Bài 11. LẬP TRÌNH XỬ LÝ NGẮT

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Assignment 1

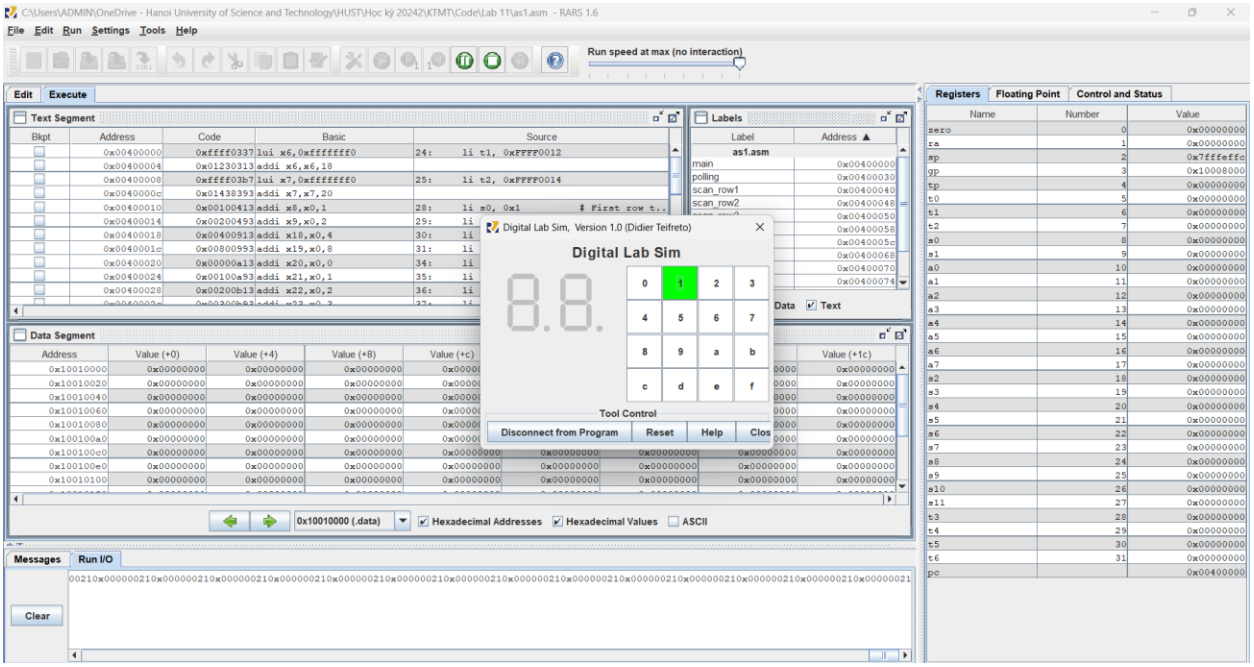
Code:

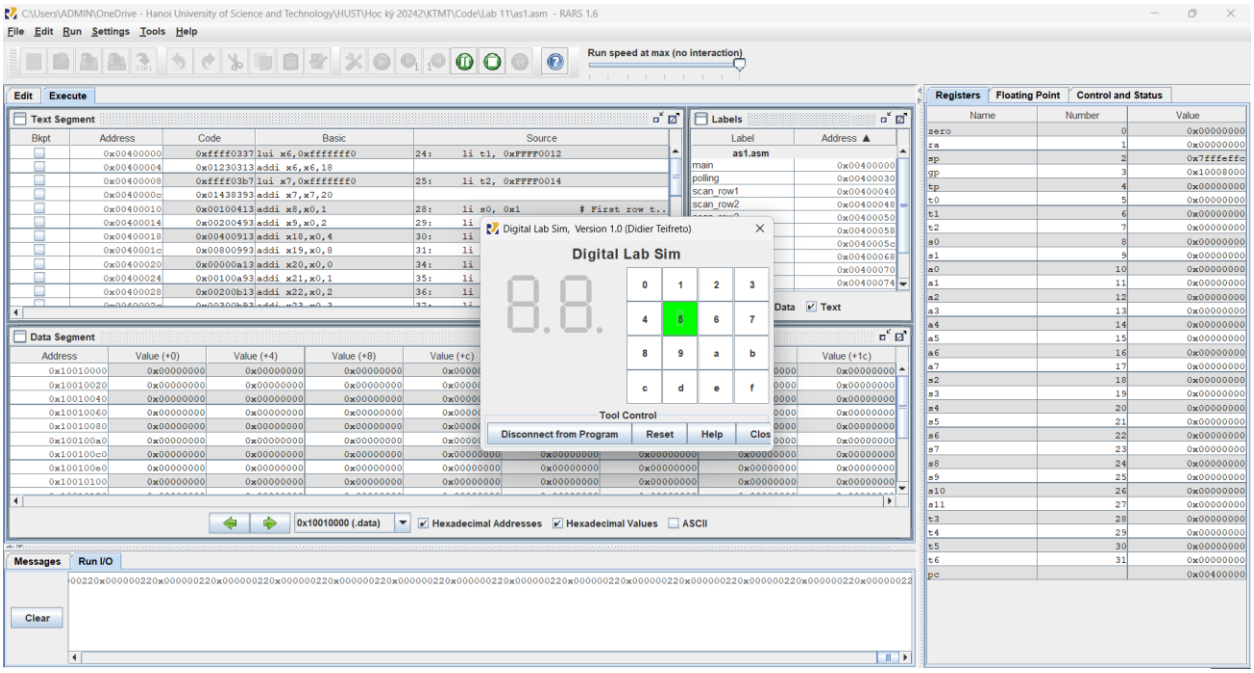
```
# ------------------------------------------------------
# col 0x1 col 0x2 col 0x4 col 0x8
# row 0x1 0 1 2 3
# 0x11 0x21 0x41 0x81
# row 0x2 4 5 6 7
# 0x12 0x22 0x42 0x82
# row 0x4 8 9 a b
# 0x14 0x24 0x44 0x84
# row 0x8 c d e f
# 0x18 0x28 0x48 0x88
# ------------------------------------------------------
# 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
.text
main:
  li t1, IN_ADDRESS_HEXA_KEYBOARD
  li t2, OUT_ADDRESS_HEXA_KEYBOARD

  # Initialize row values to scan (0x1, 0x2, 0x4, 0x8)
  li s0, 0x1        # First row to scan
  li s1, 0x2        # Second row to scan
  li s2, 0x4        # Third row to scan
  li s3, 0x8        # Fourth row to scan

  # Initialize counter for row scanning
  li s4, 0          # Current row index (0-3)
  li s5, 1          # Constant 1 for comparison
```

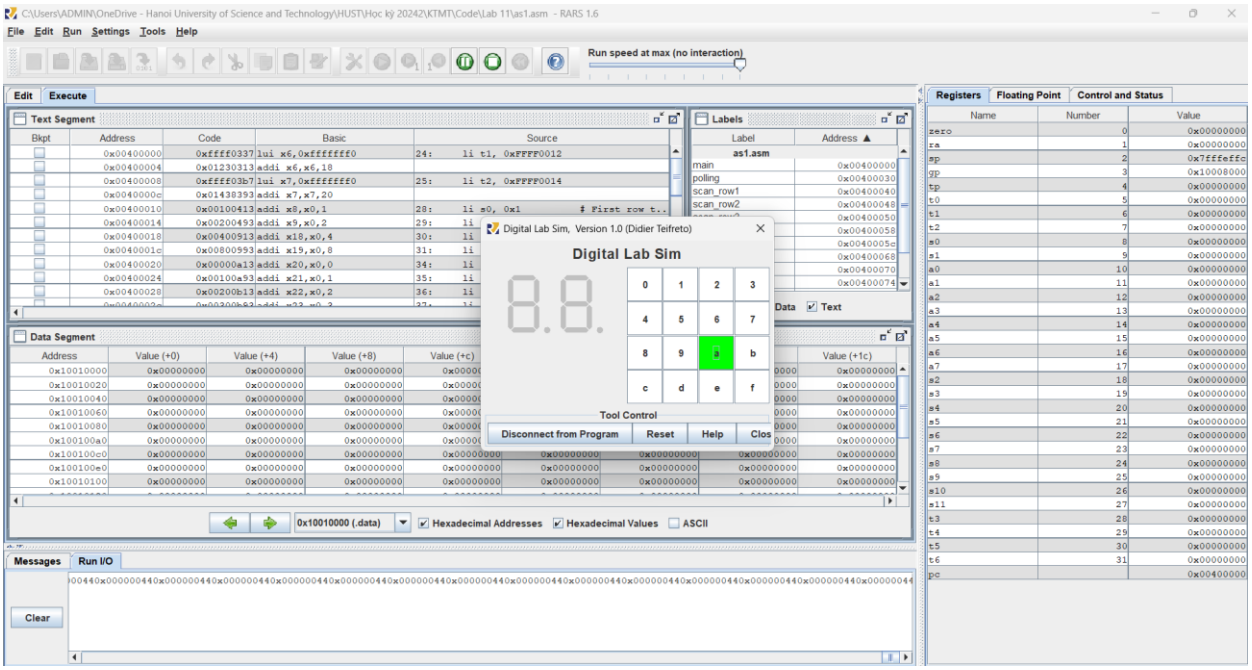
```
   li s6, 2          # Constant 2 for comparison
   li s7, 3          # Constant 3 for comparison



polling:
   # Select which row to scan based on s4
   beq s4, zero, scan_row1
   beq s4, s5, scan_row2
   beq s4, s6, scan_row3
   beq s4, s7, scan_row4

scan_row1:
   sb s0, 0(t1)      # Scan row 1
   j read_key

scan_row2:
   sb s1, 0(t1)      # Scan row 2
   j read_key

scan_row3:
   sb s2, 0(t1)      # Scan row 3
   j read_key

scan_row4:
   sb s3, 0(t1)      # Scan row 4

read_key:
   lb t3, 0(t2)      # Read scan code of key button into t3
   li t4, 0
   beq t3, t4, no_new_key   # If no key pressed, keep old key

new_key_pressed:
   mv s8, t3         # Update last key pressed
   j print_key

no_new_key:
   # Do not update s8, keep old value
   nop

print_key:
   mv a0, s8         # Move last valid key to a0
   li a7, 34         # Print integer (hexadecimal)
   ecall
```

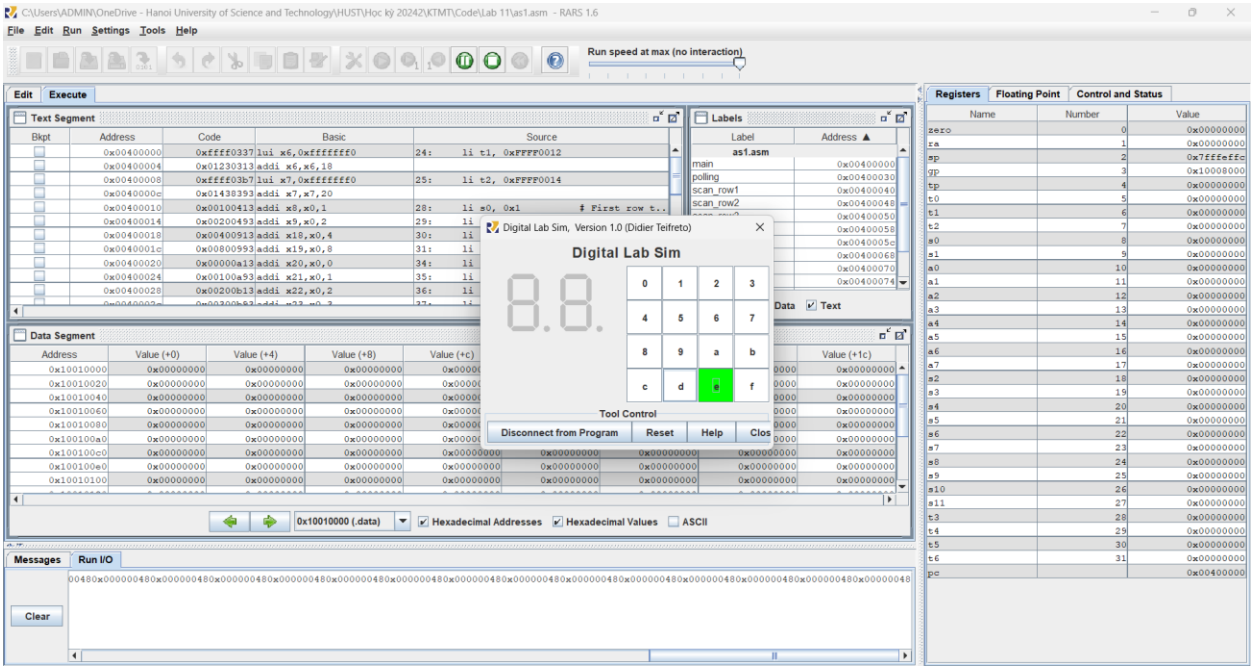
```
next_row:
   addi s4, s4, 1     # Increment row counter
   li t0, 4
   beq s4, t0, reset_counter

sleep:
   li a0, 100        # Sleep 100ms
   li a7, 32
   ecall
   j polling

reset_counter:
   li s4, 0          # Reset row counter
   j polling
```

Kết quả khi chạy:




C:\Users\ADMIN\OneDrive - Hanoi University of Science and Technology\HUST\Hoc ky 20242\KTMT\Code\Lab 11\as1.asm - RARS 1.6
File Edit Run Settings Tools Help
Run speed at max (no interaction)
Edit Execute
Text Segment
Bkpt Address Code Basic Source
0x00400000 0xffff0337 lui x6,0xffffffff0 24: li t1, 0xFFFF0012
0x00400004 0x01230313 addi x6,x6,18
0x00400008 0xffff03b7 lui x7,0xffffffff0 25: li t2, 0xFFFF0014
0x0040000c 0x01438393 addi x7,x7,20
0x00400010 0x00100413 addi x8,x0,1 28: li s0, 0x1 # First row t..
0x00400014 0x00200493 addi x9,x0,2 29: li
0x00400018 0x00400913 addi x18,x0,4 30: li
0x0040001c 0x00800993 addi x19,x0,8 31: li
0x00400020 0x00000a13 addi x20,x0,0 34: li
0x00400024 0x00100a93 addi x21,x0,1 35: li
0x00400028 0x00200b13 addi x22,x0,2 36: li
Labels
Label Address
as1.asm
main 0x00400000
polling 0x00400030
scan_row1 0x00400040
scan_row2 0x00400048
Data Text
Digital Lab Sim, Version 1.0 (Didier Teifreto)
Digital Lab Sim
0 1 2 3
4 5 6 7
8 9 a b
c d e f
Tool Control
Disconnect from Program Reset Help Clos
Data Segment
Address Value (+0) Value (+4) Value (+8) Value (+c) Value (+1c)
0x10010000 0x00000000 0x00000000 0x00000000
0x10010020 0x00000000 0x00000000 0x00000000
0x10010040 0x00000000 0x00000000 0x00000000
0x10010060 0x00000000 0x00000000 0x00000000
0x10010080 0x00000000 0x00000000 0x00000000
0x100100a0 0x00000000 0x00000000 0x00000000
0x100100c0 0x00000000 0x00000000 0x00000000
0x100100e0 0x00000000 0x00000000 0x00000000
0x10010100 0x00000000 0x00000000 0x00000000
0x10010000 (.data) Hexadecimal Addresses Hexadecimal Values ASCII
Messages Run I/O
Clear
Registers Floating Point Control and Status
Name Number Value
zero 0 0x00000000
ra 1 0x00000000
sp 2 0x7fffeffc
gp 3 0x10008000
tp 4 0x00000000
t0 5 0x00000000
t1 6 0x00000000
t2 7 0x00000000
s0 8 0x00000000
s1 9 0x00000000
a0 10 0x00000000
a1 11 0x00000000
a2 12 0x00000000
a3 13 0x00000000
a4 14 0x00000000
a5 15 0x00000000
a6 16 0x00000000
a7 17 0x00000000
s2 18 0x00000000
s3 19 0x00000000
s4 20 0x00000000
s5 21 0x00000000
s6 22 0x00000000
s7 23 0x00000000
s8 24 0x00000000
s9 25 0x00000000
s10 26 0x00000000
s11 27 0x00000000
t3 28 0x00000000
t4 29 0x00000000
t5 30 0x00000000
t6 31 0x00000000
pc 0x00400000





Giải thích:

- Bàn phím 16 phím (4 hàng x 4 cột).
- Mỗi lần chỉ quét **1 hàng**.
- Nếu **có phím nhấn**: ghi nhận và in ra phím đó.
- Nếu **không có phím nhấn**: vẫn **in lại** phím **cuối cùng đã nhấn**

Assignment 2

Code:

```
.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
```

Giải thích:

- Đoạn code:

```
# Load the interrupt service routine address to the UTVEC register
la t0, handler
csrrs zero, utvec, t0
```

la t0, handler: nạp địa chỉ nhãn handler vào thanh ghi t0.

csrrs zero, utvec, t0:

- Ghi địa chỉ đó vào **thanh ghi CSR utvec**.
- utvec = **User Trap Vector**: chứa địa chỉ trình xử lý ngắt.

➔ Khi có ngắt xảy ra, CPU tự động nhảy tới handler.

- Đoạn code:

```
li t1, 0x100
csrrs zero, uie, t1 # uie - ueie bit (bit 8)
```

t1 = 0x100 (bit 8 = 1).

Ghi giá trị này vào **CSR uie** (User Interrupt Enable Register).

Bit 8 (UEIE) cho phép ngắt từ thiết bị ngoài (keypad).

➔ Cho phép ngắt ngoài cấp user (bàn phím).

- Đoạn code:

```
csrrsi zero, ustatus, 1 # ustatus - enable uie (bit 0)
```

➔ Cho phép hệ thống nhận bất kỳ ngắt nào.

- Đoạn code:

```
li t1, IN_ADDRESS_HEXA_KEYBOARD
li t3, 0x80 # bit 7 = 1 to enable interrupt
sb t3, 0(t1)
```

Ghi 0x80 (bit 7 = 1) vào IN_ADDRESS_HEXA_KEYBOARD.

Cụ thể: **bit 7 bật tính năng interrupt** của bàn phím.

➔ Bàn phím sẽ gửi ngắt khi nhấn nút.

Assignment 3

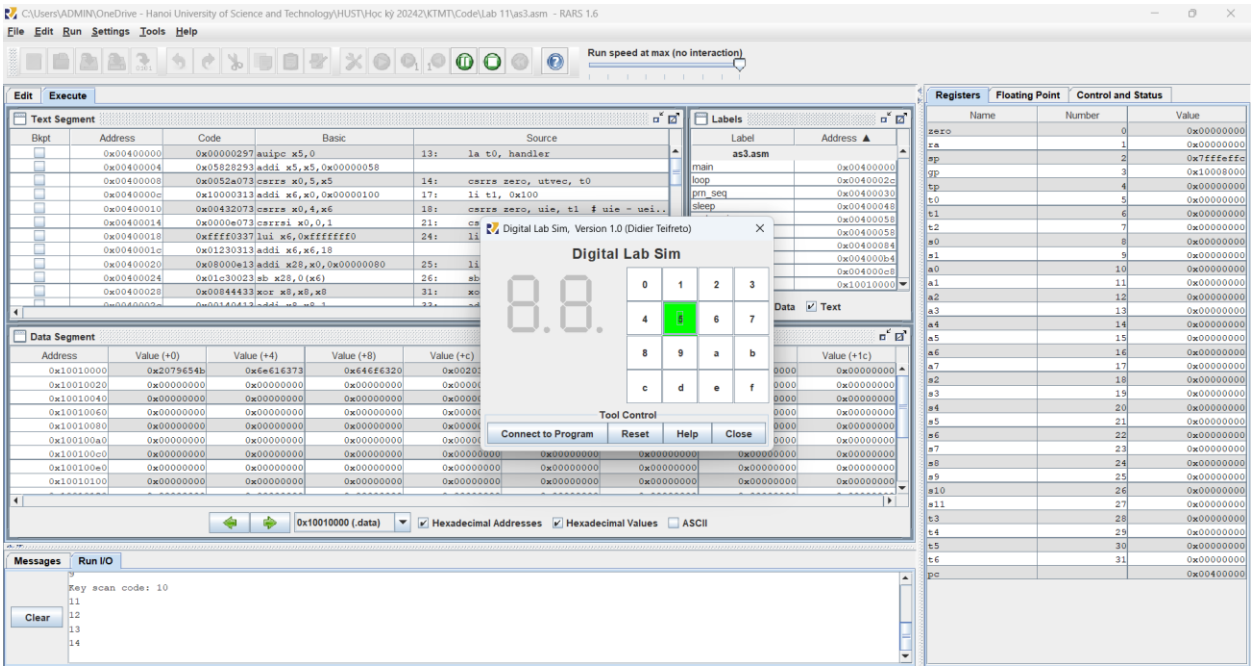
Code:

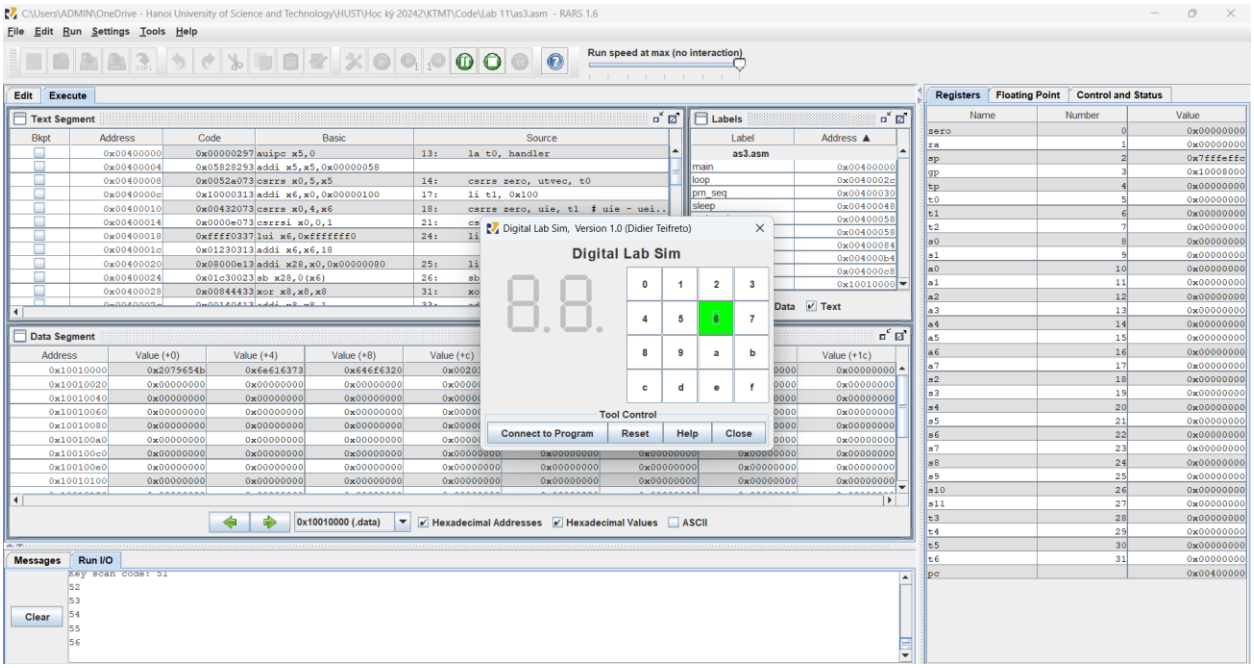
```
.eqv IN_ADDRESS_HEXA_KEYBOARD  0xFFFF0012
.eqv OUT_ADDRESS_HEXA_KEYBOARD 0xFFFF0014

.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 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)

   # -----------------------------------------------------------
   # 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:
   # Save context
   addi sp, sp, -16
   sw a0, 0(sp)
   sw a7, 4(sp)
   sw t1, 8(sp)
   sw t2, 12(sp)

   # Print message
   addi a7, zero, 4
   la a0, message
   ecall

   # Scan all 4 rows to find which key is pressed
   li t3, 0x1    # Start from row 0x1
   li t4, 0x8    # Maximum row value is 0x8

scan_rows:
   li t1, IN_ADDRESS_HEXA_KEYBOARD
   li t5, 0x80       # Load immediate 0x80 vào thanh ghi t5
   or t2, t3, t5     # t2 = row bit | enable interrupt bit
   sb t2, 0(t1)      # Select the row to scan
```

```
    li t1, OUT_ADDRESS_HEXA_KEYBOARD
    lb a0, 0(t1)       # Read key scan code

    bne a0, zero, found_key   # If a key is detected, jump to print

    slli t3, t3, 1      # Shift to next row (1->2->4->8)
    ble t3, t4, scan_rows
    j end_handler       # No key found

found_key:
    # Print the scan code
    li a7, 34          # Print integer (hex)
    ecall

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

end_handler:
    # Restore context
    lw t2, 12(sp)
    lw t1, 8(sp)
    lw a7, 4(sp)
    lw a0, 0(sp)
    addi sp, sp, 16

    # Return from interrupt
    uret
```

Kết quả khi chạy chương trình:





Giải thích:

- **Chạy main → in ra một dãy số đếm** (74,75,76,...). <Với mục đích là để chương trình vẫn chạy liên tục mà không bị ngắt>
- Nếu **nhấn nút** trên bàn phím keypad (hex keypad):

- **Tự động ngắt** chương trình chính (main),
- **Xử lý ngắt**: in ra mã số phím bấm theo định dạng: Key scan code: <địa chỉ>

- **Quay lại** chương trình chính.

Bonus:

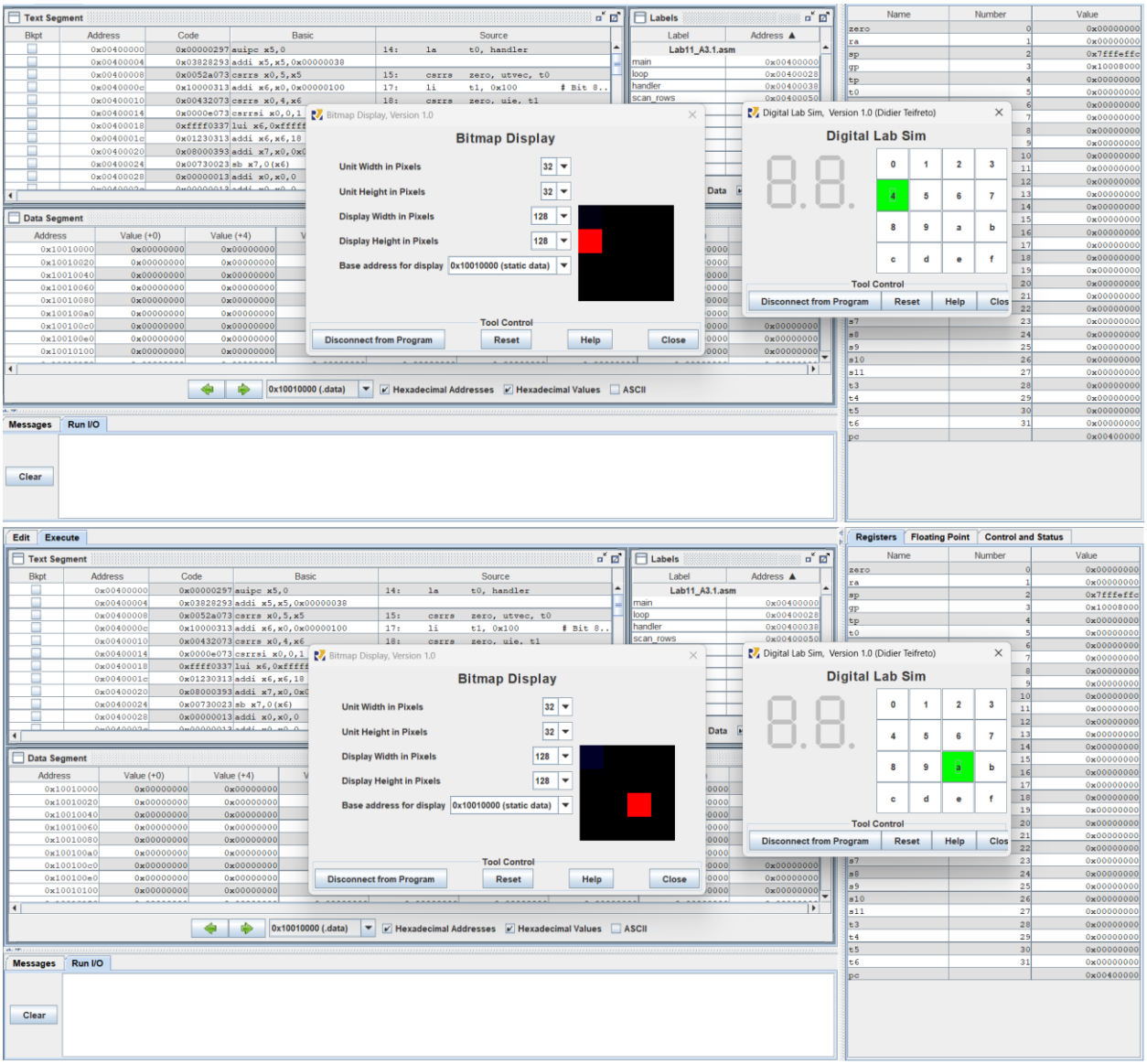
Code:

```
.eqv IN_ADDRESS_HEXA_KEYBOARD    0xFFFF0012
.eqv OUT_ADDRESS_HEXA_KEYBOARD   0xFFFF0014
.eqv MONITOR_SCREEN          0x10010000  # Địa chỉ nơi Bitmap Display vẽ

.eqv RED                  0xFF0000    # RGB Red
.eqv BLACK                  0x000000    # RGB Black

.data
last_red_addr: .word 0                # Địa chỉ ô đã tô đỏ trước đó

.text
main:
   # Thiết lập handler ngắt
   la     t0, handler
   csrrs   zero, utvec, t0

   li     t1, 0x100      # Bit 8 = UEIE
   csrrs   zero, uie, t1

   csrrsi  zero, ustatus, 1 # Bit 0 = UIE

   # Bật ngắt keypad
   li     t1, IN_ADDRESS_HEXA_KEYBOARD
   li     t2, 0x80
   sb     t2, 0(t1)

loop:
   nop
   nop
   nop
   j      loop          # Vòng lặp không làm gì cả, chờ ngắt

# ---------------------------------------------------------
# INTERRUPT HANDLER
# ---------------------------------------------------------
handler:
   # Lưu context
   addi    sp, sp, -16
   sw      a0, 0(sp)
```

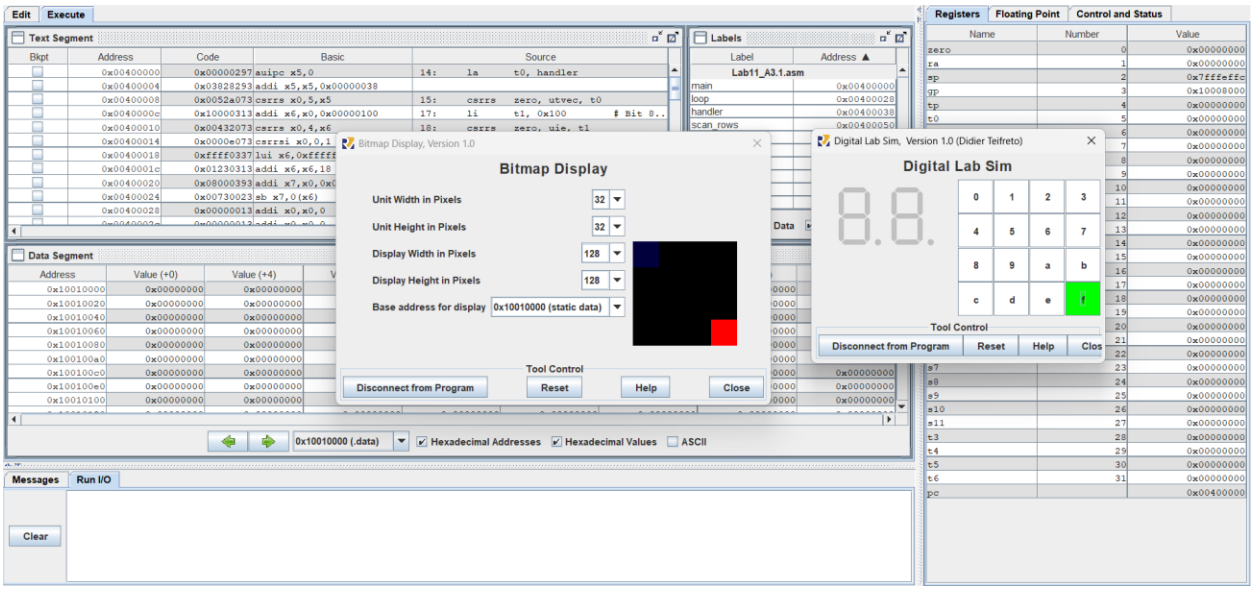
```
   sw     a7, 4(sp)
   sw     t1, 8(sp)
   sw     t2, 12(sp)

   li     t3, 0         # chỉ số hàng
scan_rows:
   li     t1, IN_ADDRESS_HEXA_KEYBOARD
   li     t2, 0x80      # Bật ngắt của bàn phím
   li     t4, 1
   sll    t4, t4, t3    # t4 = t4 * 2^t3
   or     t2, t2, t4    # bật bit tương ứng với hàng cần quét
   sb     t2, 0(t1)
   # Đọc mã phím
   li     t1, OUT_ADDRESS_HEXA_KEYBOARD
   lb     a0, 0(t1)
   beq    a0, zero, next_row    # Không phím nào nhấn thì quét hàng tiếp theo

   # Nếu phát hiện có phím được nhấn thì tìm toạ độ của phím
   # a0 hiện tại đang chứa hàng và cột của phím đó
   # 4 bit từ 0-3 chứa số hàng, chính là giá trị của t3
   # 4 bit từ 4-7 chứa số cột, sẽ được tìm ra và lưu vào t5
   li     t5, 0         # chỉ số cột
find_col:
   li     t6, 1
   sll    t6, t6, t5    # t6 = t6 * 2^t5
   slli   t6, t6, 4     # Di chuyển để t6 đến bit từ 4-7 để check cột
   and    t6, t6, a0    # thực hiện and với a0 để tìm ra vị trí bit được đổi thành 1

   # Nếu kq phép and = 0 nghĩa là tại vị trí bit tương ứng là 0, ngược lại thì bit tại đó bằng 1
và thực hiện vẽ.
   bnez   t6, draw_square
   addi   t5, t5, 1     # Tăng chỉ số cột để tìm
   li     t0, 4
   blt    t5, t0, find_col # Điều kiện thoát vòng lặp tìm cột
   j      end_handler

draw_square:
   # Tính chỉ số ô
   mul    s0, t3, t0     # s0 = row * 4
   add    s0, s0, t5     # s0 = index = row * 4 + col
   slli   s0, s0, 2      # s0 = offset byte = index * 4
   li     s1, MONITOR_SCREEN
   add    s0, s0, s1     # s0 = địa chỉ ô cần tô màu đỏ
```

```
   la     a1, last_red_addr      # Đọc địa chỉ ô được tô màu đỏ trước đó
   lw     a2, 0(a1)
   beq    a2, zero, skip_clear   # Nếu a2 = 0, tức đây là lần đầu nhấn phím thì bỏ qua bước
tô đen ô cũ
   li     a3, BLACK              # Tô đen ô đỏ cũ
   sw     a3, 0(a2)
skip_clear:
   li     a4, RED                # Tô đỏ ô mới
   sw     a4, 0(s0)

   sw     s0, 0(a1)              # Lưu giá trị s0 vào bộ nhớ để dùng lần sau

next_row:
   addi   t3, t3, 1
   li     t0, 4
   blt    t3, t0, scan_rows      # Kiểm tra hết thì quay về đầu bàn phím

end_handler:
   # Khôi phục ngữ cảnh
   lw     t2, 12(sp)
   lw     t1, 8(sp)
   lw     a7, 4(sp)
   lw     a0, 0(sp)
   addi   sp, sp, 16
   uret
```

Kết quả:


Text Segment
Bkpt Address Code Basic Source
0x00400000 0x00000297 auipc x5,0 14: la t0, handler
0x00400004 0x03828293 addi x5,x5,0x00000038
0x00400008 0x0052a073 csrrs x0,5,x5 15: csrrs zero, utvec, t0
0x0040000c 0x10000313 addi x6,x0,0x00000100 17: li t1, 0x100 # Bit 8..
0x00400010 0x00432073 csrrs x0,4,x6 18: csrrs zero, uie, t1
0x00400014 0x0000e073 csrrsi x0,0,1
0x00400018 0xffff0337 lui x6,0xffff
0x0040001c 0x01230313 addi x6,x6,18
0x00400020 0x08000393 addi x7,x0,0x0
0x00400024 0x00730023 sb x7,0(x6)
0x00400028 0x00000013 addi x0,x0,0
Labels
Label Address
Lab11_A3.1.asm
main 0x00400000
loop 0x00400028
handler 0x00400038
scan_rows 0x00400050
Data Segment
Address Value (+0) Value (+4)
0x10010000 0x00000000 0x00000000
0x10010020 0x00000000 0x00000000
0x10010040 0x00000000 0x00000000
0x10010060 0x00000000 0x00000000
0x10010080 0x00000000 0x00000000
0x100100a0 0x00000000 0x00000000
0x100100c0 0x00000000 0x00000000
0x100100e0 0x00000000 0x00000000
0x10010100 0x00000000 0x00000000
0x10010000 (.data)
Hexadecimal Addresses
Hexadecimal Values
ASCII
Messages
Run I/O
Clear
Bitmap Display, Version 1.0
Bitmap Display
Unit Width in Pixels 32
Unit Height in Pixels 32
Display Width in Pixels 128
Display Height in Pixels 128
Base address for display 0x10010000 (static data)
Tool Control
Disconnect from Program
Reset
Help
Close
Digital Lab Sim, Version 1.0 (Didier Teifreto)
Digital Lab Sim
0 1 2 3
4 5 6 7
8 9 a b
c d e f
Tool Control
Disconnect from Program
Reset
Help
Clos
Name Number Value
zero 0 0x00000000
ra 1 0x00000000
sp 2 0x7fffeffc
gp 3 0x10008000
tp 4 0x00000000
t0 5 0x00000000
s7 23 0x00000000
s8 24 0x00000000
s9 25 0x00000000
s10 26 0x00000000
s11 27 0x00000000
t3 28 0x00000000
t4 29 0x00000000
t5 30 0x00000000
t6 31 0x00000000
pc 0x00400000

Edit
Execute
Registers
Floating Point
Control and Status
Text Segment
Bkpt Address Code Basic Source
0x00400000 0x00000297 auipc x5,0 14: la t0, handler
0x00400004 0x03828293 addi x5,x5,0x00000038
0x00400008 0x0052a073 csrrs x0,5,x5 15: csrrs zero, utvec, t0
0x0040000c 0x10000313 addi x6,x0,0x00000100 17: li t1, 0x100 # Bit 8..
0x00400010 0x00432073 csrrs x0,4,x6 18: csrrs zero, uie, t1
0x00400014 0x0000e073 csrrsi x0,0,1
0x00400018 0xffff0337 lui x6,0xffff
0x0040001c 0x01230313 addi x6,x6,18
0x00400020 0x08000393 addi x7,x0,0x0
0x00400024 0x00730023 sb x7,0(x6)
0x00400028 0x00000013 addi x0,x0,0
Labels
Label Address
Lab11_A3.1.asm
main 0x00400000
loop 0x00400028
handler 0x00400038
scan_rows 0x00400050
Data Segment
Address Value (+0) Value (+4)
0x10010000 0x00000000 0x00000000
0x10010020 0x00000000 0x00000000
0x10010040 0x00000000 0x00000000
0x10010060 0x00000000 0x00000000
0x10010080 0x00000000 0x00000000
0x100100a0 0x00000000 0x00000000
0x100100c0 0x00000000 0x00000000
0x100100e0 0x00000000 0x00000000
0x10010100 0x00000000 0x00000000
0x10010000 (.data)
Hexadecimal Addresses
Hexadecimal Values
ASCII
Messages
Run I/O
Clear
Bitmap Display, Version 1.0
Bitmap Display
Unit Width in Pixels 32
Unit Height in Pixels 32
Display Width in Pixels 128
Display Height in Pixels 128
Base address for display 0x10010000 (static data)
Tool Control
Disconnect from Program
Reset
Help
Close
Digital Lab Sim, Version 1.0 (Didier Teifreto)
Digital Lab Sim
0 1 2 3
4 5 6 7
8 9 a b
c d e f
Tool Control
Disconnect from Program
Reset
Help
Clos
Name Number Value
zero 0 0x00000000
ra 1 0x00000000
sp 2 0x7fffeffc
gp 3 0x10008000
tp 4 0x00000000
t0 5 0x00000000
s7 23 0x00000000
s8 24 0x00000000
s9 25 0x00000000
s10 26 0x00000000
s11 27 0x00000000
t3 28 0x00000000
t4 29 0x00000000
t5 30 0x00000000
t6 31 0x00000000
pc 0x00400000


Edit
Execute
Text Segment
Bkpt
Address
Code
Basic
Source
Labels
Label
Address
Lab11_A3.1.asm
main
loop
handler
scan_rows
Data Segment
Address
Value (+0)
Value (+4)
Bitmap Display, Version 1.0
Bitmap Display
Unit Width in Pixels
Unit Height in Pixels
Display Width in Pixels
Display Height in Pixels
Base address for display
0x10010000 (static data)
Tool Control
Disconnect from Program
Reset
Help
Close
Digital Lab Sim, Version 1.0 (Didier Teifreto)
Digital Lab Sim
Tool Control
Disconnect from Program
Reset
Help
Clos
0x10010000 (.data)
Hexadecimal Addresses
Hexadecimal Values
ASCII
Messages
Run I/O
Clear
Registers
Floating Point
Control and Status
Name
Number
Value