Task 1: helloWorld.c

ltrace -c ./helloWorld.o
Hello World - Ananya
% time   seconds usecs/call   calls   function
------ ----------- ----------- --------- --------------------
------ ----------- ----------- --------- --------------------
100.00   0.000000   0 total

ltrace -S ./helloWorld.o
SYS_brk(0)   = 0x5638f46cc000
SYS_arch_prctl(0x3001, 0x7fff4c6c2a90, 0x7fb32bbe8230, 0x7fb32bbf1e13) = -22
SYS_access("/etc/ld.so.preload", 04)   = -2
SYS_openat(0xffffff9c, 0x7fb32bbf1b80, 0x80000, 0) = 3
SYS_fstat(3, 0x7fff4c6c1c90)   = 0
SYS_mmap(0, 0x11e75, 1, 2)   = 0x7fb32bbba000
SYS_close(3)   = 0

```
SYS_openat(0xffffff9c, 0x7fb32bbfbe10, 0x80000, 0) = 3
SYS_read(3, "\177ELF\002\001\001\003", 832)    = 832
SYS_pread(3, 0x7fff4c6c1a50, 784, 64)        = 784
SYS_pread(3, 0x7fff4c6c1a20, 32, 848)        = 32
SYS_pread(3, 0x7fff4c6c19d0, 68, 880)        = 68
SYS_fstat(3, 0x7fff4c6c1ce0)              = 0
SYS_mmap(0, 8192, 3, 34)                 = 0x7fb32bbb8000
SYS_pread(3, 0x7fff4c6c1930, 784, 64)        = 784
SYS_pread(3, 0x7fff4c6c1610, 32, 848)        = 32
SYS_pread(3, 0x7fff4c6c15f0, 68, 880)         = 68
SYS_mmap(0, 0x1f14d8, 1, 2050)              = 0x7fb32b9c6000
SYS_mprotect(0x7fb32b9eb000, 1847296, 0)      = 0
SYS_mmap(0x7fb32b9eb000, 0x178000, 5, 2066)    = 0x7fb32b9eb000
SYS_mmap(0x7fb32bb63000, 0x4a000, 1, 2066)     = 0x7fb32bb63000
SYS_mmap(0x7fb32bbae000, 0x6000, 3, 2066)      = 0x7fb32bbae000
SYS_mmap(0x7fb32bbb4000, 0x34d8, 3, 50)        = 0x7fb32bbb4000
SYS_close(3)                      = 0
SYS_arch_prctl(4098, 0x7fb32bbb9540, 0xffff804cd44461a0, 64) = 0
SYS_mprotect(0x7fb32bbae000, 12288, 1)        = 0
SYS_mprotect(0x5638f2d9b000, 4096, 1)         = 0
SYS_mprotect(0x7fb32bbf9000, 4096, 1)         = 0
SYS_munmap(0x7fb32bbba000, 73333)             = 0
SYS_fstat(1, 0x7fff4c6c28f0)              = 0
SYS_brk(0)                       = 0x5638f46cc000
SYS_brk(0x5638f46ed000)                 = 0x5638f46ed000
SYS_write(1, "Hello World - Ananya\n", 21Hello World - Ananya
)     = 21
SYS_exit_group(0 <no return ...>
+++ exited (status 0) +++
```

ltrace -t ./helloWorld.o
Hello World - Ananya
17:21:09 +++ exited (status 0) +++

ltrace -T ./helloWorld.o
Hello World - Ananya
+++ exited (status 0) +++

strace -c ./helloWorld.o
Hello World - Ananya

% time	seconds	usecs/call	calls	errors	syscall
0.00	0.000000	0	1		read
0.00	0.000000	0	1		write

0.00	0.000000	0	2		close
0.00	0.000000	0	3		fstat
0.00	0.000000	0	7		mmap
0.00	0.000000	0	4		mprotect
0.00	0.000000	0	1		munmap
0.00	0.000000	0	3		brk
0.00	0.000000	0	6		pread64
0.00	0.000000	0	1	1	access
0.00	0.000000	0	1		execve
0.00	0.000000	0	2	1	arch_prctl
0.00	0.000000	0	2		openat

```
------ ----------- ----------- --------- --------- ----------------
100.00   0.000000                34       2 total
```

strace -C ./helloWorld.o

```
execve("./helloWorld.o", ["./helloWorld.o"], 0x7fffb090f048 /* 49 vars */) = 0
brk(NULL)                        = 0x562b57923000
arch_prctl(0x3001 /* ARCH_??? */, 0x7ffc63afb890) = -1 EINVAL (Invalid argument)
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
openat(AT_FDCWD, "/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=73333, ...}) = 0
mmap(NULL, 73333, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7ff9c2d18000
close(3)                     = 0
openat(AT_FDCWD, "/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\360q\2\0\0\0\0\0"..., 832) = 832
pread64(3, "\6\0\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\0\3\0\0\0\0\0\0\0"..., 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
fstat(3, {st_mode=S_IFREG|0755, st_size=2029224, ...}) = 0
mmap(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0)
= 0x7ff9c2d16000
pread64(3, "\6\0\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\0\3\0\0\0\0\0\0\0"..., 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
mmap(NULL, 2036952, PROT_READ, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) =
0x7ff9c2b24000
mprotect(0x7ff9c2b49000, 1847296, PROT_NONE) = 0
mmap(0x7ff9c2b49000, 1540096, PROT_READ|PROT_EXEC,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x25000) = 0x7ff9c2b49000
```

```
mmap(0x7ff9c2cc1000, 303104, PROT_READ,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x19d000) = 0x7ff9c2cc1000
mmap(0x7ff9c2d0c000, 24576, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1e7000) = 0x7ff9c2d0c000
mmap(0x7ff9c2d12000, 13528, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7ff9c2d12000
close(3)                       = 0
arch_prctl(ARCH_SET_FS, 0x7ff9c2d17540) = 0
mprotect(0x7ff9c2d0c000, 12288, PROT_READ) = 0
mprotect(0x562b5735c000, 4096, PROT_READ) = 0
mprotect(0x7ff9c2d57000, 4096, PROT_READ) = 0
munmap(0x7ff9c2d18000, 73333)        = 0
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(0x88, 0), ...}) = 0
brk(NULL)                      = 0x562b57923000
brk(0x562b57944000)              = 0x562b57944000
write(1, "Hello World - Ananya\n", 21Hello World - Ananya
)  = 21
exit_group(0)                  = ?
+++ exited with 0 +++
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
  0.00   0.000000         0      1            read
  0.00   0.000000         0      1            write
  0.00   0.000000         0      2            close
  0.00   0.000000         0      3            fstat
  0.00   0.000000         0      7            mmap
  0.00   0.000000         0      4            mprotect
  0.00   0.000000         0      1            munmap
  0.00   0.000000         0      3            brk
  0.00   0.000000         0      6            pread64
  0.00   0.000000         0      1        1 access
  0.00   0.000000         0      1            execve
  0.00   0.000000         0      2        1 arch_prctl
  0.00   0.000000         0      2            openat
------ ----------- ----------- --------- --------- ----------------
100.00   0.000000               34        2 total
```

strace -t ./helloWorld.o
```
17:25:15 execve("./helloWorld.o", ["./helloWorld.o"], 0x7ffca895dde8 /* 49 vars */) = 0
17:25:15 brk(NULL)                = 0x55803d85b000
17:25:15 arch_prctl(0x3001 /* ARCH_??? */, 0x7ffdf07c6c30) = -1 EINVAL (Invalid argument)
17:25:15 access("/etc/ld.so.preload", R_OK) = -1 ENOENT (No such file or directory)
17:25:15 openat(AT_FDCWD, "/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
17:25:15 fstat(3, {st_mode=S_IFREG|0644, st_size=73333, ...}) = 0
```

```
17:25:15 mmap(NULL, 73333, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7ffbdfc4b000
17:25:15 close(3)                = 0
17:25:15 openat(AT_FDCWD, "/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
17:25:15 read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\360q\2\0\0\0\0\0"..., 832) = 832
17:25:15 pread64(3, "\6\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64)
= 784
17:25:15 pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\3\0\0\0\0\0\0\0", 32, 848)
= 32
17:25:15 pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
17:25:15 fstat(3, {st_mode=S_IFREG|0755, st_size=2029224, ...}) = 0
17:25:15 mmap(NULL, 8192, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x7ffbdfc49000
17:25:15 pread64(3, "\6\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64)
= 784
17:25:15 pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\3\0\0\0\0\0\0\0", 32, 848)
= 32
17:25:15 pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
17:25:15 mmap(NULL, 2036952, PROT_READ, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) =
0x7ffbdfa57000
17:25:15 mprotect(0x7ffbdfa7c000, 1847296, PROT_NONE) = 0
17:25:15 mmap(0x7ffbdfa7c000, 1540096, PROT_READ|PROT_EXEC,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x25000) = 0x7ffbdfa7c000
17:25:15 mmap(0x7ffbdfbf4000, 303104, PROT_READ,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x19d000) = 0x7ffbdfbf4000
17:25:15 mmap(0x7ffbdfc3f000, 24576, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1e7000) = 0x7ffbdfc3f000
17:25:15 mmap(0x7ffbdfc45000, 13528, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7ffbdfc45000
17:25:15 close(3)                = 0
17:25:15 arch_prctl(ARCH_SET_FS, 0x7ffbdfc4a540) = 0
17:25:15 mprotect(0x7ffbdfc3f000, 12288, PROT_READ) = 0
17:25:15 mprotect(0x55803baf5000, 4096, PROT_READ) = 0
17:25:15 mprotect(0x7ffbdfc8a000, 4096, PROT_READ) = 0
17:25:15 munmap(0x7ffbdfc4b000, 73333)  = 0
17:25:15 fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(0x88, 0), ...}) = 0
17:25:15 brk(NULL)               = 0x55803d85b000
17:25:15 brk(0x55803d87c000)         = 0x55803d87c000
17:25:15 write(1, "Hello World - Ananya\n", 21Hello World - Ananya
) = 21
17:25:15 exit_group(0)             = ?
```

17:25:15 +++ exited with 0 +++

strace -c -w ./helloWorld.o
Hello World - Ananya

% time	seconds	usecs/call	calls	errors	syscall
48.03	0.000255	254	1		execve
8.23	0.000044	43	1		write
7.76	0.000041	5	7		mmap
6.34	0.000034	11	3		brk
5.72	0.000030	7	4		mprotect
5.60	0.000030	9	3		fstat
4.23	0.000022	3	6		pread64
4.21	0.000022	11	2		openat
2.96	0.000016	15	1	1	access
2.39	0.000013	6	2	1	arch_prctl
2.30	0.000012	12	1		munmap
1.38	0.000007	3	2		close
0.84	0.000004	4	1		read
100.00	0.000530		34	2	total

time ./helloWorld.o
Hello World - Ananya

real 0m0.001s
user 0m0.001s
sys 0m0.000s

/usr/bin/time -v ./helloWorld.o
Hello World - Ananya
Command being timed: "./helloWorld.o"
User time (seconds): 0.00
System time (seconds): 0.00
Percent of CPU this job got: 0%
Elapsed (wall clock) time (h:mm:ss or m:ss): 0:00.00
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1296
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 61

Voluntary context switches: 1
Involuntary context switches: 2
Swaps: 0
File system inputs: 0
File system outputs: 0
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0

helloWorld.c is an I/O bound job

After modifying the program, to make helloWorld.c a CPU bound job -
/usr/bin/time -v ./helloWorld.o
Hello World - Ananya
Command being timed: "./helloWorld.o"
User time (seconds): 0.19
System time (seconds): 0.00
Percent of CPU this job got: 96%
Elapsed (wall clock) time (h:mm:ss or m:ss): 0:00.20
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1212
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 61
Voluntary context switches: 1
Involuntary context switches: 23
Swaps: 0
File system inputs: 0
File system outputs: 0
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0

Task 2

ltrace ./toh.o
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 3 from rod A to rod C
Move disk 1 from rod B to rod A
Move disk 2 from rod B to rod C
Move disk 1 from rod A to rod C
Move disk 4 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 2 from rod C to rod A
Move disk 1 from rod B to rod A
Move disk 3 from rod C to rod B
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 5 from rod A to rod C
Move disk 1 from rod B to rod A
Move disk 2 from rod B to rod C
Move disk 1 from rod A to rod C
Move disk 3 from rod B to rod A
Move disk 1 from rod C to rod B
Move disk 2 from rod C to rod A
Move disk 1 from rod B to rod A
Move disk 4 from rod B to rod C
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 3 from rod A to rod C
Move disk 1 from rod B to rod A
Move disk 2 from rod B to rod C
Move disk 1 from rod A to rod C
Move disk 6 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 2 from rod C to rod A
Move disk 1 from rod B to rod A
Move disk 3 from rod C to rod B
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 4 from rod C to rod A
Move disk 1 from rod B to rod A

Move disk 2 from rod B to rod C
Move disk 1 from rod A to rod C
Move disk 3 from rod B to rod A
Move disk 1 from rod C to rod B
Move disk 2 from rod C to rod A
Move disk 1 from rod B to rod A
Move disk 5 from rod C to rod B
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 3 from rod A to rod C
Move disk 1 from rod B to rod A
Move disk 2 from rod B to rod C
Move disk 1 from rod A to rod C
Move disk 4 from rod A to rod B
Move disk 1 from rod C to rod B
Move disk 2 from rod C to rod A
Move disk 1 from rod B to rod A
Move disk 3 from rod C to rod B
Move disk 1 from rod A to rod C
Move disk 2 from rod A to rod B
Move disk 1 from rod C to rod B+++ exited (status 0) +++

strace ./toh.o
execve("./toh.o", ["./toh.o"], 0x7ffd878b5660 /* 49 vars */) = 0
brk(NULL)   = 0x556642feb000
arch_prctl(0x3001 /* ARCH_??? */, 0x7ffe0e664dd0) = -1 EINVAL (Invalid argument)
access("/etc/ld.so.preload", R_OK)   = -1 ENOENT (No such file or directory)
openat(AT_FDCWD, "/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=73333, ...}) = 0
mmap(NULL, 73333, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f93d5503000
close(3)   = 0
openat(AT_FDCWD, "/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\360q\2\0\0\0\0\0"..., 832) = 832
pread64(3, "\6\0\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\0\3\0\0\0\0\0\0\0", 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
fstat(3, {st_mode=S_IFREG|0755, st_size=2029224, ...}) = 0
mmap(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0)
= 0x7f93d5501000
pread64(3, "\6\0\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\0\3\0\0\0\0\0\0\0", 32, 848) = 32

```
pread64(3,
"\4\0\0\0\24\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
mmap(NULL, 2036952, PROT_READ, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) =
0x7f93d530f000
mprotect(0x7f93d5334000, 1847296, PROT_NONE) = 0
mmap(0x7f93d5334000, 1540096, PROT_READ|PROT_EXEC,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x25000) = 0x7f93d5334000
mmap(0x7f93d54ac000, 303104, PROT_READ,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x19d000) = 0x7f93d54ac000
mmap(0x7f93d54f7000, 24576, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1e7000) = 0x7f93d54f7000
mmap(0x7f93d54fd000, 13528, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7f93d54fd000
close(3)                    = 0
arch_prctl(ARCH_SET_FS, 0x7f93d5502540) = 0
mprotect(0x7f93d54f7000, 12288, PROT_READ) = 0
mprotect(0x5566419d6000, 4096, PROT_READ) = 0
mprotect(0x7f93d5542000, 4096, PROT_READ) = 0
munmap(0x7f93d5503000, 73333)      = 0
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(0x88, 0x1), ...}) = 0
brk(NULL)                   = 0x556642feb000
brk(0x55664300c000)            = 0x55664300c000
write(1, "\n", 1
)                = 1
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 2 from rod A to rod B"..., 33 Move disk 2 from rod A to rod B
) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 3 from rod A to rod C"..., 33 Move disk 3 from rod A to rod C
) = 33
write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33
write(1, " Move disk 2 from rod B to rod C"..., 33 Move disk 2 from rod B to rod C
) = 33
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 4 from rod A to rod B"..., 33 Move disk 4 from rod A to rod B
) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 2 from rod C to rod A"..., 33 Move disk 2 from rod C to rod A
```

) = 33

write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33

write(1, " Move disk 3 from rod C to rod B"..., 33 Move disk 3 from rod C to rod B
) = 33

write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33

write(1, " Move disk 2 from rod A to rod B"..., 33 Move disk 2 from rod A to rod B
) = 33

write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33

write(1, " Move disk 5 from rod A to rod C"..., 33 Move disk 5 from rod A to rod C
) = 33

write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33

write(1, " Move disk 2 from rod B to rod C"..., 33 Move disk 2 from rod B to rod C
) = 33

write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33

write(1, " Move disk 3 from rod B to rod A"..., 33 Move disk 3 from rod B to rod A
) = 33

write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33

write(1, " Move disk 2 from rod C to rod A"..., 33 Move disk 2 from rod C to rod A
) = 33

write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33

write(1, " Move disk 4 from rod B to rod C"..., 33 Move disk 4 from rod B to rod C
) = 33

write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33

write(1, " Move disk 2 from rod A to rod B"..., 33 Move disk 2 from rod A to rod B
) = 33

write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33

write(1, " Move disk 3 from rod A to rod C"..., 33 Move disk 3 from rod A to rod C
) = 33

write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33

write(1, " Move disk 2 from rod B to rod C"..., 33 Move disk 2 from rod B to rod C
) = 33

write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33

write(1, " Move disk 6 from rod A to rod B"..., 33 Move disk 6 from rod A to rod B

) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 2 from rod C to rod A"..., 33 Move disk 2 from rod C to rod A
) = 33
write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33
write(1, " Move disk 3 from rod C to rod B"..., 33 Move disk 3 from rod C to rod B
) = 33
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 2 from rod A to rod B"..., 33 Move disk 2 from rod A to rod B
) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 4 from rod C to rod A"..., 33 Move disk 4 from rod C to rod A
) = 33
write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33
write(1, " Move disk 2 from rod B to rod C"..., 33 Move disk 2 from rod B to rod C
) = 33
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 3 from rod B to rod A"..., 33 Move disk 3 from rod B to rod A
) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 2 from rod C to rod A"..., 33 Move disk 2 from rod C to rod A
) = 33
write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33
write(1, " Move disk 5 from rod C to rod B"..., 33 Move disk 5 from rod C to rod B
) = 33
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 2 from rod A to rod B"..., 33 Move disk 2 from rod A to rod B
) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 3 from rod A to rod C"..., 33 Move disk 3 from rod A to rod C
) = 33
write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33
write(1, " Move disk 2 from rod B to rod C"..., 33 Move disk 2 from rod B to rod C

) = 33
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 4 from rod A to rod B"..., 33 Move disk 4 from rod A to rod B
) = 33
write(1, " Move disk 1 from rod C to rod B"..., 33 Move disk 1 from rod C to rod B
) = 33
write(1, " Move disk 2 from rod C to rod A"..., 33 Move disk 2 from rod C to rod A
) = 33
write(1, " Move disk 1 from rod B to rod A"..., 33 Move disk 1 from rod B to rod A
) = 33
write(1, " Move disk 3 from rod C to rod B"..., 33 Move disk 3 from rod C to rod B
) = 33
write(1, " Move disk 1 from rod A to rod C"..., 33 Move disk 1 from rod A to rod C
) = 33
write(1, " Move disk 2 from rod A to rod B"..., 33 Move disk 2 from rod A to rod B
) = 33
write(1, " Move disk 1 from rod C to rod B", 32 Move disk 1 from rod C to rod B) = 32
exit_group(0)   = ?
+++ exited with 0 +++

time ./toh.o   (I have cut down the print statements to shorten the pdf)
 Move disk 1 from rod A to rod C
 Move disk 2 from rod A to rod B
 Move disk 1 from rod C to rod B

real 0m0.002s
user 0m0.001s
sys 0m0.000s

It is a CPU bound job, which can be seen from the following command:

/usr/bin/time -v ./toh.o   (I have cut down the print statements to shorten the pdf)
 Move disk 1 from rod A to rod C
 Move disk 2 from rod A to rod B
 Move disk 1 from rod C to rod B
 Move disk 1 from rod C to rod B Command being timed: "./toh.o"
User time (seconds): 0.00
System time (seconds): 0.00
Percent of CPU this job got: 100%
Elapsed (wall clock) time (h:mm:ss or m:ss): 0:00.00
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0

Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 1444
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 65
Voluntary context switches: 1
Involuntary context switches: 126
Swaps: 0
File system inputs: 0
File system outputs: 0
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0

strace -c -w ./toh.o (For answering the following two questions)

time	seconds	usecs/call	calls	errors	syscall
62.76	0.001217	19	64		write
15.09	0.000292	292	1		execve
5.25	0.000102	14	7		mmap
3.90	0.000076	18	4		mprotect
3.03	0.000059	9	6		pread64
1.82	0.000035	11	3		fstat
1.64	0.000032	15	2		openat
1.59	0.000031	10	3		brk
1.57	0.000030	30	1		munmap
0.96	0.000019	9	2	1	arch_prctl
0.93	0.000018	9	2		close
0.90	0.000017	17	1	1	access
0.57	0.000011	10	1		read
100.00	0.001939		97	2	total

Which system call is called most frequently? Why?

write() is being called most frequently. This program has an exponential time complexity and thus the number of printf statements executed are also O(2^n).

Which system call consumed more execution time?

write() consumed 63% of execution time.

Task 3

ltrace ./ex1.o
hi 1
hi 2
chmod failed, errno = 2
hi 3
+++ exited (status 0) +++

strace ./ex1.o
execve("./ex1.o", ["./ex1.o"], 0x7fffd341c810 /* 22 vars */) = 0
brk(NULL)   = 0x55cdd8f45000
arch_prctl(0x3001 /* ARCH_??? */, 0x7ffd7ee91bd0) = -1 EINVAL (Invalid argument)
access("/etc/ld.so.preload", R_OK)   = -1 ENOENT (No such file or directory)
openat(AT_FDCWD, "/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
fstat(3, {st_mode=S_IFREG|0644, st_size=73333, ...}) = 0
mmap(NULL, 73333, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7fa021afb000
close(3)   = 0
openat(AT_FDCWD, "/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\360q\2\0\0\0\0\0"..., 832) = 832
pread64(3, "\6\0\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\0\3\0\0\0\0\0\0\0"..., 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
fstat(3, {st_mode=S_IFREG|0755, st_size=2029224, ...}) = 0
mmap(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0)
= 0x7fa021af9000
pread64(3, "\6\0\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\0\3\0\0\0\0\0\0\0"..., 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
mmap(NULL, 2036952, PROT_READ, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) =
0x7fa021907000
mprotect(0x7fa02192c000, 1847296, PROT_NONE) = 0
mmap(0x7fa02192c000, 1540096, PROT_READ|PROT_EXEC,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x25000) = 0x7fa02192c000
mmap(0x7fa021aa4000, 303104, PROT_READ,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x19d000) = 0x7fa021aa4000
mmap(0x7fa021aef000, 24576, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1e7000) = 0x7fa021aef000
mmap(0x7fa021af5000, 13528, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7fa021af5000

```
close(3)                        = 0
arch_prctl(ARCH_SET_FS, 0x7fa021afa540) = 0
mprotect(0x7fa021aef000, 12288, PROT_READ) = 0
mprotect(0x55cdd81ac000, 4096, PROT_READ) = 0
mprotect(0x7fa021b3a000, 4096, PROT_READ) = 0
munmap(0x7fa021afb000, 73333)        = 0
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(0x88, 0x1), ...}) = 0
brk(NULL)                       = 0x55cdd8f45000
brk(0x55cdd8f66000)             = 0x55cdd8f66000
write(1, "hi 1\n", 5hi 1
)           = 5
chmod("/etc/*****", 0444)       = -1 ENOENT (No such file or directory)
write(1, "hi 2\n", 5hi 2
)           = 5
write(2, "chmod failed, errno = 2\n", 24chmod failed, errno = 2
) = 24
write(1, "hi 3\n", 5hi 3
)           = 5
exit_group(0)                   = ?
+++ exited with 0 +++
```

time ./ex1.o
```
hi 1
hi 2
chmod failed, errno = 2
hi 3

real 0m0.002s
user 0m0.001s
sys 0m0.000s
```

ltrace ./ex2.o
```
hi 4
hi 5
hi 6
+++ exited (status 0) +++
```

strace ./ex2.o
```
execve("./ex2.o", ["./ex2.o"], 0x7fff2b5105c0 /* 22 vars */) = 0
brk(NULL)                       = 0x55eaf0ad3000
arch_prctl(0x3001 /* ARCH_??? */, 0x7ffd5d516a10) = -1 EINVAL (Invalid argument)
access("/etc/ld.so.preload", R_OK)      = -1 ENOENT (No such file or directory)
openat(AT_FDCWD, "/etc/ld.so.cache", O_RDONLY|O_CLOEXEC) = 3
```

```
fstat(3, {st_mode=S_IFREG|0644, st_size=73333, ...}) = 0
mmap(NULL, 73333, PROT_READ, MAP_PRIVATE, 3, 0) = 0x7f43926bf000
close(3)                    = 0
openat(AT_FDCWD, "/lib/x86_64-linux-gnu/libc.so.6", O_RDONLY|O_CLOEXEC) = 3
read(3, "\177ELF\2\1\1\3\0\0\0\0\0\0\0\0\3\0>\0\1\0\0\0\360q\2\0\0\0\0\0"..., 832) = 832
pread64(3, "\6\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\3\0\0\0\0\0\0", 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
fstat(3, {st_mode=S_IFREG|0755, st_size=2029224, ...}) = 0
mmap(NULL, 8192, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0)
= 0x7f43926bd000
pread64(3, "\6\0\0\4\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0@\0\0\0\0\0\0\0"..., 784, 64) = 784
pread64(3, "\4\0\0\0\20\0\0\5\0\0\0GNU\0\2\0\0\300\4\0\0\3\0\0\0\0\0\0", 32, 848) = 32
pread64(3,
"\4\0\0\0\24\0\0\3\0\0\0GNU\0\363\377?\332\200\270\27\304d\245n\355Y\377\t\334"..., 68,
880) = 68
mmap(NULL, 2036952, PROT_READ, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) =
0x7f43924cb000
mprotect(0x7f43924f0000, 1847296, PROT_NONE) = 0
mmap(0x7f43924f0000, 1540096, PROT_READ|PROT_EXEC,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x25000) = 0x7f43924f0000
mmap(0x7f4392668000, 303104, PROT_READ,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x19d000) = 0x7f4392668000
mmap(0x7f43926b3000, 24576, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_DENYWRITE, 3, 0x1e7000) = 0x7f43926b3000
mmap(0x7f43926b9000, 13528, PROT_READ|PROT_WRITE,
MAP_PRIVATE|MAP_FIXED|MAP_ANONYMOUS, -1, 0) = 0x7f43926b9000
close(3)                    = 0
arch_prctl(ARCH_SET_FS, 0x7f43926be540) = 0
mprotect(0x7f43926b3000, 12288, PROT_READ) = 0
mprotect(0x55eaeeeeb000, 4096, PROT_READ) = 0
mprotect(0x7f43926fe000, 4096, PROT_READ) = 0
munmap(0x7f43926bf000, 73333)       = 0
fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(0x88, 0x1), ...}) = 0
brk(NULL)                   = 0x55eaf0ad3000
brk(0x55eaf0af4000)             = 0x55eaf0af4000
write(1, "hi 4\n", 5hi 4
)               = 5
chmod("/etc/passwd", 0444)          = 0
write(1, "hi 5\n", 5hi 5
)               = 5
write(1, "hi 6\n", 5hi 6
```

)   = 5
exit_group(0)   = ?
+++ exited with 0 +++

time ./ex2.o
hi 4
hi 5
hi 6

real 0m0.002s
user 0m0.001s
sys 0m0.000s

All the system calls in ex1.o:
write, execve, mmap, chmod, mprotect, pread64,munmap, brkfstat, openat, close arch_prctl, access, read.
All the procedure calls in ex1.o:
printf, fprintf, chmod, errno.
All the system calls in ex2.o:
write, execve, mmap, chmod, mprotect, pread64,munmap, brkfstat, openat, close arch_prctl, access, read.
All the procedure calls in ex2.o:
printf, fprintf, chmod, errno.