Thực hành kiến trúc máy tính

Báo cáo thực hành

Bài 11. Lập trình xử lý ngắt

Họ Tên	Lê Thành An
MSSV	20235631

ASSIGNMENT 1

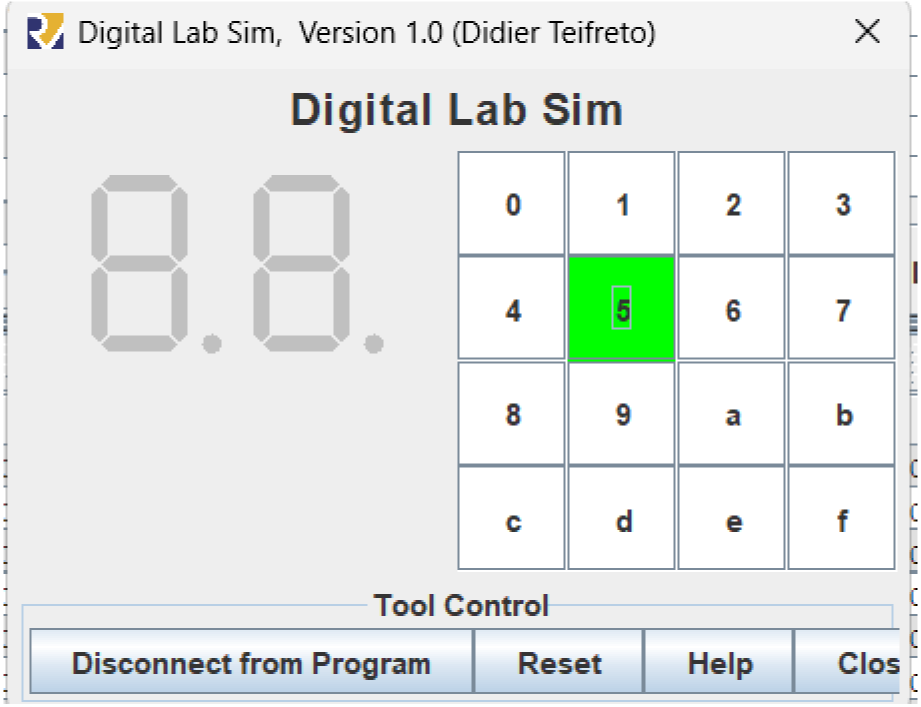
ĐOẠN MÃ :

```
# ------------------------------------------------------
#       col 0x1    col 0x2    col 0x4    col 0x8
# row 0x1     0    1     2    3
#       0x11  0x21 0x41  0x81
# row 0x2     4    5     6    7
#       0x12  0x22 0x42  0x82
# row 0x4     8    9     a    b
#       0x14  0x24 0x44  0x84
# row 0x8     c    d     e    f
#       0x18  0x28 0x48  0x88
# ------------------------------------------------------
# Command row number of hexadecimal keyboard (bit 0 to 3)
# Eg. assign 0x1, to get key button 0,1,2,3
# assign 0x2, to get key button 4,5,6,7
# NOTE must reassign value for this address before reading,
# eventhough you only want to scan 1 row
.eqv IN_ADDRESS_HEXA_KEYBOARD 0xFFFF0012
# Receive row and column of the key pressed, 0 if not key pressed
# Eg. equal 0x11, means that key button 0 pressed.
# Eg. equal 0x28, means that key button D pressed.
.eqv OUT_ADDRESS_HEXA_KEYBOARD 0xFFFF0014
.data
A: .asciz "\n"
.text
main:
li t1, IN_ADDRESS_HEXA_KEYBOARD
li t2, OUT_ADDRESS_HEXA_KEYBOARD
li t3, 0x01 # start with row 1 (0x01)
polling:
print:
# Check current row
sb t3, 0(t1)
lb a0, 0(t2)
# set the row to scan
 # read scan code of key button
# Only print if a key is pressed (a0 != 0)
```

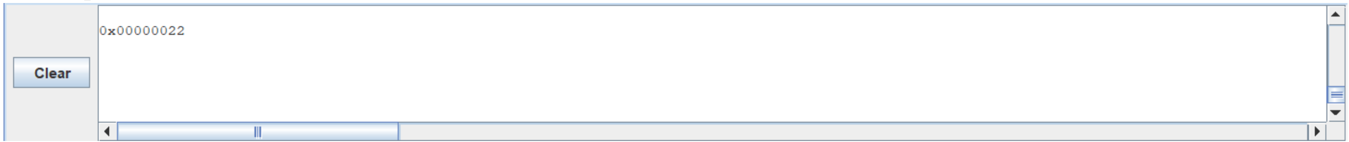
```
beqz a0, slow_down    # if no key pressed, skip print
li a7, 34
ecall
# print integer (hexa)
# Print space for readability
li a0, 32
li a7, 11
ecall
slow_down:
li a7, 4
la a0, A
ecall
next_row:
 # sleep 300ms - longer delay to keep execution speed under control
# Rotate through rows in sequence: 0x01 -> 0x02 -> 0x04 -> 0x08 -> 0x01
 li t4, 0x01
 beq t3, t4, set_row_2
 li t4, 0x02
 beq t3, t4, set_row_4
 li t4, 0x04
 beq t3, t4, set_row_8
 li t4, 0x08
 beq t3, t4, set_row_1

 # Fallback (shouldn't reach here)
 li t3, 0x01
 j polling

set_row_1:
 li t3, 0x01
 j polling

set_row_2:
 li t3, 0x02
 j polling

set_row_4:
 li t3, 0x04
 j polling

set_row_8:
 li t3, 0x08
 j polling
```

Kết quả:

Ấn 5

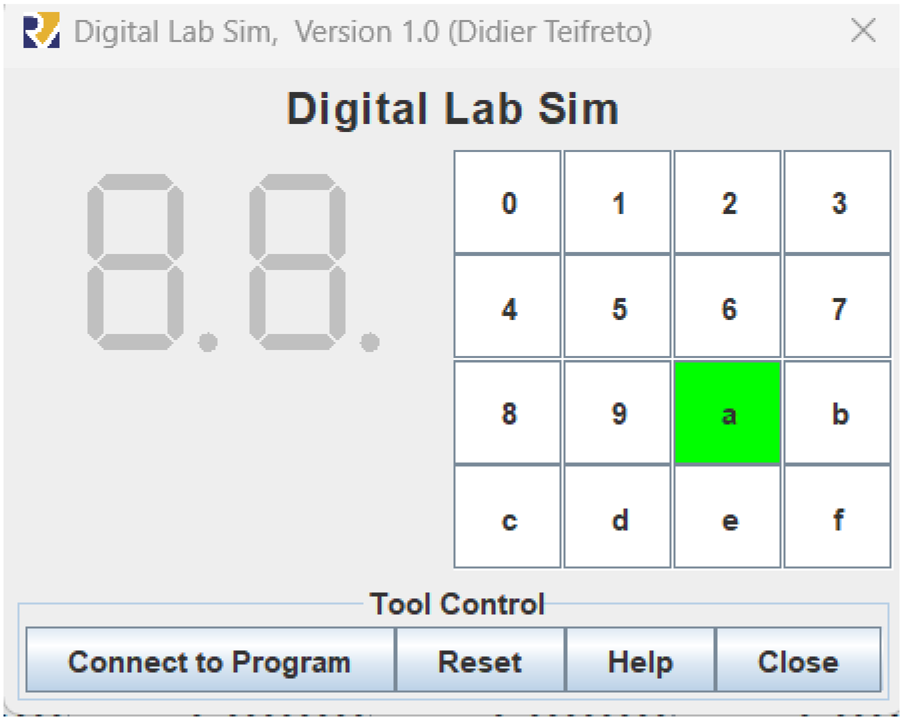


Kết quả là:

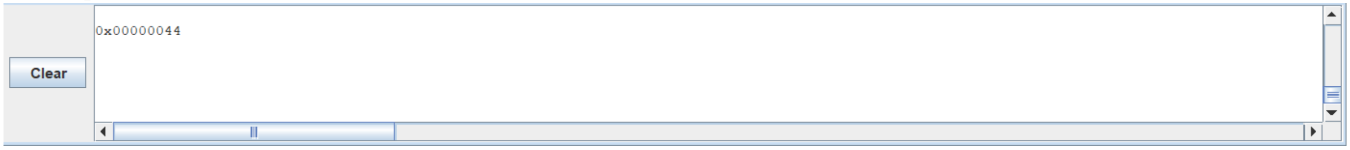


```
0x00000022
```

Ấn a:



Kết quả là:



```
0x00000044
```

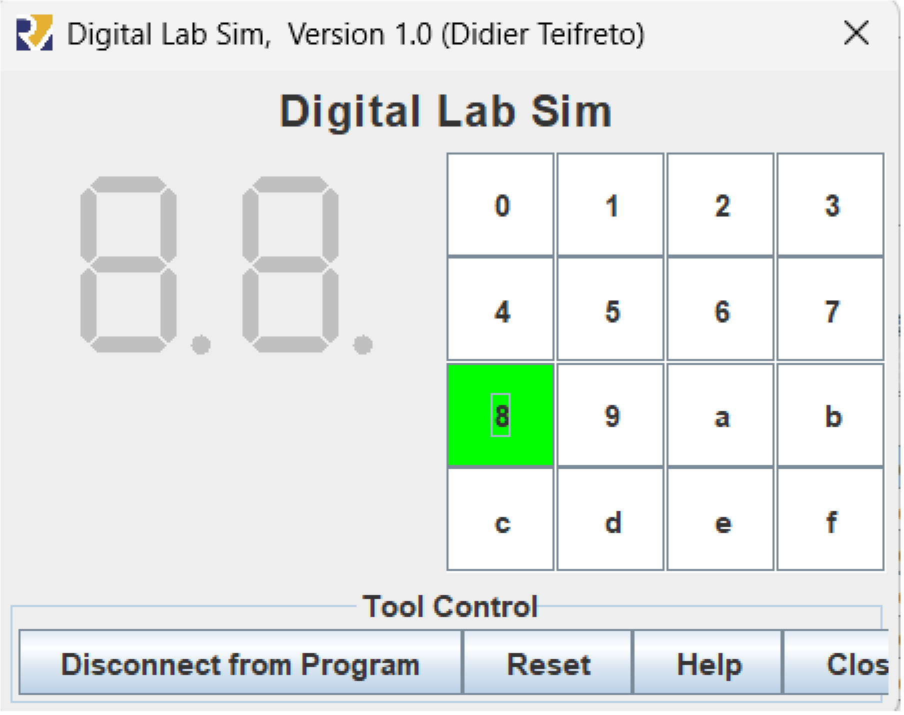
ASSIGNMENT 2

ĐOẠN MÃ :

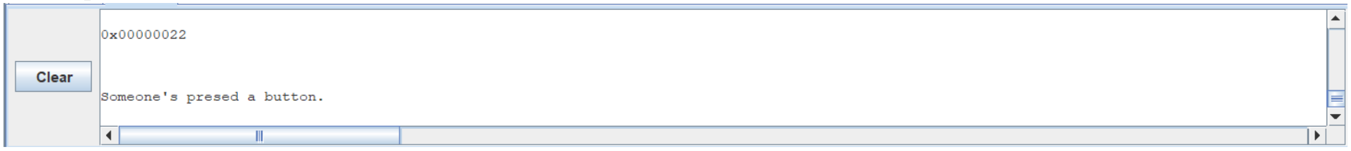
```
.eqv IN_ADDRESS_HEXA_KEYBOARD 0xFFFF0012
.data
message: .asciz "Someone's presed a button.\n"
# -----------------------------------------------------------------
# MAIN Procedure
# -----------------------------------------------------------------
.text
main:
   # Load the interrupt service routine address to the UTVEC register
   la t0, handler
   csrrs zero, utvec, t0
   # Set the UEIE (User External Interrupt Enable) bit in UIE register
   li t1, 0x100
   csrrs zero, uie, t1 # uie - ueie bit (bit 8)
   # Set the UIE (User Interrupt Enable) bit in USTATUS register
   csrrsi zero, ustatus, 1 # ustatus - enable uie (bit 0)
   # Enable the interrupt of keypad of Digital Lab Sim
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li t3, 0x80 # bit 7 = 1 to enable interrupt
   sb t3, 0(t1)
   # ---------------------------------------------------------
   # No-end loop, main program, to demo the effective of interrupt
   # ---------------------------------------------------------
loop:
   nop
   nop
   nop
   j loop
   end_main:
   # -----------------------------------------------------------------
   # Interrupt service routine
   # -----------------------------------------------------------------
handler:
   # ebreak # Can pause the execution to observe registers
   # Saves the context
   addi sp, sp, -8
   sw a0, 0(sp)
   sw a7, 4(sp)
   # Handles the interrupt
   # Shows message in Run I/O
   li a7, 4
   la a0, message
   ecall
   # Restores the context
   lw a7, 4(sp)
   lw a0, 0(sp)
   addi sp, sp, 8
   # Back to the main procedure
   uret
```

Kết quả:

Ấn 1 nút bất kì:



Kết quả là :



```
0x00000022


Someone's presed a button.
```

Thanh ghi:

Thời điểm	utvec	uie	ustatus	PC (giả định)	Ghi chú
Trước cấu hình ngắt	Không xác định	0	0	main	Bắt đầu chương trình
Sau csrrs utvec, t0	handler addr	0	0	tiếp tục dòng tiếp theo	Gán địa chỉ trình xử lý ngắt
Sau csrrs uie, t1	Không đổi	0x100	0	tiếp tục	Mở ngắt ngoài người dùng
Sau csrrsi ustatus, 1	Không đổi	0x100	0x1	tiếp tục	Cho phép tiếp nhận ngắt
Trước khi có ngắt	Không đổi	0x100	0x1	loop (vị trí j loop)	Đang thực hiện vòng lặp vô tận
Khi có ngắt xảy ra	Không đổi	0x100	0x1	handler addr	PC nhảy đến handler
Sau uret	Không đổi	0x100	0x1	trở về loop	PC quay lại tiếp tục thực thi

ĐOẠN MÃ :

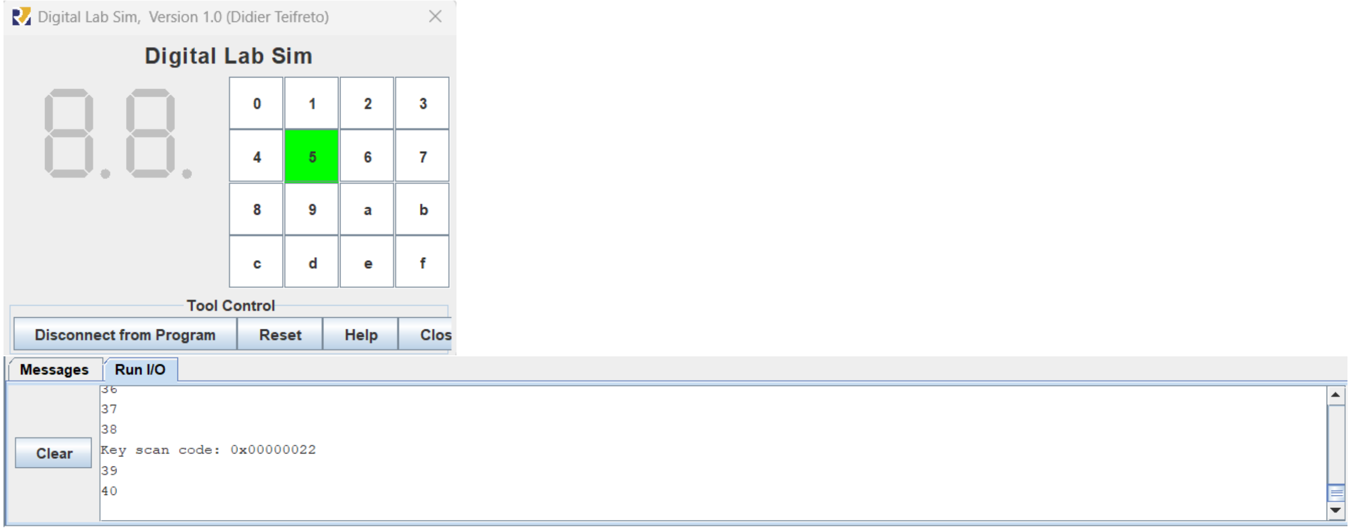
```
.eqv IN_ADDRESS_HEXA_KEYBOARD 0xFFFF0012
.eqv OUT_ADDRESS_HEXA_KEYBOARD 0xFFFF0014
.data
message: .asciz "Key scan code: "
# ------------------------------------------------------------------
# MAIN Procedure
# ------------------------------------------------------------------
```

```
.text
main:
   # Load the interrupt service routine address to the UTVEC register
   la t0, handler
   csrrs zero, utvec, t0
   # Set the UEIE (User External Interrupt Enable) bit in UIE register
   li t1, 0x100
   csrrs zero, uie, t1 # uie - ueie bit (bit
   # Set the UIE (User Interrupt Enable) bit in USTATUS register
   csrrsi zero, ustatus, 1 # ustatus - enable uie (bit 0)
   # Enable the interrupt of keypad of Digital Lab Sim
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li t3, 0x80 # bit 7 = 1 to enable interrupt
   sb t3, 0(t1)
   # ---------------------------------------------------------
   # Loop to print a sequence numbers
   # ---------------------------------------------------------
   xor s0, s0, s0 # count = s0 = 0
loop:
   addi s0, s0, 1 # count = count + 1
prn_seq:
   addi a7, zero, 1
   add a0, s0, zero # Print auto sequence number
   ecall
   addi a7, zero, 11
   li a0, '\n' # Print EOL
   ecall
sleep:
   addi a7, zero, 32
   li a0, 300 # Sleep 300 ms
   ecall
   j loop
end_main:
# ------------------------------------------------------------------
# Interrupt service routine
# ------------------------------------------------------------------
handler:# Saves the context
   addi sp, sp, -16
   sw a0, 0(sp)
   sw a7, 4(sp)
   sw t1, 8(sp)
   sw t2, 12(sp)
   # Handles the interrupt
prn_msg:
   addi a7, zero, 4
   la a0, message
   ecall
get_key_code:
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li a0, 0
check_row_1:
   li t2, 0x81 # Check row 4 and re-enable bit 7
   sb t2, 0(t1) # Must reassign expected row
   li t1, OUT_ADDRESS_HEXA_KEYBOARD
   lb a0, 0(t1)
   bne a0, zero, prn_key_code
```

```
check_row_2:
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li t2, 0x82
   sb t2, 0(t1)
   li t1, OUT_ADDRESS_HEXA_KEYBOARD
   lb a0, 0(t1)
   bne a0, zero, prn_key_code
check_row_3:
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li t2, 0x84
   sb t2, 0(t1)
   li t1, OUT_ADDRESS_HEXA_KEYBOARD
   lb a0, 0(t1)
   bne a0, zero, prn_key_code
check_row_4:
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li t2, 0x88
   sb t2, 0(t1)
   li t1, OUT_ADDRESS_HEXA_KEYBOARD
   lb a0, 0(t1)
   bne a0, zero, prn_key_code
prn_key_code:
   li a7, 34
   ecall
   li a7, 11
   li a0, '\n' # Print EOL
   ecall
   # Restores the context
   lw t2, 12(sp)
   lw t1, 8(sp)
   lw a7, 4(sp)
   lw a0, 0(sp)
   addi sp, sp, 16
   # Back to the main procedure
   uret
```

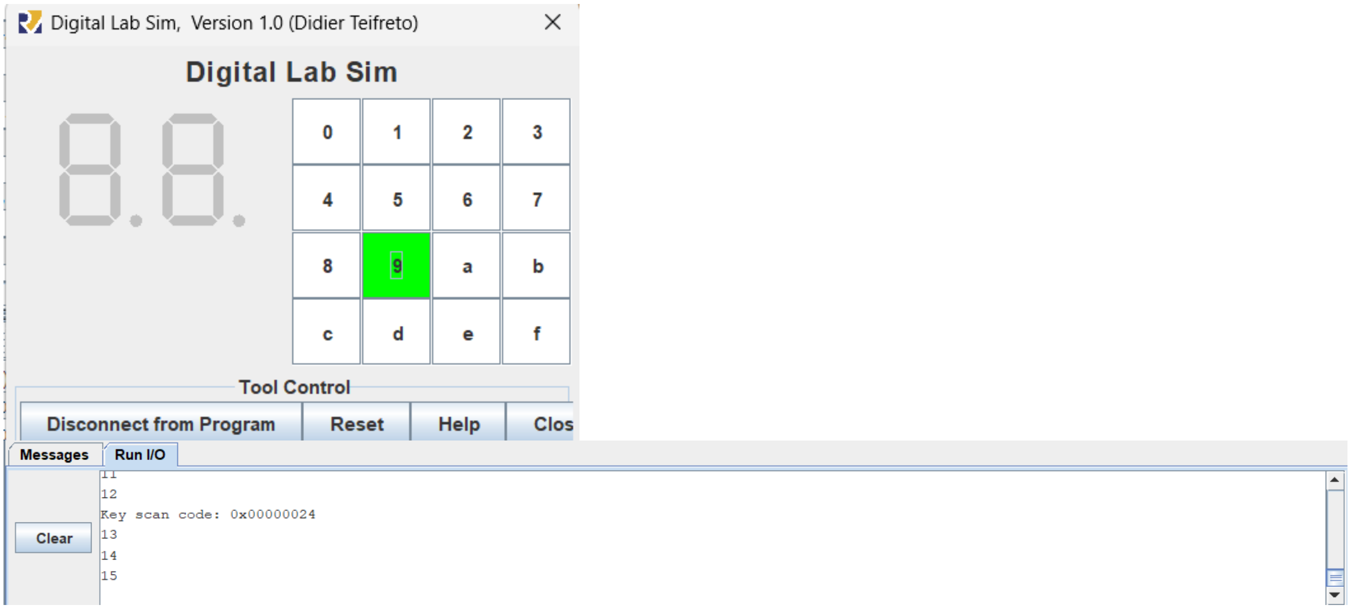
Kết quả:

ấn 5



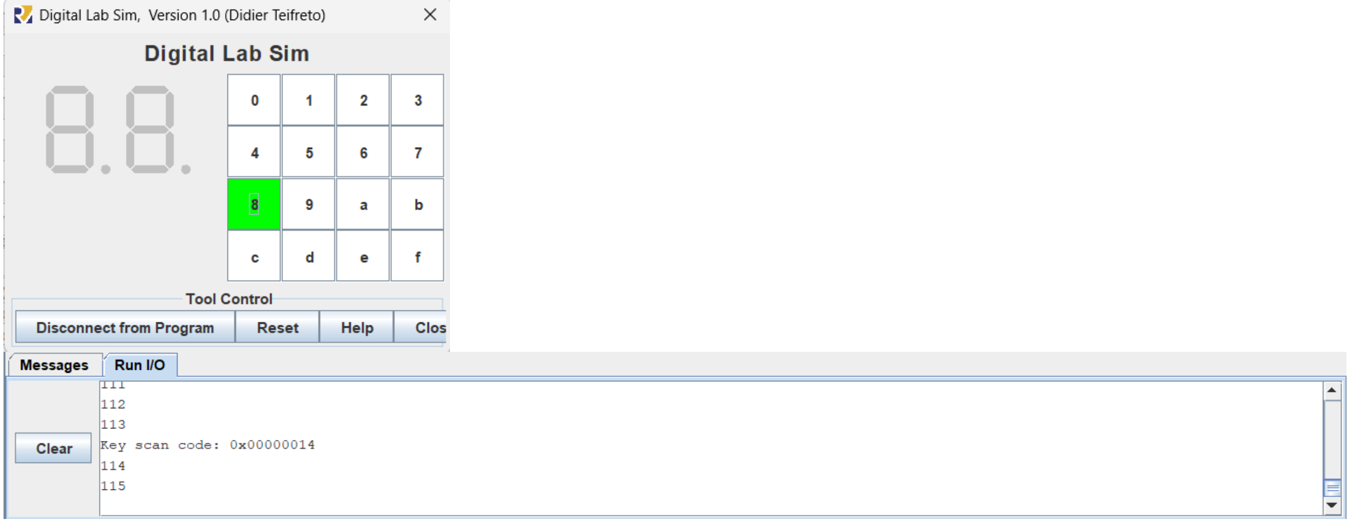
```
36
37
38
Key scan code: 0x00000022
39
40
```

ấn 9



```
11
12
Key scan code: 0x00000024
13
14
15
```

ấn 8



```
111
112
113
Key scan code: 0x00000014
114
115
```

Thanh ghi:

Thời điểm	utvec	uie	ustatus	PC	Ghi chú
Trước khi chạy `main`	Chưa xác định	0	0	entry point	Các ngắt chưa được bật
Sau `csrrs utvec, t0`	`handler` addr	0	0	sau dòng đó	Gán địa chỉ trình phục vụ ngắt
Sau `csrrs uie, t1`	Giữ nguyên	0x100	0	tiếp tục	Bật ngắt người dùng ngoài
Sau `csrrsi ustatus,1`	Giữ nguyên	0x100	0x1	tiếp tục	Cho phép nhận ngắt trong u-mode
Khi xảy ra ngắt	không đổi	không đổi	không đổi	nhảy tới `handler`	PC nhảy tới địa chỉ `handler`
Sau `uret`	không đổi	không đổi	không đổi	trở về PC cũ	Tiếp tục vòng lặp từ vị trí bị gián đoạn

ASSIGNMENT Bổ sung

ĐOẠN MÃ :

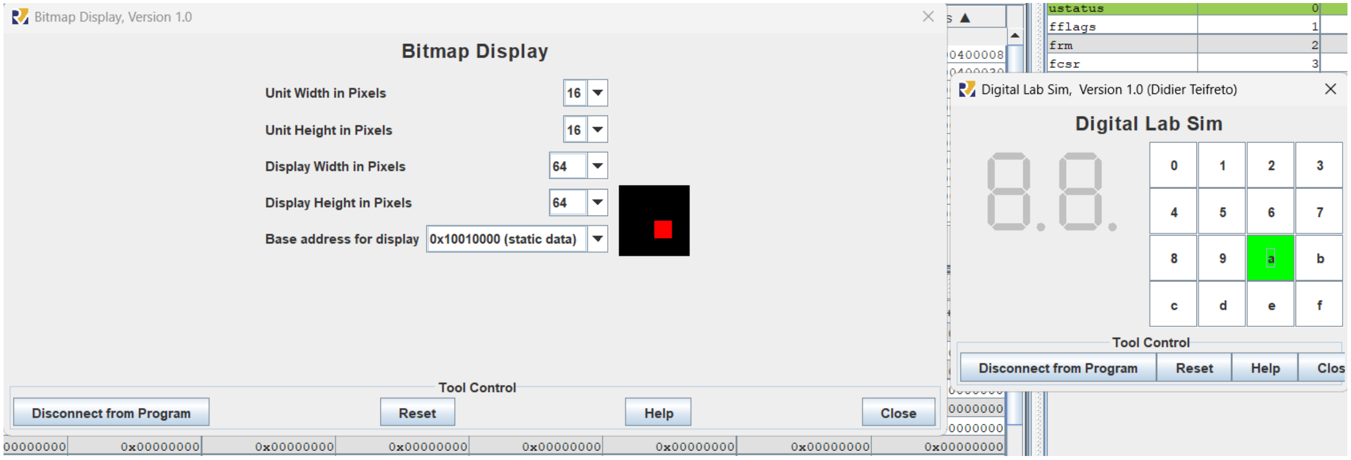
```
.eqv IN_ADDRESS_HEXA_KEYBOARD   0xFFFF0012  # Address of keyboard
.eqv OUT_ADDRESS_HEXA_KEYBOARD  0xFFFF0014  # Output address of keyboard
.eqv MONITOR_SCREEN             0x10010000  # Start address of display memory

# Bitmap display settings: 32x32, 128x128 pixels
# Each cell will be 8x8 pixels (2x2 words)

# Color constants
.eqv RED                        0x00FF0000

.data
message:        .asciz "Key scan code: \n"

# --------------------------------------------------------
# MAIN Procedure
# --------------------------------------------------------
.text
li  s10, MONITOR_SCREEN
main:
    # Load the interrupt service routine address to the UTVEC register
    la      t0, handler
    csrrs   zero, utvec, t0

    # Set the UEIE (User External Interrupt Enable) bit in UIE register
    li      t1, 0x100
    csrrs   zero, uie, t1       # uie - ueie bit (bit 8)

    # Set the UIE (User Interrupt Enable) bit in USTATUS register
    csrrsi  zero, ustatus, 1    # ustatus - enable uie (bit 0)

    # Enable the interrupt of keypad of Digital Lab Sim
    li      t1, IN_ADDRESS_HEXA_KEYBOARD
    li      t3, 0x80            # bit 7 = 1 to enable interrupt
    sb      t3, 0(t1)

    # --------------------------------------------------------
    # No-end loop, main program
    # --------------------------------------------------------
loop:
    nop
    nop
    nop
    j       loop
end_main:

# --------------------------------------------------------
# Draw a colored cell on the bitmap display based on the key code
# a0 - contains the key scan code
# --------------------------------------------------------
draw_cell:
    # Save the context
```

```
addi    sp, sp, -16
sw      ra, 0(sp)
sw      s0, 4(sp)
sw      s1, 8(sp)
sw      s2, 12(sp)

# Map key scan code to grid position based on provided data:
# Row 1: 0x11(0), 0x21(1), 0x41(2), 0x81(3)
# Row 2: 0x12(4), 0x22(5), 0x42(6), 0x82(7)
# Row 3: 0x14(8), 0x24(9), 0x44(10), 0x84(11)
# Row 4: 0x18(12), 0x28(13), 0x48(14), 0x88(15)

# Calculate position on grid
li      s0, -1              # Default cell number

# Row 1
li      t0, 0x11
beq     a0, t0, cell_0
li      t0, 0x21
beq     a0, t0, cell_1
li      t0, 0x41
beq     a0, t0, cell_2
li      t0, 0x81
beq     a0, t0, cell_3

# Row 2
li      t0, 0x12
beq     a0, t0, cell_4
li      t0, 0x22
beq     a0, t0, cell_5
li      t0, 0x42
beq     a0, t0, cell_6
li      t0, 0x82
beq     a0, t0, cell_7

# Row 3
li      t0, 0x14
beq     a0, t0, cell_8
li      t0, 0x24
beq     a0, t0, cell_9
li      t0, 0x44
beq     a0, t0, cell_10
li      t0, 0x84
beq     a0, t0, cell_11

# Row 4
li      t0, 0x18
beq     a0, t0, cell_12
li      t0, 0x28
beq     a0, t0, cell_13
li      t0, 0x48
beq     a0, t0, cell_14
li      t0, 0x88
beq     a0, t0, cell_15

j       draw_exit           # Invalid key code
```

```
cell_0:
    li  s9, RED
    sw  s9, 0(s10)
    j      draw_exit            # Return after drawing the cell
cell_1:
    li  s9, RED
    sw  s9, 4(s10)
    j      draw_exit            # Return after drawing the cell
cell_2:
    li  s9, RED
    sw  s9, 8(s10)
    j      draw_exit            # Return after drawing the cell
cell_3:
    li  s9, RED
    sw  s9, 12(s10)
    j      draw_exit            # Return after drawing the cell
cell_4:
    li  s9, RED
    sw  s9, 16(s10)
    j      draw_exit            # Return after drawing the cell
cell_5:
    li  s9, RED
    sw  s9, 20(s10)
    j      draw_exit            # Return after drawing the cell
cell_6:
    li  s9, RED
    sw  s9, 24(s10)
    j      draw_exit            # Return after drawing the cell
cell_7:
    li  s9, RED
    sw  s9, 28(s10)
    j      draw_exit            # Return after drawing the cell
cell_8:
    li  s9, RED
    sw  s9, 32(s10)
    j      draw_exit            # Return after drawing the cell
cell_9:
    li  s9, RED
    sw  s9, 36(s10)
    j      draw_exit            # Return after drawing the cell
cell_10:
    li  s9, RED
    sw  s9, 40(s10)
    j      draw_exit            # Return after drawing the cell
cell_11:
    li  s9, RED
    sw  s9, 44(s10)
    j      draw_exit            # Return after drawing the cell
cell_12:
    li  s9, RED
    sw  s9, 48(s10)
    j      draw_exit            # Return after drawing the cell
cell_13:
    li  s9, RED
    sw  s9, 52(s10)
    j      draw_exit            # Return after drawing the cell
cell_14:
    li  s9, RED
    sw  s9, 56(s10)
    j      draw_exit            # Return after drawing the cell
cell_15:
    li  s9, RED
    sw  s9, 60(s10)
    j      draw_exit            # Return after drawing the cell

draw_exit:
    # Restore the context
    lw      ra, 0(sp)
    lw      s0, 4(sp)
    lw      s1, 8(sp)
    lw      s2, 12(sp)
    addi    sp, sp, 16
    jr ra

# --------------------------------------------------------
# Interrupt service routine
# --------------------------------------------------------
handler:
    # Save the context
    addi    sp, sp, -24
    sw      ra, 0(sp)
    sw      a0, 4(sp)
    sw      a7, 8(sp)
    sw      t0, 12(sp)
    sw      t1, 16(sp)
    sw      t2, 20(sp)

    # Handle the interrupt
    # Print message
    li      a7, 4
    la      a0, message
    ecall

    # Get key scan code
    li      t0, IN_ADDRESS_HEXA_KEYBOARD
    li      t2, 0x81      # Check row 1 (0x1) and re-enable interrupt (0x80)
    sb      t2, 0(t0)
    li      t0, OUT_ADDRESS_HEXA_KEYBOARD
    lb      t1, 0(t0)
    bnez    t1, key_found

    li      t0, IN_ADDRESS_HEXA_KEYBOARD
    li      t2, 0x82      # Check row 2 (0x2) and re-enable interrupt (0x80)
    sb      t2, 0(t0)
    li      t0, OUT_ADDRESS_HEXA_KEYBOARD
    lb      t1, 0(t0)
    bnez    t1, key_found

    li      t0, IN_ADDRESS_HEXA_KEYBOARD
    li      t2, 0x84      # Check row 3 (0x4) and re-enable interrupt (0x80)
    sb      t2, 0(t0)
```

```
        li      t0, OUT_ADDRESS_HEXA_KEYBOARD
        lb      t1, 0(t0)
        bnez    t1, key_found

        li      t0, IN_ADDRESS_HEXA_KEYBOARD
        li      t2, 0x88      # Check row 4 (0x8) and re-enable interrupt (0x80)
        sb      t2, 0(t0)
        li      t0, OUT_ADDRESS_HEXA_KEYBOARD
        lb      t1, 0(t0)

    key_found:
        # Print key scan code in hex
        mv      a0, t1
        li      a7, 34          # Print in hex
        ecall

        # Print newline
        li      a7, 11
        li      a0, '\n'
        ecall

        # Draw the cell based on the key scan code
        mv      a0, t1
        jal     draw_cell

        # Restore the context
        lw      ra, 0(sp)
        lw      a0, 4(sp)
        lw      a7, 8(sp)
        lw      t0, 12(sp)
        lw      t1, 16(sp)
        lw      t2, 20(sp)
        addi    sp, sp, 24

        # Return from the interrupt routine
        uret
```

Kết quả:



Bitmap Display

Unit Width in Pixels: 16

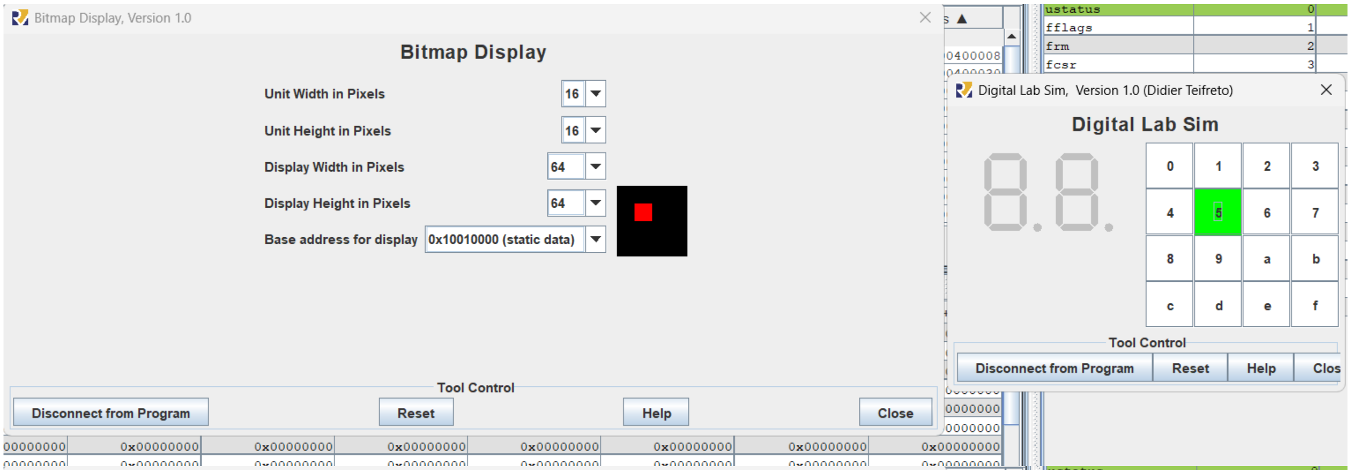
Unit Height in Pixels: 16

Display Width in Pixels: 64

Display Height in Pixels: 64

Base address for display: 0x10010000 (static data)

ustatus	0
fflags	1
frm	2
fcsr	3



Bitmap Display, Version 1.0

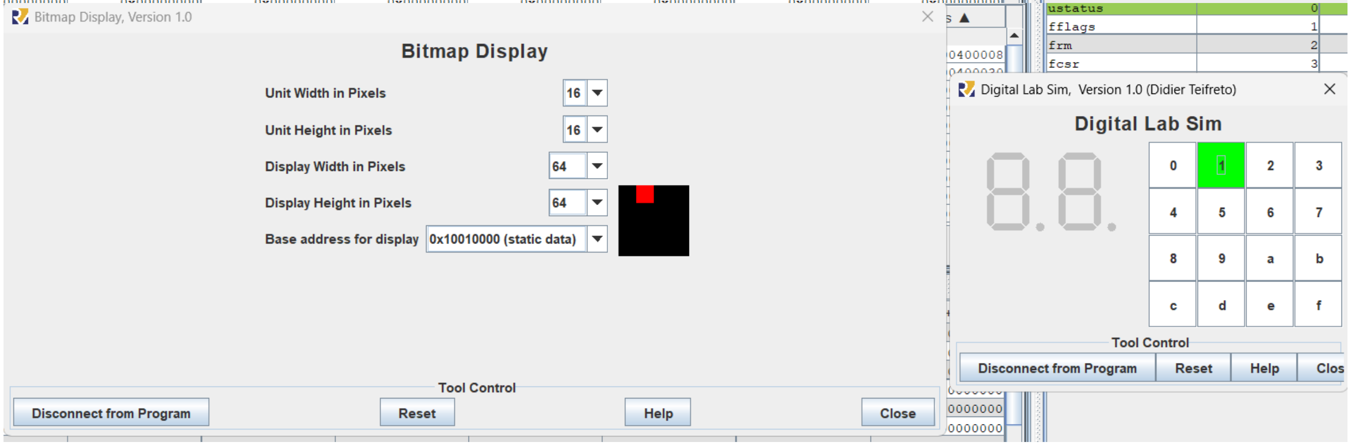
Bitmap Display

Unit Width in Pixels 16
Unit Height in Pixels 16
Display Width in Pixels 64
Display Height in Pixels 64
Base address for display 0x10010000 (static data)

Digital Lab Sim, Version 1.0 (Didier Teifreto)

Digital Lab Sim

ustatus 0
fflags 1
frm 2
fcsr 3



Bitmap Display, Version 1.0

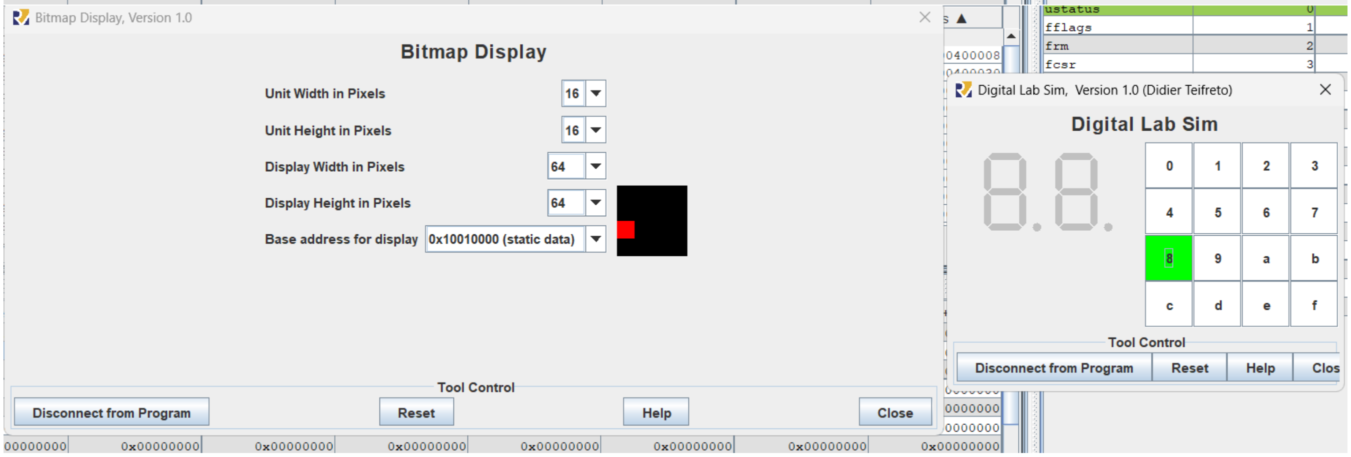
Bitmap Display

Unit Width in Pixels 16
Unit Height in Pixels 16
Display Width in Pixels 64
Display Height in Pixels 64
Base address for display 0x10010000 (static data)

Digital Lab Sim, Version 1.0 (Didier Teifreto)

Digital Lab Sim

ustatus 0
fflags 1
frm 2
fcsr 3



Bitmap Display, Version 1.0

Bitmap Display

Unit Width in Pixels 16
Unit Height in Pixels 16
Display Width in Pixels 64
Display Height in Pixels 64
Base address for display 0x10010000 (static data)

Digital Lab Sim, Version 1.0 (Didier Teifreto)

Digital Lab Sim

ustatus 0
fflags 1
frm 2
fcsr 3