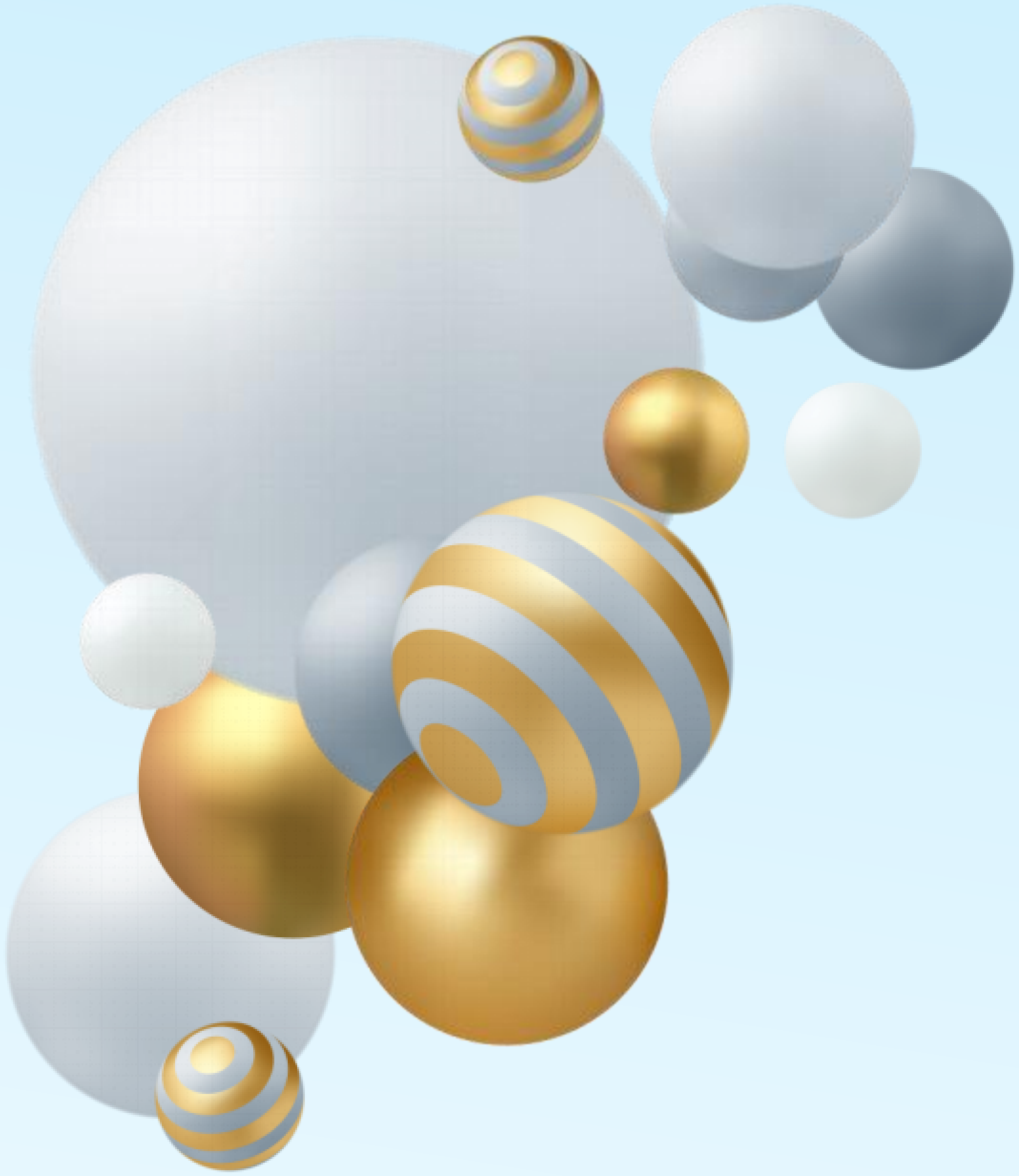
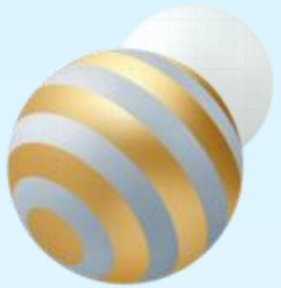


Computer Organization

Lab4 RISC-V instructions(2)

Procedure & Memory

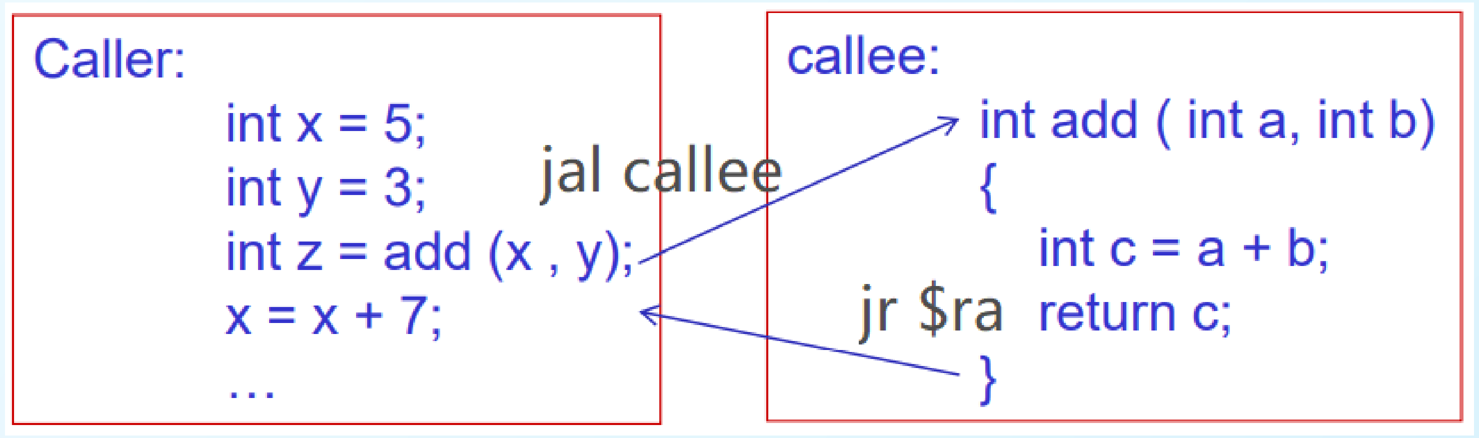


Topics

- Procedure
  - ✓ Caller & Callee
  - ✓ Stack
  - ✓ Recursion
- Memory
  - ✓ Static Data vs Dynamic Data
  - ✓ Stack vs Heap
- Practice

Procedure: Caller & Callee(1)

- Caller: The program that instigates a procedure and provides the necessary parameter values.
- Callee: A procedure that executes a series of stored instructions based on parameters provided by the caller and then returns control to the caller.
- Return Address: A link to the calling site that allows a procedure to return to the proper address; in RISC-V it is stored in register **x1(ra)**.



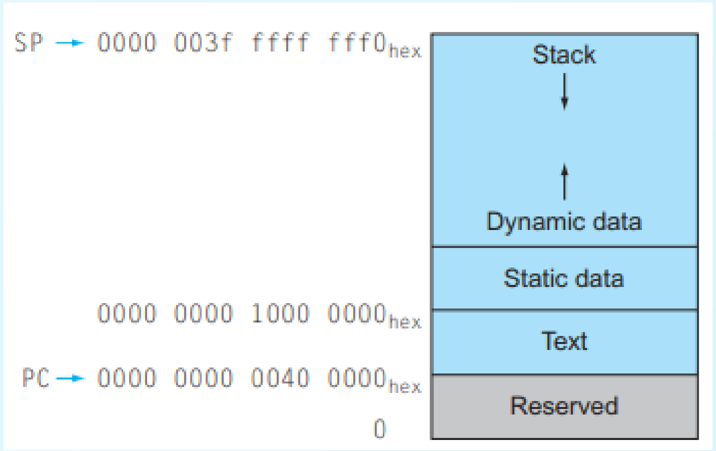
Procedure: Caller & Callee(2)

- **jal rd, function_lable** #jump-and-link instruction
  - ✓ **Save** return address (related to PC) in **register rd.**
  - ✓ **Unconditionally jump** to the instruction at function_lable.
  - ✓ Used in **caller** while calling the function.
- **jalr rd, rs1, imm** #jump-and-link register instruction
  - ✓ **Save** return address in **register rd.**
  - ✓ **Unconditionally jump** to the instruction according the sum of register rs1 and imm.
  - ✓ jalr x0, x1, 0 can be used in **callee** while returning to the caller.
- Some extended/pseudo instructions: j, jr, …
- Limit of destination address
  - ✓ For jal instruction, function_lable is a 20-bit value, adding a 0 at the end, and then be sign-extended to 32-bit. So the jumping range is **PC +/- 1MB**.
  - ✓ For jalr instruction, imm is a 12-bit value, being sign-extended to 32-bit. So the jumping range is value of **RS1 +/- 2KB**.

Procedure: Stack Segment

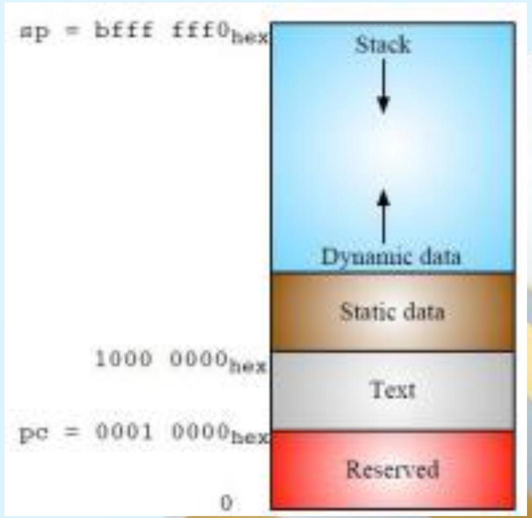
- Stack: A data structure for spilling registers organized as a last-in-first-out queue.
- Stack Pointer: A value denoting the most recently allocated address in a stack that shows where registers should be spilled or where old register values can be found. In RISC-V, it is register sp, or x2.
  - ✓ In the RISC-V software specification, the stack pointer (sp) starts to grow downwards from.
  - ✓ Like dynamic data, the maximum size of a program's stack is not known in advance.
  - ✓ As the program pushes values on the stack, the operating system expands the stack segment down, toward the data segment.
  - ✓ In Rars, the memory is allocated as follows.

The RISC-V memory allocation for program and data (64-bit)

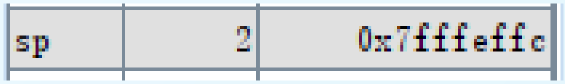


SP → $0000\ 003f\ ffff\ fff0_{hex}$
Stack
Dynamic data
Static data
$0000\ 0000\ 1000\ 0000_{hex}$
Text
PC → $0000\ 0000\ 0040\ 0000_{hex}$
Reserved
0

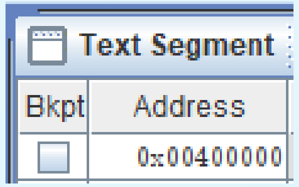
The RISC-V memory allocation for program and data (32-bit)



SP in Rars

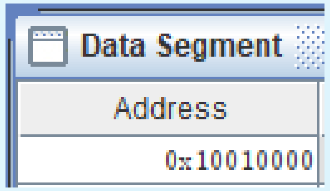


sp	2	0x7fffeffc



Text Segment

Bkpt	Address
☐	0x00400000



Data Segment

Address
0x10010000

Procedure: Stack Segment demo(1)

- Run the demo, learn the push and pop operation of stack, and answer questions.
  - Q1: What is the value of register **ra** before calling “print_string” each time?
  - Q2: Is it OK to remove the push and pop processing of ra on the stack in “print_string” ?
  - Q3: Is it OK to remove the push and pop processing of a0 on the stack in “print_string” ?

```
# Piece 4-1-1
.data
	tdata: .space 6
	str1:  .asciz "\nThe orignal string is: "
	str2:  .asciz "\nThe last two character of the string is: "
.text
	la a0, tdata
	addi a1, zero, 6
	li a7, 8
	ecall
```

```
# Piece 4-1-2
	la a0, str1
	jal print_string

	la a0, tdata
	jal print_string

	la a0, str2
	jal print_string

	la a0, tdata
	addi a0, a0, 3
	jal print_string

	li a7, 10
	ecall
```

```
# Piece 4-1-3
print_string:
	addi sp, sp, -8
	sw ra, 4(sp)
	sw a0, 0(sp)
	li a7, 4
	ecall
	lw a0, 0(sp)
	lw ra, 4(sp)
	addi sp, sp, 8
	jr ra
```

Procedure: Stack Segment demo(2)

- Run the demo, and answer questions.
  - Q1: Is it OK to remove the push and pop processing of register ra on the stack in "print_string", "print_new_line", "print_dec_result", and "print_hex_result" ?
  - Q2: What about register a0?

```
# Piece 4-2-1
.data
        tdata: .word 0x00000001
        str1:  .asciz "\nThe result is: "
        str2:  .asciz "\n"
.text
        li a7, 5
        ecall
        lw a1, tdata
        add a0, a0, a1
        mv t0, a0
```

```
# Piece 4-2-2
        la a0, str1
        jal print_string

        mv a0, t0
        jal print_dec_result
        jal print_new_line
        jal print_hex_result

        li a7, 10
        ecall
```

```
# Piece 4-2-3
print_string:
        addi sp, sp, -8
        sw ra, 4(sp)
        sw a0, 0(sp)
        li a7, 4
        ecall
        lw a0, 0(sp)
        lw ra, 4(sp)
        addi sp, sp, 8
        jr ra
```

```
# Piece 4-2-4
print_new_line:
        addi sp, sp, -8
        sw ra, 4(sp)
        sw a0, 0(sp)
        la a0, str2
        li a7, 4
        ecall
        lw a0, 0(sp)
        lw ra, 4(sp)
        addi sp, sp, 8
        jr ra
```

```
# Piece 4-2-5
print_dec_result:
        addi sp, sp, -8
        sw ra, 4(sp)
        sw a0, 0(sp)
        li a7, 1
        ecall
        lw a0, 0(sp)
        lw ra, 4(sp)
        addi sp, sp, 8
        jr ra
```

```
# Piece 4-2-6
print_hex_result:
        addi sp, sp, -8
        sw ra, 4(sp)
        sw a0, 0(sp)
        li a7, 34
        ecall
        lw a0, 0(sp)
        lw ra, 4(sp)
        addi sp, sp, 8
        jr ra
```

Procedure: Recursion

- ***"fact"*** is a function to calculate the Calculate the factorial.
- Run the demo, and answer the question: While calculate ***fact(6)***, how many times does push and pop processing on stack happen? How does the value of a0 change when calculate ***fact(6)***?

Code in C

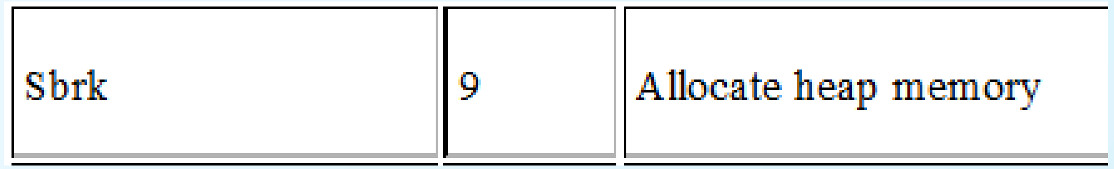
```
int     fact(int n) {
        if(n<1)
                return 1;
        else
                return (n*fact(n-1));
}
```

Code in RISC-V

```
# Piece 4-3
.include "macro_print_str.asm"
.text
main:
        print_string("Please enter an integer: ")
        li a7, 5
        ecall                   #get n, and set in register a0
        jal fact                #call the fact function
        li a7, 1
        ecall
        end
fact:
        addi sp, sp,-8                  #adjust stack for 2 items
        sw ra, 4(sp)            #save the return address
        sw a0, 0(sp)            #save the argument n

        slti t0, a0, 1          #test for n<1
        beq t0, zero, L1        #if n>=1,go to L1

        addi a0, zero, 1        #else return 1
        addi sp, sp, 8                  #pop 2 items off stack
        jr ra                   #return to caller

L1:     addi a0, a0, -1                 #n>=1; argument gets(n-1)
        jal fact                #call fact with(n-1)

        addi t1, a0, 0                  #
        lw a0, 0(sp)            #return from jal: restore argument
        lw ra, 4(sp)            #restore the return address
        addi sp, sp, 8                  #adjust stack pointer to pop 2 items

        mul a0, a0, t1                  #return n*fact(n-1)
        jr ra                   #return to the caller
```

Memory: Static Data vs Dynamic Data

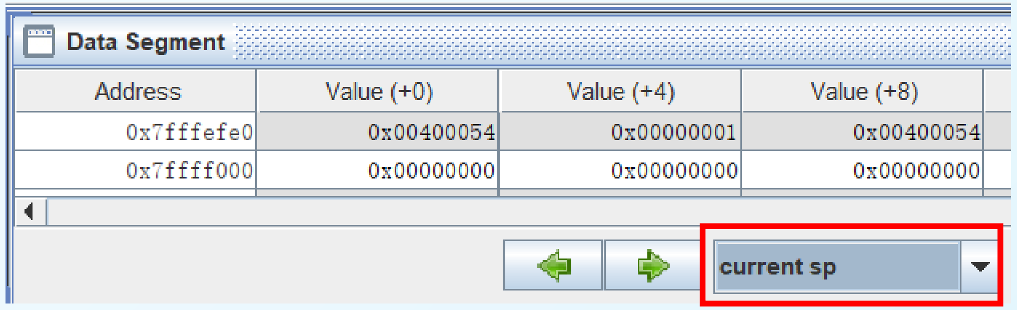
- **Static data**
  - ✓The portion of memory that contains data whose size is **known** to the compiler and whose lifetime is the program's entire execution.
  - ✓To simplify access to static data, some RISC-V compilers reserve a register **x3** for use as the global pointer, or **gp**.
  - ✓In Rars, we use ".data" to explicit static data.
- **Dynamic data**
  - ✓Allocated by malloc() in C and by new in Java.
  - ✓Including heap and stack segment.
  - ✓In Rars, we use **Sbrk**(NO. 9) system call to allocate heap memory.



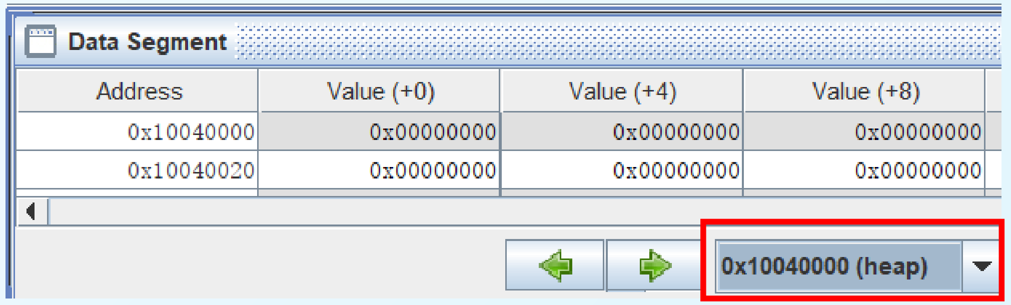
Sbrk	9	Allocate heap memory

Memory: Stack vs Heap

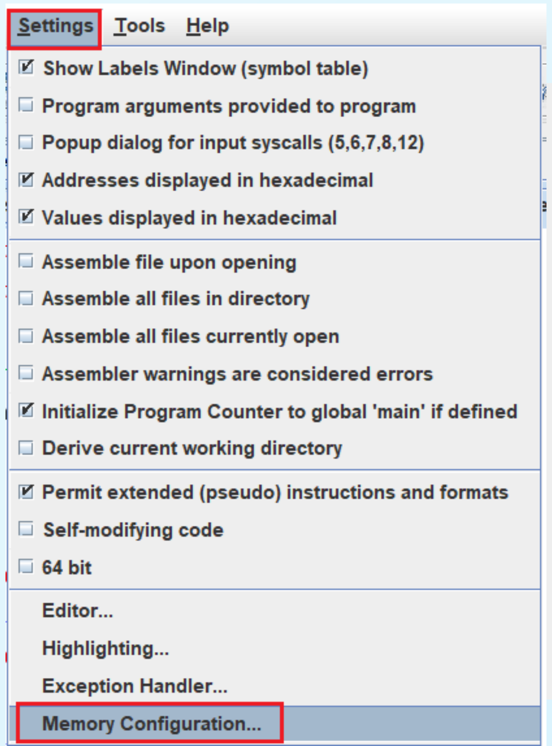
- **Stack**: Be used to store the local variable. It's continuous in memory.
- **Heap**: Heap is a discontinuous memory allocation method, and commonly used for dynamic allocation and release of memory.
- The stack and heap grow toward each other, thereby allowing the efficient use of memory as the two segments wax and wane.


Data Segment

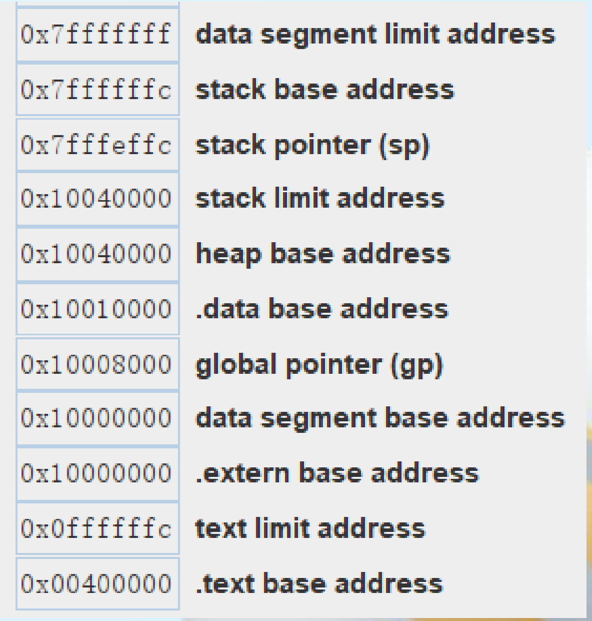
Address	Value (+0)	Value (+4)	Value (+8)
0x7fffefe0	0x00400054	0x00000001	0x00400054
0x7ffff000	0x00000000	0x00000000	0x00000000


Data Segment

Address	Value (+0)	Value (+4)	Value (+8)
0x10040000	0x00000000	0x00000000	0x00000000
0x10040020	0x00000000	0x00000000	0x00000000



- ☑ Show Labels Window (symbol table)
- ☐ Program arguments provided to program
- ☐ Popup dialog for input syscalls (5,6,7,8,12)
- ☑ Addresses displayed in hexadecimal
- ☑ Values displayed in hexadecimal
- ☐ Assemble file upon opening
- ☐ Assemble all files in directory
- ☐ Assemble all files currently open
- ☐ Assembler warnings are considered errors
- ☑ Initialize Program Counter to global 'main' if defined
- ☐ Derive current working directory
- ☑ Permit extended (pseudo) instructions and formats
- ☐ Self-modifying code
- ☐ 64 bit
- Editor...
- Highlighting...
- Exception Handler...
- Memory Configuration...



0x7fffffff	data segment limit address
0x7ffffffc	stack base address
0x7fffeffc	stack pointer (sp)
0x10040000	stack limit address
0x10040000	heap base address
0x10010000	.data base address
0x10008000	global pointer (gp)
0x10000000	data segment base address
0x10000000	.extern base address
0x0ffffffc	text limit address
0x00400000	.text base address

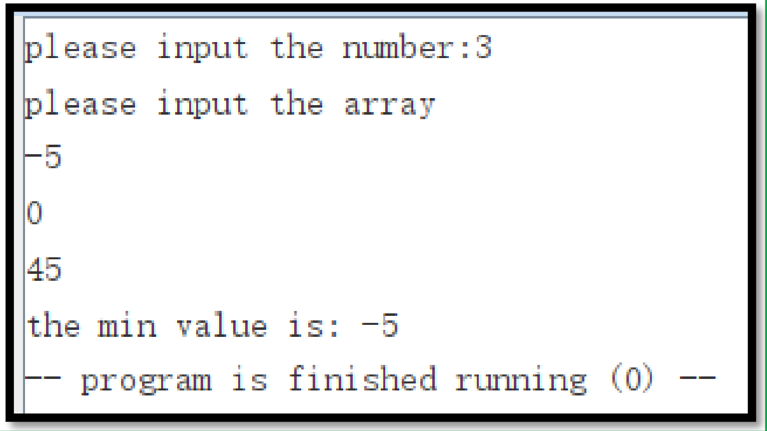
Practice 1

- The **Fibonacci sequence**, also known as the golden ratio sequence, was introduced by mathematician Leonardo Fibonacci using rabbit breeding as an example, and is also known as the "rabbit sequence".
- Its values are: 1, 1, 2, 3, 5, 8, 13, 21, 34, ...
- Its definition: ***F(0) = 1, F(1) = 1, F(n) = F(n-1) + F(n-2)*** $(n \geq 2, \ n \in N^*)$
- Please use recursive methods to complete the calculation about the Fibonacci sequence.
  - ✓ Input a integer *m*.
  - ✓ Use *m* as the index, and output the m^{th} number in Fibonacci sequence.
  - ✓ The 0th number in Fibonacci sequence is 1, and the 1st number is 1, the 2nd number is 2, ……

Practice 2 (1)

```
# Piece 4-4-1
.include "macro_print_str.asm"
.data
        min_value: .word 0
.text
        print_string("please input the number:")
        li a7, 5                #read an integer
        ecall
        mv t0, a0    #t0 is the number of integers

        slli a0, t0, 2          #new a heap with 4*t0
        li a7, 9        #a0 is both used as argument and return value
        ecall
        mv t1, a0    #t1 is the start of the heap
        mv t2, a0    #t2 is the pointer
print_string("please input the array\n")
        add t3, zero, zero          #set t3 as i

loop_read:
        li a7, 5        #read the array
        ecall
        sw a0, (t2)

        addi t2, t2, 4
        addi t3, t3, 1
        bne t3, t0, loop_read
```

```
# Piece 4-4-2
        lw a0, (t1)     #initialize the min_value
        la t4, min_value
        sw a0, (t4)
        add t3, zero, zero
        add t2, t1, zero     #t1 is the start of the heap

loop_find_min:
        lw a0, min_value
        lw a1, (t2)
        jal find_min
        la t4, min_value
        sw a0, (t4)
        addi t2, t2, 4                      #t2 is the pointer
        addi t3, t3, 1
        bne t3, t0, loop_find_min  #t0 is the number of integers

        print_string("the min value is: ")
        li a7, 1
        la t4, min_value
        lw a0, (t4)
        ecall

        end

find_min:
        blt a0, a1, not_update
        mv a0, a1

not_update:
        jr ra
```



```
please input the number:3
please input the array
-5
0
45
the min value is: -5
-- program is finished running (0) --
```

Practice 2 (2)

- The demo on previous page is supposed to get and store the data from user input, find and output the minimal value among the data. Answer the questions below.
  - ✓ Q1. What’s the value of register a0 after finish executing the system call with yellow background ? Is it the same with the value of register sp?
  - ✓ Q2. On what addresses are the input data stored in memory? Are the addresses belong to static storage or dynamic storage? Are the addresses belong to stack or heap?
  - ✓ Q3. On what address is the minimal data stored in memory? Is the address belong to static storage or dynamic storage? Is the address belong to stack or heap?
  - ✓ Q4. If the 1st input number is 0 (the number of integers), what will happen? why?
  - ✓ Q5. Modify this demo to make it better when the number is 0.