually rename things

Naming guidelines – Use dictionary words

- **Only use dictionary words and abbreviations that appear in a dictionary.**
  - For example: FileCpy -> FileCopy
  - Avoid vague abbreviations such as acc, mod, auth, etc..

Avoid using single-letter names

- **Single letters are unsearchable**
  - Give no hints as to the variable's usage

- **Exceptions are loop counters**
  - Especially if you know why i, j, etc were originally used
  - C/unix systems have a few other common conventions, such as 'fd' for "file descriptor" and "str" for a string argument to a function. Following existing style is fine & good.

Limit name character length

“Good naming limits individual name length, and reduces the need for specialized vocabulary” – Philip Relf

Limit name word count

- Keep names to a four word maximum
- Limit names to the number of words that people can read at a glance.

- Which of each pair do you prefer?

```
a1) arraysOfSetsOfLinesOfBlocks

a2) cache


b1) evictedData

b2) evictedDataBytes
```

Describe Meaning

- **Use descriptive names.**
- **Avoid names with no meaning: a, foo, blah, tmp, etc**

- **There are reasonable exceptions:**

```
void swap(int* a, int* b) {
  int tmp = *a;
  *a = *b;
  *b = tmp;
}
```

Use a large vocabulary

- **Be more specific when possible:**
  - Person -> Employee

- **What is size in this binaryTree?**

```
struct binaryTree {
  int size;
  …
};
```

height
numChildren
subTreeNumNodes
keyLength

Use problem domain terms

- **Use the correct term in the problem domain's language.**
  - Hint: as a student, consider the terms in the assignment

- **In cachelab, consider the following:**

```
line

element
```

Use opposites precisely

- **Consistently use opposites in standard pairs**
  - first/end -> first/last

Comments

Don’t Comments

- **Don’t say what the code does**
  - because the code already says that
- **Don’t explain awkward logic**
  - improve the code to make it clear
- **Don’t add too many comments**
  - it’s messy, and they get out of date

Awkward Code

- **Imagine someone (TA, employer, etc) has to read your code**
  - Would you rather rewrite or comment the following?

```
(*(void **)((*(void **)(bp)) + DSIZE)) = (*(void **)(bp + DSIZE));
```

  - How about?

```
bp->prev->next = bp->next;
```

  - Both lines update program state in the same way.

Do Comments

- Answer the question: why the code exists

- When should I use this code?
- When shouldn't I use it?
- What are the alternatives to this code?

Why does this exist?

- **Explain why a magic number is what it is.**

```
// Each address is 64-bit, which is 16 + 1 hex characters
const int MAX_ADDRESS_LENGTH = 17;
```

- **When should this code be used? Is there an alternative?**

```
unsigned power2(unsigned base, unsigned expo){
    unsigned i;
    unsigned result = 1;
    for(i=0;i<expo;i++){
        result+=result;
    }
    return result;
}
```

How to write good comments

1. **Code by commenting!**
   Write short comment
   1. Helps you think about design & overcome blank-page problem
   2. Single line comments
   3. Example: Write four one-line comments for quick sort

```
// Initialize locals
// Pick a pivot value
// Reorder array around the pivot
// Recurse
```

How to write good comments

1. **Write short comments of what the code will do.**
    1. Single line comments
    2. Example: Write four one-line comments for quick sort

2. **Write that code.**

3. **Revise comments / code**
    1. If the code or comments are awkward or complex
    2. Join / Split comments as needed

4. **Maintain code and revised comments**

Commit Messages

- **Committing code to a source repository is a vital part of development**
  - Protects against system failures and typos:
    - cat foo.c versus cat > foo.c
  - The commit messages are your record of your work
    - Communicating to your future self
    - Describe in one line what you did

  "Parses command line arguments"

  "fix bug in unique tests, race condition not solved"

  "seg list finished, performance is …"
- **Use branches**

Summary

- **Programs have defects**
  - Be systematic about finding them
- **Programs are more complex than humans can manage**
  - Write code to be manageable
- **Programming is not solitary, even if you are communicating with a grader or a future self**
  - Be understandable in your communication

Acknowledgements

- **Some debugging content derived from:**
  - http://www.whyprogramsfail.com/slides.php
- **Some code examples for design are based on:**
  - "The Art of Readable Code". Boswell and Foucher. 2011.
- **Lecture originally written by**
  - Michael Hilton and Brian Railing