Task 3- Answers

Part 1 (src/condition.cpp and ir/condition.ll):

check():

```
define dso_local noundef i32 @"?check@@YAHH@Z"(i32 noundef %0) {
  ; Allocate space for return value
  %2 = alloca i32, align 4
  ; Allocate space for input parameter x
  %3 = alloca i32, align 4
  ; Store the input argument %0 into local variable %3
  store i32 %0, ptr %3, align 4
  ; Load x from memory
  %4 = load i32, ptr %3, align 4
  ; Compare x > 5 using signed greater-than
  %5 = icmp sgt i32 %4, 5
  ; Conditional branch: if (x > 5) → %6 (then), else → %7
  br i1 %5, label %6, label %7
6:                                ; if.then block
  ; Store return value 1 (true branch)
  store i32 1, ptr %2, align 4
  br label %8                     ; jump to merge
7:                                ; if.else block
  ; Store return value 0 (false branch)
  store i32 0, ptr %2, align 4
  br label %8                     ; jump to merge
8:  ; merge/return block
  ; Load the final return value from %2
  %9 = load i32, ptr %2, align 4
  ; Return the selected value (1 or 0)
  ret i32 %9
}
```

- How is x>5 checked?
  - Via script – ‘ %5 = icmp sgt i32 %4, 5 ’.
  - This is the signed int comparison between x and 5.
  - sgt stands for signed greater than
- How is the if/else structure implemented?
  - Via script – ‘ br i1 %5, label %6, label %7 ’.
  - %6 is the "then" block, %7 is the "else" block.
- How does LLVM determine which return value to use?
  - By assigning 1 or 0 to memeory (%2) in %6 or %7 resp.
  - Then, at merge block %8, it loads the value from %2 and returns it as in the following script:
    %9 = load i32, ptr %2
    ret i32 %9

Part 2 (src/loop.cpp and ir/loop.ll):

```
sum():
define dso_local noundef i32 @"?sum@@YAHH@Z"(i32 noundef %0) {
  ; Allocate space for parameters and local variables
  %2 = alloca i32, align 4     ; n
  %3 = alloca i32, align 4     ; s (accumulator)
  %4 = alloca i32, align 4     ; i (loop index)
  ; Store the input value (n) into %2
  store i32 %0, ptr %2, align 4
  ; Initialize s = 0
  store i32 0, ptr %3, align 4
  ; Initialize i = 0
  store i32 0, ptr %4, align 4
  ; Jump to loop condition check
  br label %5
; %5: Loop condition block
5:                                ; preds = %13 (loop), %1 (entry)
  %6 = load i32, ptr %4, align 4          ; load i
  %7 = load i32, ptr %2, align 4          ; load n
  %8 = icmp slt i32 %6, %7                ; i < n ?
  br i1 %8, label %9, label %16           ; if true → %9 (body), else → %16 (exit)
```

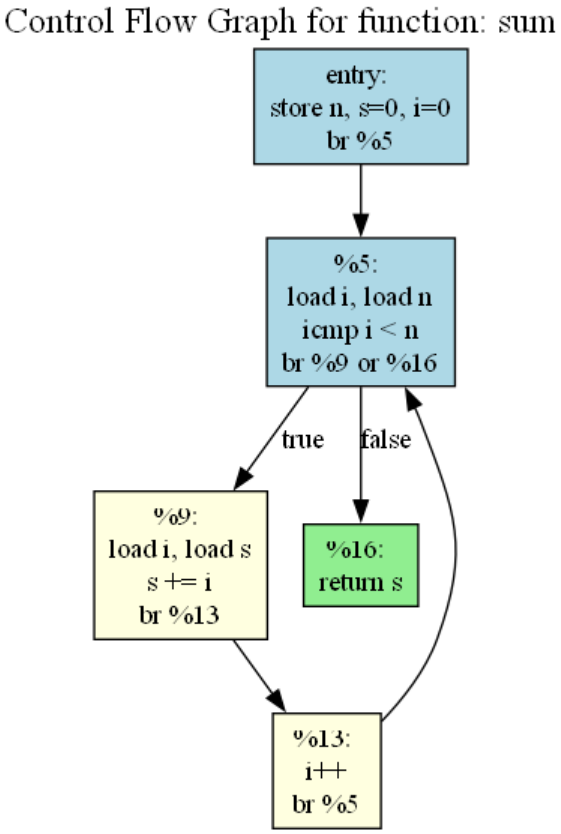
```
; %9: Loop body block
9:                                ; preds = %5
  %10 = load i32, ptr %4, align 4          ; load i
  %11 = load i32, ptr %3, align 4          ; load s
  %12 = add nsw i32 %11, %10               ; s = s + i
  store i32 %12, ptr %3, align 4           ; update s
  br label %13                             ; jump to increment
; %13: Increment block
13:                               ; preds = %9
  %14 = load i32, ptr %4, align 4          ; load i
  %15 = add nsw i32 %14, 1                 ; i = i + 1
  store i32 %15, ptr %4, align 4           ; update i
  br label %5, !llvm.loop !5               ; go back to loop condition
; %16: Exit block
16:                               ; preds = %5
  %17 = load i32, ptr %3, align 4          ; load final sum
  ret i32 %17                              ; return s
}
```

- What role does the phi node play?
  - phi merges values from multiple control paths (e.g., from entry and loop back-edge)
  - It tracks loop variables like ‘i’ and accumulators like ‘s’.
- How does LLVM remember the loop variable i across iterations?
  - Via the script :
    ‘ %14 = load i32, ptr %4
    %15 = add nsw i32 %14, 1
    store i32 %15, ptr %4
  - LLVM uses memory allocation (%4) to store and update i.
  - In each iteration, it:
    - loads i,
    - increments i,
    - and stores i again.
- How is the loop exit condition implemented?
  - Via the script:
    %6 = load i32, ptr %4
    %7 = load i32, ptr %2
    %8 = icmp slt i32 %6, %7

br i1 %8, label %9, label %16

- LLVM checks ‘i<n’ as follows:
  - If true, branches to loop body
  - If false, goes to return block

Part 3 (loop_cfg.dot and loop_cfg.png): CFG for loop.ll



Bonus Challenge (src/switch.cpp and ir/switch.ll):

- How does LLVM represent the switch statement?
  - Via the script ‘ switch i32 %4, label %7 [i32 1, label %5, i32 2, label %6] ’
  - %4 is the value of x
  - If %4 == 1, control goes to block %5
  - If %4 == 2, control goes to %6
  - Otherwise, it jumps to %7 (the default case)
- This is a direct representation of the switch, not expanded into icmp and br.
- Each case block (%5, %6, %7) stores the result to %2, and unconditionally jumps to %8, where the return value is loaded and returned as follows:
  ‘ %9 = load i32, ptr %2
  ret i32 %9 ’