УНИВЕРСИТЕТ ИТМО

факультет программной инженерии и компьютерной техники

Направление подготовки 09.04.04 Системное и прикладное программное обеспечение

Системное програмное обеспечение
Семестр 1

Лабораторная работа No3

Студент
Хуссейн, Авин
P4114

Преподаватель
Кореньков Ю.Д

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1. Goals

Implement linear code generation using certain instructions set by CFG analysis for a number of subprograms. Print mnemonic representation of the generated linear code to the output file as an assembly listing.

2. Subtasks

1 Describe a virtual machine having instruction set and memory model according to your variant number

a. Learn the notation for the target architecture definitions

b. Describe VM according to your variant number

i. Describe a number of registers and memory banks

ii. Describe an instructions set: come up with an opcode encoding for each instruction, its
operands and a VM state changing operation description

1 Describe data movement and constant loading instructions

2 Describe arithmetic and logical instructions

3 Describe conditional and unconditional branching instructions

4 Describe IO-instructions using hidden registry store and an internal IO-port

iii. Describe a number of mnemonics for the instructions set

c. Prepare a script for assembled listing execution using target VM definition

i. Create a test listing using prepared mnemonics

ii. Use listing translator to generate binary module containing native code according to the target VM definition

iii. Execute binary module and retrieve its resulting output

iv. Ensure that all the prepared VM instructions work correctly

2 Choose and learn existing hardware VM ISA a. For a given VM

i. There should be an existing emulator (for example: qemu)

ii. There should be an existing toolchain (developer tools set): C compiler, assembler, disassembler, linker and debugger

b. Approve your VM choice with the teacher

c. Learn memory model and instruction set of the VM

d. Learn how to use machine toolchain (building and launching programs in form of the assembly listing)

e. Prepare a script for assembled listing execution using emulator

i. Create a test listing using VM instructions' mnemonics

ii. Use assembler and linker from the existing toolchain

iii. Execute binary module and get its resulting output

3. Solution description

modules this stage of the solution is included in 2 files, "asm.c"."asm.h" ,"localVariabl.c" and "localVariable.h"

In the "localVariable.h" header file, we define different structures to represent a linked list of variables. The variables have the structure varDeclaration which was defined in lab2.

More detail will be mentioned on that structure, and for full reference please refer to СПО2 report. The basic information about variables declaration was saved previously in the control flow graph as Instruction structures. Those variable declaration structures keep information about the name and the type of the variable, this type was divided into 2 categories : simple and array. The job of this module is to depth first traverse the CFG and create a linked list of all the local variables.

After this list of variables is compiled, the module asm.c starts its job of translating the variables and also in traversing the control flow graph to create the linear code.

3.1 Modules Overview

The codebase is organized into several interrelated modules, each responsible for specific functionality. Below is an explanation of the primary modules and their purposes:

3.1.1. Local variable list

This module defines and manages local variables used in the program. It consists of:

- varDeclaration: holds information about the variable such as its type and id. The type can be a simple type or array. Simple types are ones such as int, bool and long. And array types have 2 important fields which are the type of the elements (which could also be an array) and the number of those elements.
- Node*: a pointer to the next variable.
- filename: name of the file in which the variable was declared.

In the module asm.c, the main function is translate(). This function invokes a number of different methods and is responsible for translating the cfg into a linear code.

3.1.2 dynamic typing and variable translation

- local variables declarations are being translated first. a structure was chosen to represent a variable in the memory in order to retrieve and change meta data about its type at runtime.
- This structure for meta data follows this example

```
i_input2:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x10 ; Offset for `value
```

- For each variable we keep two values which are its type and payload, local variables are stored on the stack frame while literals are stored on the stack (of the stack machine).
- The types and values are pushed to the stack and inside the arithmetic functions in assembly a check is done at runtime to make sure that the operation is done in a type appropriate way. The following snippet shows an example.

```
// Check if both operands are of type "number" (type == 2)
//both the type and value have been pushed to the stack
// Increment stack pointer to "pop" the first operand's pointer
    sp = sp + 2;
    let type1 = m_stack:2[sp];        // First operand type (address of operand)
    sp = sp + 2;
    let value1 = m_stack:2[sp];        // Type of first operand (e.g., 2 for number)

    // Increment stack pointer to "pop" the second operand's pointer
    sp = sp + 2;
    let type2 = m_stack:2[sp];        // Second operand pointer
    sp = sp + 2;
    let value2 = m_stack:2[sp];         // Type of second operand

    // Check if both operands are of type "number" (type == 2)
    if (type1 == 2) && (type2 == 2) then {

            let r = value1 + value2;
              …
```

1.1.2 Translation implementation details

- **translate() Function**: this function distributes the traversal of the control flow graph into smaller functions that are responsible for translating:
    - Operation trees
    - While loops
    - If conditions
    - Literals and their types
- **translateOT() Function**: This is an important function. Its mission is to check the kinds of operations and operands and distribute them to the correct assembly operations. Since we are using a stack, the operands are pushed to the stack first and then they are translated into assembly functions such as wide_add and wide_store. These functions in assembly are responsible to type check the variables and literals in real time and also to store the values and types after the execution of the operations.

Code Generation Process

- **Assembly Instructions**: the assembly listing is written after the execution of this project
- **RemoteTasks**: is then used to assemble the listing, create a binary file and execute and debug this file.

5. Results

As a result of the work done in this lab I was able to implement linear code translation unit with dynamic type checking. The memory banks used is a common ram and a stack. The result of this lab allowed us to create a fully functioning program in our own language and execute it. First of all we can see the architecture created in the course of this lab work.

```
architecture spo {
/*
    case                18
    data word length    2
    code model          m_stack
    spaces              common ram
*/
registers:

  storage sp [16];     // Stack pointer
  storage ip [16];     // Program counter (Instruction pointer)
  storage ebp [16];
  storage esp [16];
  storage inp [16];     // Input register (for input operations)
  storage outp [16];    // Output register (for output operations)

memory:

  range ram [0x0000..0xffff] {   // Common RAM space for code/data
    cell = 16;     // 8-bit cells
    endianess = little-endian;  // Little endian
    granularity = 2;  // 2-byte chunks
  }

  range m_stack [0x0000..0xffff] {   // Stack space
    cell = 16;
    endianess = little-endian;
    granularity = 2;
  }

instructions:
    encode imm16 field = immediate [16];
    encode reg field = register {
        esp = 0,
        ebp = 1};

 // Push immediate value onto the stack
  instruction push = { 0000 0000, imm16 as value } {
    m_stack:2[sp] = value;
    sp = sp - 2;   // Decrement stack pointer
    ip = ip + 3;   // Increment instruction pointer
  };
  // Pop value from the stack into outp
  instruction pop = { 0000 0001 } {
    sp = sp + 2;        // Increment stack pointer
    ip = ip + 1;        // Increment instruction pointer
  };

  instruction popOut = { 0000 0010 } {
    sp = sp + 2;        // Increment stack pointer
    outp = m_stack:2[sp]; // Retrieve value from stack to standard
output
    ip = ip + 1;        // Increment instruction pointer
```

```
  };



// Add the top two integers on the stack
  instruction iadd = {0000 0011 } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    sp = sp + 2;                // Increment stack pointer
    let y = m_stack:2[sp];         // Pop second value into outp (next
top value)

    let r = x + y;          // Perform addition

    m_stack:2[sp] = r;         // Push result back onto the stack
    sp = sp - 2;                // Decrement stack pointer
    ip = ip + 1;                // Increment instruction pointer
};
// Add the top two longs on the stack
 instruction ladd = { 0000 0100 } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    sp = sp + 2;                // Increment stack pointer
    let y = m_stack:2[sp];         // Pop second value into outp (next
top value)

    let r = x + y;          // Perform addition

    m_stack:2[sp] = r;         // Push result back onto the stack
    sp = sp - 2;                // Decrement stack pointer
    ip = ip + 1;                // Increment instruction pointer
};
// store the type and the value , maybe I should push the type and
value on the top of the stack
//must test store
instruction st = { 0000 0101, imm16 as ptr }
{
    sp=sp + 2;
    ram:2[ptr] = m_stack:2[sp];
    //ram:1[ptr+1] = from>>8;

    ip = ip + 3;
};
//instruction r_st = { 0000 1100,  reg as target}
//{
//  sp=sp + 2;
//  target = m_stack:2[sp];
//  ip = ip + 3;
//};
// I will use this to store the size of the array for array type
instruction a_st = { 0000 0110, imm16 as ptr }
{
    sp=sp + 2;
```

```
    ram:2[ptr+4] = m_stack:2[sp];// we save 8 bytes for each variable ,
store the type in the first 4 bytes (32 bits from the stack) and the
value in the next
    ip = ip + 3;
};
// to create load I have to have different loads (iload, lload..) I
also need a general funciton to dispatch to them, but I also need a to
recieve the type
// and a way to extract it, and a way to handle the labels, in short I
need to know how I figuered out how to store it in metadata section
// were I keep all my variables and their types, or simple just how I
am storing so that I can load
  instruction jmp = { 0000 0111, imm16 as target } {
    ip = target;
  };


  instruction jz = { 0000 1000, imm16 as target } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];           // Pop first value into inp (top
value of the stack)

    if x == 0x0 then
      ip = target;
    else
      ip = ip + 3;
  };
  // for now, everywhere I pushed the value and then pushed the type to
the stack
instruction wide_add ={0000 1001} {
    // Increment stack pointer to "pop" the first operand's pointer
    sp = sp + 2;
    let type1 = m_stack:2[sp];         // First operand type (address
of operand)
    sp = sp + 2;
    let value1 = m_stack:2[sp];          // Type of first operand (e.g.,
2 for number)

    // Increment stack pointer to "pop" the second operand's pointer
    sp = sp + 2;
    let type2 = m_stack:2[sp];         // Second operand pointer
    sp = sp + 2;
    let value2 = m_stack:2[sp];           // Type of second operand

    // Check if both operands are of type "number" (type == 2)
    if (type1 == 2) && (type2 == 2) then {

        let r = value1 + value2;                // Perform addition

        // Push the result back onto the stack
        m_stack:2[sp] = r;
        sp = sp - 2;                    // Decrement stack pointer
        m_stack:2[sp]= 2; // push the type
        sp= sp -2;
    } else {
        // Push error code (-1) onto the stack if types don't match
        m_stack:2[sp] = -1;
```

```
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp] = -1;
        sp=sp -2; // push type error
    }

    // Increment instruction pointer to the next instruction
    ip = ip + 1;
};
instruction wide_store = { 0000 1010 }
{   sp=sp + 2;
    let ptr = m_stack:2[sp];// TO

    sp=sp + 2;
    let type=m_stack:2[sp];//pop type
    sp=sp + 2;
    let value=m_stack:2[sp];//pop value
    ram:2[ptr] = type;// store type

    ram:2[ptr+4] = value;// store value
    ip = ip + 1;
};
instruction wide_sub ={0000 1011} {
    // Increment stack pointer to "pop" the first operand's pointer
    sp = sp + 2;
    let type1 = m_stack:2[sp];         // First operand type (address
of operand)
    sp = sp + 2;
    let value1 = m_stack:2[sp];         // Type of first operand (e.g.,
2 for number)

    // Increment stack pointer to "pop" the second operand's pointer
    sp = sp + 2;
    let type2 = m_stack:2[sp];         // Second operand pointer
    sp = sp + 2;
    let value2 = m_stack:2[sp];          // Type of second operand

    // Check if both operands are of type "number" (type == 2)
    if (type1 == 2) && (type2 == 2) then {

        let r = value1 - value2;                // Perform addition

        // Push the result back onto the stack
        m_stack:2[sp] = r;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp]= 2; // push the type
        sp= sp -2;
    } else {
        // Push error code (-1) onto the stack if types don't match
        m_stack:2[sp] = -1;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp] = -1;
        sp=sp -2; // push type error
    }

    // Increment instruction pointer to the next instruction

    ip = ip + 1;
```

```
};
instruction wide_mult ={0000 1100} {
    // Increment stack pointer to "pop" the first operand's pointer
    sp = sp + 2;
    let type1 = m_stack:2[sp];         // First operand type (address
of operand)
    sp = sp + 2;
    let value1 = m_stack:2[sp];         // Type of first operand (e.g.,
2 for number)

    // Increment stack pointer to "pop" the second operand's pointer
    sp = sp + 2;
    let type2 = m_stack:2[sp];         // Second operand pointer
    sp = sp + 2;
    let value2 = m_stack:2[sp];          // Type of second operand

    // Check if both operands are of type "number" (type == 2)
    if (type1 == 2) && (type2 == 2) then {

        let r = value1 * value2;                // Perform addition

        // Push the result back onto the stack
        m_stack:2[sp] = r;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp]= 2; // push the type
        sp= sp -2;
    } else {
        // Push error code (-1) onto the stack if types don't match
        m_stack:2[sp] = -1;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp] = -1;
        sp=sp -2; // push type error
    }

    // Increment instruction pointer to the next instruction
    ip = ip + 1;
};
instruction wide_div ={0000 1101} {
     // Increment stack pointer to "pop" the first operand's pointer
    sp = sp + 2;
    let type1 = m_stack:2[sp];         // First operand type (address
of operand)
    sp = sp + 2;
    let value1 = m_stack:2[sp];         // Type of first operand (e.g.,
2 for number)

    // Increment stack pointer to "pop" the second operand's pointer
    sp = sp + 2;
    let type2 = m_stack:2[sp];         // Second operand pointer
    sp = sp + 2;
    let value2 = m_stack:2[sp];          // Type of second operand

    // Check if both operands are of type "number" (type == 2)
    if (type1 == 2) && (type2 == 2) then {

        let r = value1 / value2;                // Perform addition
```

```
        // Push the result back onto the stack
        m_stack:2[sp] = r;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp]= 2; // push the type
        sp= sp -2;
    } else {
        // Push error code (-1) onto the stack if types don't match
        m_stack:2[sp] = -1;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp] = -1;
        sp=sp -2; // push type error
    }

    // Increment instruction pointer to the next instruction
    ip = ip + 1;
};
  instruction jgt = { 0000 1111, imm16 as target } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    if (x >> 15 == 0x0) && (x != 0x0) then
      ip = target;
    else
      ip = ip + 3;
  };
    instruction jge = { 0001 0000, imm16 as target } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    if (x >> 15 == 0x0)  then
      ip = target;
    else
      ip = ip + 3;
  };

      instruction jlt = { 0001 0001, imm16 as target } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    if (x >> 15 == 0x1)  then
      ip = target;
    else
      ip = ip + 3;
  };

        instruction jle = { 0001 0010, imm16 as target } {
    sp = sp + 2;                // Increment stack pointer
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    if (x >> 15 == 0x1) || (x == 0x0) then
      ip = target;
    else
      ip = ip + 3;
```

```
  };
  // Halt execution
  instruction hlt = { 1111 1111 } {
    // Execution halts
  };

    instruction write = { 0001 0011 } {
    sp = sp +2 ;
    let x = m_stack:2[sp];          // Pop first value into inp (top
value of the stack)

    outp = x; // Retrieve value from stack to standard output
    ip = ip + 1;        // Increment instruction pointer
  };
    instruction read = { 0001 0100  } {
    sp = sp + 2 ;
    let ptr= m_stack:2[sp];

    ram:2[ptr+4] = inp;
    ip = ip + 1;   // Increment instruction pointer
  };
    instruction jmp_emp = { 0001 0101, imm16 as ptr } {
    sp = sp + 2;              // Increment stack pointer
    let target = ram:2[ptr];
    ip = target;
  };
  instruction wide_mod ={0001 0110} {
     sp = sp + 2;
    let type1 = m_stack:2[sp];         // First operand type (address
of operand)
    sp = sp + 2;
    let value1 = m_stack:2[sp];         // Type of first operand (e.g.,
2 for number)

    // Increment stack pointer to "pop" the second operand's pointer
    sp = sp + 2;
    let type2 = m_stack:2[sp];         // Second operand pointer
    sp = sp + 2;
    let value2 = m_stack:2[sp];          // Type of second operand

    // Check if both operands are of type "number" (type == 2)
    if (type1 == 2) && (type2 == 2) then {

        let r = value1 % value2;                // Perform addition

        // Push the result back onto the stack
        m_stack:2[sp] = r;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp]= 2; // push the type
        sp= sp -2;
    } else {
        // Push error code (-1) onto the stack if types don't match
        m_stack:2[sp] = -1;
        sp = sp - 2;                  // Decrement stack pointer
        m_stack:2[sp] = -1;
        sp=sp -2; // push type error
    }
```

```
    // Increment instruction pointer to the next instruction
    ip = ip + 1;
};

  instruction push_sf ={0001 0111 , imm16 as value} {
    ram[esp]= value;
    esp = esp - 4;   // Decrement stack pointer
    ip = ip + 3;   // Increment instruction pointer
  };
  instruction pop_sf ={0001 1000} {
    esp = esp + 4;        // Increment stack pointer

    ip = ip + 1;        // Increment instruction pointer
};

  instruction call = { 0001 1010, imm16 as ptr, 0000 0000 } {
    esp = esp + 4;
    ram:2[esp] = ip + 4; // save return point
    esp=esp + 4;
    ram:2[esp]= ebp; // save the old ebp


    ebp = esp;
    ip = ptr;
  };
  instruction ret = { 0001 1011  } {
        //if ebp != 0 then {
            esp = ebp;
            ebp = ram:2[esp] ;
            esp = esp - 4;
            ip = ram:2[esp];
            esp = esp - 4;
            //  }
        //ip = ip + 4;
    //  ip=ip + 1;
};
  instruction load = { 0001 1100 } {
        sp= sp + 2; // pop the pointer to the value in ram
        let ptr= m_stack:2[sp];
        let type = ram:2[ptr];
        let value = ram:2[ptr + 4];
        m_stack[sp]= value;
        sp =sp -2; //push the value
        m_stack[sp]= type;
        sp =sp -2; //push the type
        ip=ip+1;
};
instruction add_reg_imm = { 0001 1101, imm16 as value } {
        if value ==1 then {
        m_stack:2[sp] = ebp + 4 ;// the size of the cell is 2 bytes (16
bits) and I need 4 for value and 4 for type
        }
        else {
        m_stack:2[sp] = ebp +8 *(value - 1) +4 ;
        }
        sp = sp - 2;   // Decrement stack pointer
```

```
        ip=ip+3;
};

instruction sub_reg_imm = { 0001 1110, imm16 as value } {
        if value ==1 then {
        m_stack:2[sp] = ebp -4 * value +8;
        }
        else {
        m_stack:2[sp] = ebp - (8 * (value - 1)) + 4;
        }
        sp = sp - 2;   // Decrement stack pointer

        ip=ip+3;
};

instruction init ={ 0001 1111,imm16 as target }{
    ebp=target;
    esp=ebp;

    ip=ip + 3;
};



mnemonics:
  mnemonic init for init(target) "{1}";
  mnemonic push (value) "{1}";
  mnemonic pop() ;
  mnemonic popOut();
  mnemonic iadd();
  mnemonic ladd() ;
  mnemonic jump for jmp(target) "{1}";
  mnemonic jz(target) "{1}";
  mnemonic jgt(target) "{1}";
  mnemonic jge(target) "{1}";
  mnemonic jlt(target) "{1}";
  mnemonic jle(target) "{1}";

  mnemonic store for st(ptr) "{1}";
  mnemonic astore for a_st(ptr) "{1}";
  mnemonic wide_add();
  mnemonic wide_store();
  mnemonic wide_sub();
  mnemonic wide_mult();
  mnemonic wide_div();
  mnemonic wide_mod();
  mnemonic read();
  mnemonic write();
  mnemonic jmp_emp(ptr) "{1}";

  mnemonic push_sf (value) "{1}" ;
  mnemonic pop_sf () ;
  mnemonic call ( ptr) "{1}" ;
  mnemonic ret() ;
  mnemonic load() ;
  mnemonic add_s for add_reg_imm(value) "{1}" ;
  mnemonic sub_s for sub_reg_imm(value) "{1}" ;
```

```
  mnemonic hlt();
}
```

Architecture.pdsl

5.1 Simple calculator

And we used our language to create a simple calculator. This calculator expects 2 numbers as its input and an operation + - / *. The calculator uses loops to enter the input from the console one byte by the other. An if statement is used to direct the output to a different result depending on what operation the user want to apply to the numbers. A separate function is created to output the result from ASCII encoding, that is continuously dividing and taking the modulo of the number with 10. The output is then printed in the console. Here we can see this code example according to variant 3.

```
function calculator()
   dim i,  sum, tmp1, tmp2 as int
   tmp1 = 10;
   tmp2= 0;

   scan(i);
   sum =  i - 48;
   scan(i);
   while i != 32
      tmp1= i - 48;
      tmp2 = tmp1 * 10;
      sum = sum + tmp2;
      scan(i);
   wend
   dim i1,  sum1, tmp11, tmp21, res, x as int
   tmp11 = 10;
   tmp21= 0;

   scan(i1);
   sum1 =  i1 - 48;
   scan(i1);
   while i1 != 32
      tmp11= i1 - 48;
      tmp21 = tmp11 * 10;
      sum1 = sum1 + tmp21;
      scan(i1);
   wend

   scan(x);
   if x ==43 then
      res= sum + sum1;
   else
```

```
            if x ==45 then
              res= sum - sum1;
            else
              if x ==47 then
                res = sum / sum1;
              else
                if x ==42 then
                  res = sum * sum1;
                end if

              end if
            end if
          end if

          print_value(res);
        end function

        function print_value(res)
          dim nextLine, revertedNum, tmp as int
          nextLine = 10;
          revertedNum = 0;
          while res != 0
          revertedNum = revertedNum * 10  ;
          tmp = res % 10;
          tmp=tmp;
          revertedNum= revertedNum + tmp;
          res = res / 10;
          wend
          while revertedNum != 0
          tmp = revertedNum % 10;
          tmp=tmp + 48;
          print(tmp);
          revertedNum = revertedNum / 10;
          wend



        end function
```

Input.txt

As a result of executing the translation module we get the following listing.

```
        [section ram, code]
                store ret.value
                push 2
                store i_input2
                push 2
```

```
        store sum_input2
        push 2
        store tmp1_input2
        push 2
        store tmp2_input2
        push 2
        store i1_input2
        push 2
        store sum1_input2
        push 2
        store tmp11_input2
        push 2
        store tmp21_input2
        push 2
        store res_input2
        push 2
        store x_input2
        push 2
        store nextLine_input2
        push 2
        store revertedNum_input2
        push 2
        store tmp_input2
calculator:
        push label_0
        push tmp1_input2
        wide_store
        push label_1
        push tmp2_input2
        wide_store
        push i_input2
        read
        push label_2
        push i_input2
        wide_sub
        store label_3.type
        store label_3.value
        push label_3
        push sum_input2
        wide_store
        push i_input2
        read
                ;while
label_4:
        push label_5
        push i_input2
        wide_sub
        pop
```

```
            jz label_6
            push 1
                        ;false branch
            jump label_7
    label_6:
            push 0
                        ;true branch
    label_7:
            jz label_8
                        ;while body
            push label_9
            push i_input2
            wide_sub
            store label_10.type
            store label_10.value
            push label_10
            push tmp1_input2
            wide_store
            push label_11
            push tmp1_input2
            wide_mult
            store label_12.type
            store label_12.value
            push label_12
            push tmp2_input2
            wide_store
            push tmp2_input2
            push sum_input2
            wide_add
            store label_13.type
            store label_13.value
            push label_13
            push sum_input2
            wide_store
            push i_input2
            read
            jump label_4
    label_8:
                        ;end while
            push label_14
            push tmp11_input2
            wide_store
            push label_15
            push tmp21_input2
            wide_store
            push i1_input2
            read
            push label_16
```

```
        push i1_input2
        wide_sub
        store label_17.type
        store label_17.value
        push label_17
        push sum1_input2
        wide_store
        push i1_input2
        read
                ;while
label_18:
        push label_19
        push i1_input2
        wide_sub
        pop
        jz label_20
        push 1
                ;false branch
        jump label_21
label_20:
        push 0
                ;true branch
label_21:
        jz label_22
                ;while body
        push label_23
        push i1_input2
        wide_sub
        store label_24.type
        store label_24.value
        push label_24
        push tmp11_input2
        wide_store
        push label_25
        push tmp11_input2
        wide_mult
        store label_26.type
        store label_26.value
        push label_26
        push tmp21_input2
        wide_store
        push tmp21_input2
        push sum1_input2
        wide_add
        store label_27.type
        store label_27.value
        push label_27
        push sum1_input2
```

```
		wide_store
		push i1_input2
		read
		jump label_18
	label_22:
			;end while
		push x_input2
		read
		push label_28
		push x_input2
		wide_sub
		pop
		jz label_29
		push 0
			;false branch
		jump label_30
	label_29:
		push 1
			;true branch
	label_30:
			;if
		jz label_32
			;then
		push sum1_input2
		push sum_input2
		wide_add
		store label_33.type
		store label_33.value
		push label_33
		push res_input2
		wide_store
		push res_input2
		push label_34
		store ret.value
		jump print_value
	label_34:
		push halt
		store ret.value
		jump label_31
	label_32:
			;else
		push label_35
		push x_input2
		wide_sub
		pop
		jz label_36
		push 0
			;false branch
```

```
		jump label_37
	label_36:
		push 1
			;true branch
	label_37:
			;if
		jz label_39
			;then
		push sum1_input2
		push sum_input2
		wide_sub
		store label_40.type
		store label_40.value
		push label_40
		push res_input2
		wide_store
		push res_input2
		push label_41
		store ret.value
		jump print_value
	label_41:
		push halt
		store ret.value
		jump label_38
	label_39:
			;else
		push label_42
		push x_input2
		wide_sub
		pop
		jz label_43
		push 0
			;false branch
		jump label_44
	label_43:
		push 1
			;true branch
	label_44:
			;if
		jz label_46
			;then
		push sum1_input2
		push sum_input2
		wide_div
		store label_47.type
		store label_47.value
		push label_47
		push res_input2
```

```
            wide_store
            push res_input2
            push label_48
            store ret.value
            jump print_value
    label_48:
            push halt
            store ret.value
            jump label_45
    label_46:
                    ;else
            push label_49
            push x_input2
            wide_sub
            pop
            jz label_50
            push 0
                    ;false branch
            jump label_51
    label_50:
            push 1
                    ;true branch
    label_51:
                    ;if
            jz label_52
                    ;then
            push sum1_input2
            push sum_input2
            wide_mult
            store label_53.type
            store label_53.value
            push label_53
            push res_input2
            wide_store
            push res_input2
            push label_54
            store ret.value
            jump print_value
    label_54:
            push halt
            store ret.value
                    ;endif
    label_52:
            jump label_45
                    ;endif
    label_45:
            jump label_38
                    ;endif
```

```
label_38:
        jump label_31
                ;endif
label_31:
        jmp_emp ret.value
print_value:
        push label_55
        push nextLine_input2
        wide_store
        push label_56
        push revertedNum_input2
        wide_store
                ;while
label_57:
        push label_58
        push res_input2
        wide_sub
        pop
        jz label_59
        push 1
                ;false branch
        jump label_60
label_59:
        push 0
                ;true branch
label_60:
        jz label_61
                ;while body
        push label_62
        push revertedNum_input2
        wide_mult
        store label_63.type
        store label_63.value
        push label_63
        push revertedNum_input2
        wide_store
        push label_64
        push res_input2
        wide_mod
        store label_65.type
        store label_65.value
        push label_65
        push tmp_input2
        wide_store
        push tmp_input2
        push tmp_input2
        wide_store
        push tmp_input2
```

```
            push revertedNum_input2
            wide_add
            store label_66.type
            store label_66.value
            push label_66
            push revertedNum_input2
            wide_store
            push label_67
            push res_input2
            wide_div
            store label_68.type
            store label_68.value
            push label_68
            push res_input2
            wide_store
            jump label_57
    label_61:
                        ;end while
                        ;while
    label_69:
            push label_70
            push revertedNum_input2
            wide_sub
            pop
            jz label_71
            push 1
                        ;false branch
            jump label_72
    label_71:
            push 0
                        ;true branch
    label_72:
            jz label_73
                        ;while body
            push label_74
            push revertedNum_input2
            wide_mod
            store label_75.type
            store label_75.value
            push label_75
            push tmp_input2
            wide_store
            push label_76
            push tmp_input2
            wide_add
            store label_77.type
            store label_77.value
            push label_77
```

```
        push tmp_input2
        wide_store
        push tmp_input2
        write
        push label_78
        push revertedNum_input2
        wide_div
        store label_79.type
        store label_79.value
        push label_79
        push revertedNum_input2
        wide_store
        jump label_69
label_73:
                ;end while
        jmp_emp ret.value
        jump halt
ret:
   .type: dd 0x0 ; Offset for `type`
   .value: dd '' ; Offset for `value`
i_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
sum_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
tmp1_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
tmp2_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
i1_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
sum1_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
tmp11_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
tmp21_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
res_input2:
   .type: dd 0x0 ; Offset for `type`
   .value: dd 0x10 ; Offset for `value`
x_input2:
```

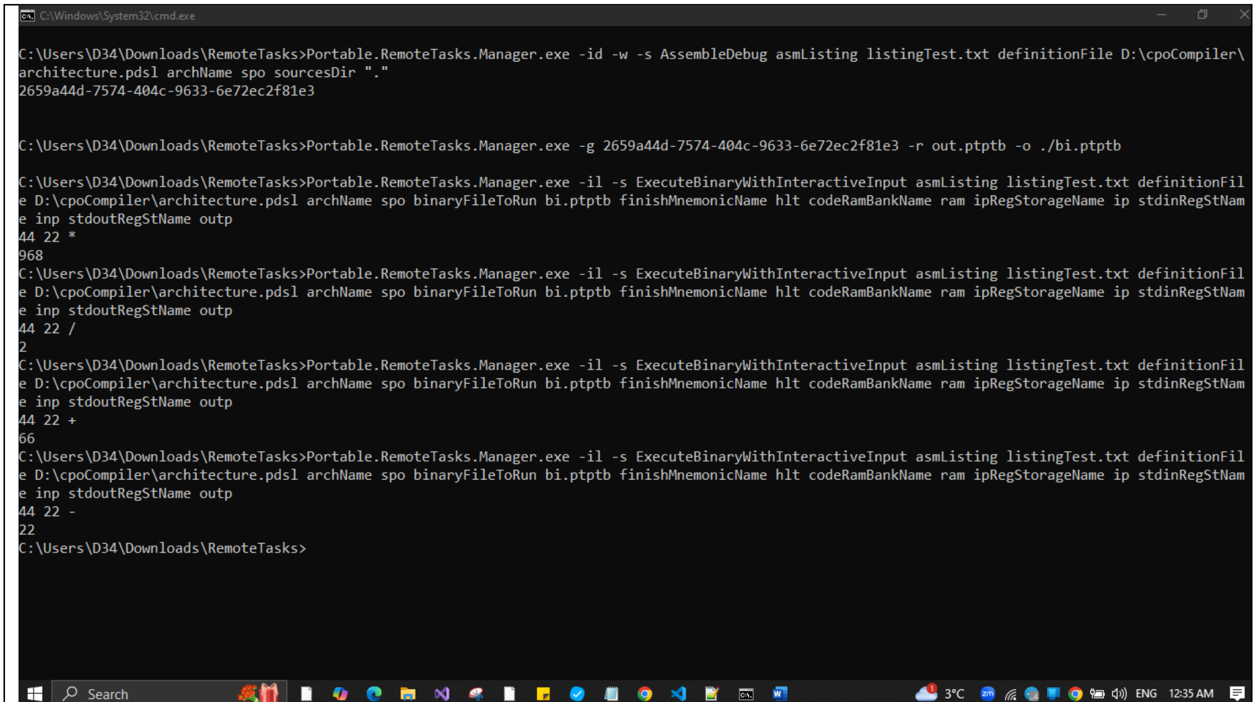
```
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x10 ; Offset for `value`
nextLine_input2:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x10 ; Offset for `value`
revertedNum_input2:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x10 ; Offset for `value`
tmp_input2:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x10 ; Offset for `value`
halt:
        hlt
label_0:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_1:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 0 ; Offset for `value`
label_2:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 48 ; Offset for `value`
label_3:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_5:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 32 ; Offset for `value`
label_9:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 48 ; Offset for `value`
label_10:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_11:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_12:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_13:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_14:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_15:
    .type: dd 0x2 ; Offset for `type`
```

```
    .value: dd 0 ; Offset for `value`
label_16:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 48 ; Offset for `value`
label_17:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_19:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 32 ; Offset for `value`
label_23:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 48 ; Offset for `value`
label_24:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_25:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_26:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_27:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_28:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 43 ; Offset for `value`
label_33:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_35:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 45 ; Offset for `value`
label_40:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_42:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 47 ; Offset for `value`
label_47:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_49:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 42 ; Offset for `value`
label_53:
    .type: dd 0x0 ; Offset for `type`
```

```
    .value: dd 0x0 ; Offset for `value`
label_55:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_56:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 0 ; Offset for `value`
label_58:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 0 ; Offset for `value`
label_62:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_63:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_64:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_65:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_66:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_67:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_68:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_70:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 0 ; Offset for `value`
label_74:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 10 ; Offset for `value`
label_75:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_76:
    .type: dd 0x2 ; Offset for `type`
    .value: dd 48 ; Offset for `value`
label_77:
    .type: dd 0x0 ; Offset for `type`
    .value: dd 0x0 ; Offset for `value`
label_78:
    .type: dd 0x2 ; Offset for `type`
```

.value: dd 10 ; Offset for `value` label_79: .type: dd 0x0 ; Offset for `type` .value: dd 0x0 ; Offset for `value`
listingTest.txt

And as a result of assembling and executing this listing according to our architecture we get the following results



Executing Calculator function with different operations with input and output in console

5.1 Fibonacci

The input we gave our module was supposed to output the Fibonacci series which it calculates recursively (until 11).

```
function fib(n as int)
  dim r, l, k,m as int
  if n < 2 then
      r = 1;
  end if
  if n >= 2 then
      r =   fib(n-2) + fib(n-1) ;
  end if
  r;
end function

function printf(res as int)
    dim nextLine, revertedNum, tmp as int
    nextLine = 10;
    revertedNum = 0;
    while res != 0
        revertedNum = revertedNum * 10  ;
        tmp = res % 10;
```

```
        revertedNum= revertedNum + tmp;
        res = res / 10;
    wend
    while revertedNum != 0
        tmp = revertedNum % 10;
        tmp=tmp + 48;
        print(tmp);
        revertedNum = revertedNum / 10;
    wend
    print(10);
end function

function main()
  dim i as int
  i = 0;
 while i < 11
      printf(fib(i));
      i = i + 1;
    wend

end function
```

Input.txt

```
[section ram, code]
        init CodeEnd
        jump main
fib:
        sub_s 1
        wide_store
        pop_sf
        pop_sf
        pop_sf
        pop_sf
        pop_sf
        pop_sf
        pop_sf
        pop_sf
        push 0
        push 2
        add_s 1
        wide_store
        push 0
        push 2
        add_s 2
        wide_store
        push 0
        push 2
        add_s 3
        wide_store
```

```
            push 0
            push 2
            add_s 4
            wide_store
            push 2
            push 2
            sub_s 1
            load
            wide_sub
            pop
            jlt label_1
            push 0
                        ;false branch
            jump label_2
label_1:
            push 1
                        ;true branch
label_2:
                        ;if
            jz label_3
                        ;then
            push 1
            push 2
            add_s 1
            wide_store
            jump label_3
label_3:
            push 2
            push 2
            sub_s 1
            load
            wide_sub
            pop
            jge label_6
            push 0
                        ;false branch
            jump label_7
label_6:
            push 1
                        ;true branch
label_7:
                        ;if
            jz label_8
                        ;then
            push 1
            push 2
            sub_s 1
            load
```

```
            wide_sub
            pop_sf
            pop_sf
            call fib
            push 2
            push 2
            sub_s 1
            load
            wide_sub
            pop_sf
            pop_sf
            call fib
            wide_add
            add_s 1
            wide_store
            jump label_8
label_8:
            add_s 1
            load
                        ;endif
                        ;endif
            ret
printf:
            sub_s 1
            wide_store
            pop_sf
            pop_sf
            pop_sf
            pop_sf
            pop_sf
            pop_sf
            push 0
            push 2
            add_s 1
            wide_store
            push 0
            push 2
            add_s 2
            wide_store
            push 0
            push 2
            add_s 3
            wide_store
            push 10
            push 2
            add_s 1
            wide_store
            push 0
```

```
        push 2
        add_s 2
        wide_store
                ;while
label_15:
        push 0
        push 2
        sub_s 1
        load
        wide_sub
        pop
        jz label_17
        push 1
                ;false branch
        jump label_18
label_17:
        push 0
                ;true branch
label_18:
        jz label_19
                ;while body
        push 10
        push 2
        add_s 2
        load
        wide_mult
        add_s 2
        wide_store
        push 10
        push 2
        sub_s 1
        load
        wide_mod
        add_s 3
        wide_store
        add_s 3
        load
        add_s 2
        load
        wide_add
        add_s 2
        wide_store
        push 10
        push 2
        sub_s 1
        load
        wide_div
        sub_s 1
```

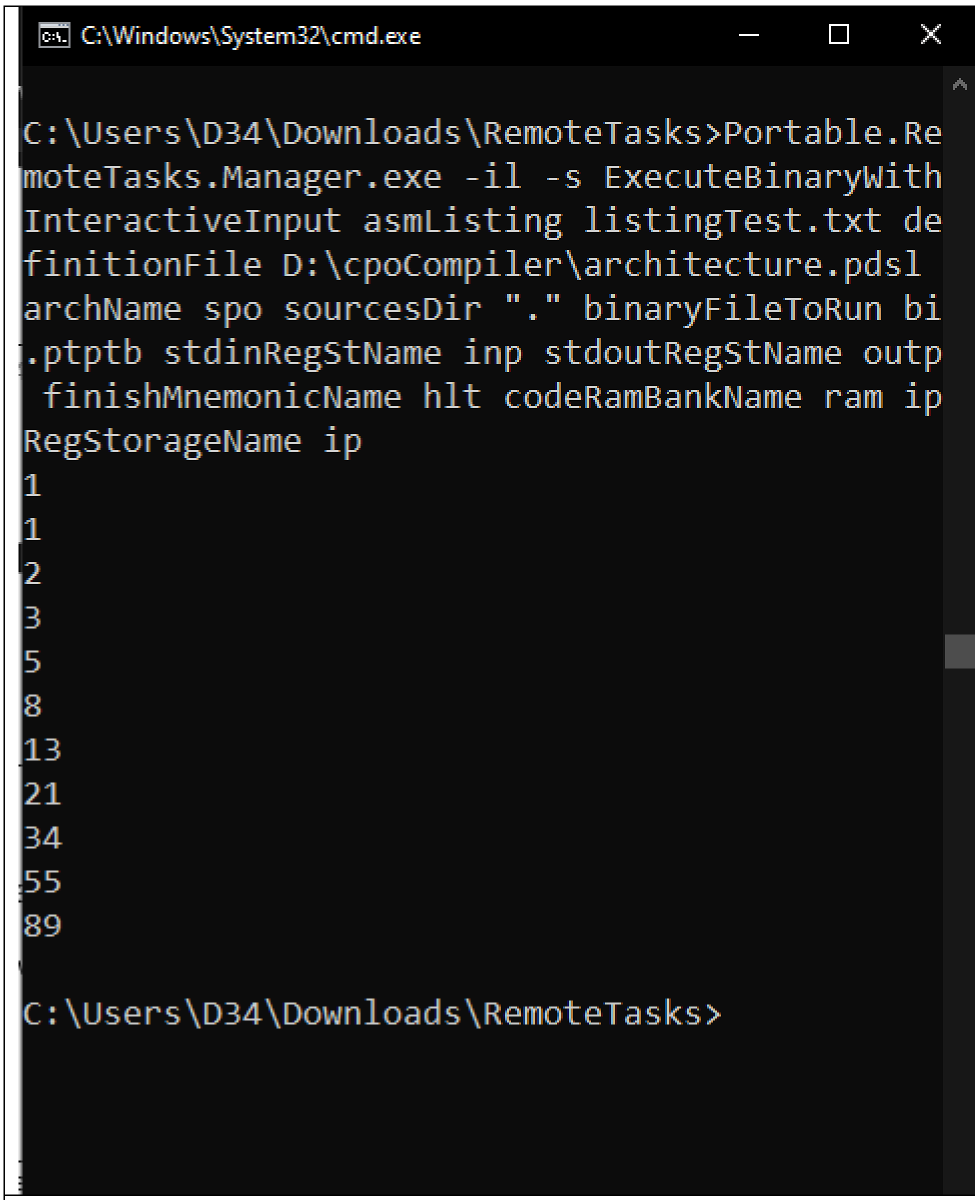
```
            wide_store
            jump label_15
label_19:
                        ;end while
                        ;while
label_23:
            push 0
            push 2
            add_s 2
            load
            wide_sub
            pop
            jz label_25
            push 1
                        ;false branch
            jump label_26
label_25:
            push 0
                        ;true branch
label_26:
            jz label_27
                        ;while body
            push 10
            push 2
            add_s 2
            load
            wide_mod
            add_s 3
            wide_store
            push 48
            push 2
            add_s 3
            load
            wide_add
            add_s 3
            wide_store
            add_s 3
            load
            pop
            write
            push 10
            push 2
            add_s 2
            load
            wide_div
            add_s 2
            wide_store
            jump label_23
```

```
label_27:
                ;end while
        push 10
        push 2
        pop
        write
        ret
main:
        pop_sf
        pop_sf
        push 0
        push 2
        add_s 1
        wide_store
        push 0
        push 2
        add_s 1
        wide_store
                ;while
label_33:
        push 11
        push 2
        add_s 1
        load
        wide_sub
        pop
        jlt label_35
        push 0
                ;false branch
        jump label_36
label_35:
        push 1
                ;true branch
label_36:
        jz label_37
                ;while body
        add_s 1
        load
        pop_sf
        pop_sf
        call fib
        pop_sf
        pop_sf
        call printf
        push 1
        push 2
        add_s 1
        load
```

```
        wide_add
        add_s 1
        wide_store
        jump label_33
label_37:
                ;end while
        jump halt
halt:
        hlt
CodeEnd:
```

Listing in assembly, generated by our module

And finally we got the following output



Fibonacci as calculated by the module, until 11

Санкт-Петербург, 2024 г.

6. Conclusions

I believe the results of this lab work align with the goals. The architecture description of the instruction set of our virtual machine was created successfully in alignment with our variant to include: arithmetic functions, branching, data movement and IO handeling. The module responsible for translating the control flow graphs' information to linear code was created successfully. And the result of this work was executed successfully to solve a meaningful task.

During the process of completing this lab assignment I learned what a virtual machine instruction set is, how the instructions are performed at a low level, what stages the compiler takes to reach an executable file, how to translate a code into a linear code, what dynamic and static typing is and learned a lot about real life architectures in the process of learning how to implement this task.

7. Link to the project on gitlab

https://gitlab.se.ifmo.ru/Aveena/cpoCompiler