NAME: _____

STUDENT ID: _____

SIGNATURE: _____

ity of New South Wales

Final Examination

June 2021

COMP3131/COMP9102

Programming Languages and Compilers

Time allowed: **2 hours**

Total number of questions: **5**

Answer **all** questions

The questions are **not** of equal value

Marks for this paper total **100**

This paper may **not** be retained by the candidate

No examination materials

Answers must be written in ink.

Question 1. Regular Expressions and Finite Automata *[15 marks]*

Consider the following regular expression:

$$(a|b)^*a(a|\epsilon)$$

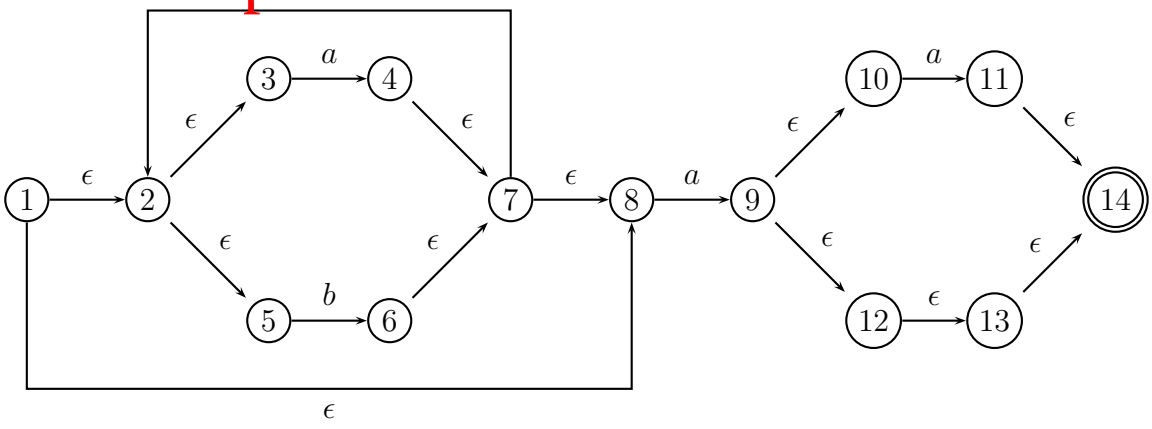
(a) Use **Th** **ion** to convert this regular expression into an NFA. *[7 marks]*

(b) Use the to convert the NFA of (a) into a DFA. *[7 marks]*

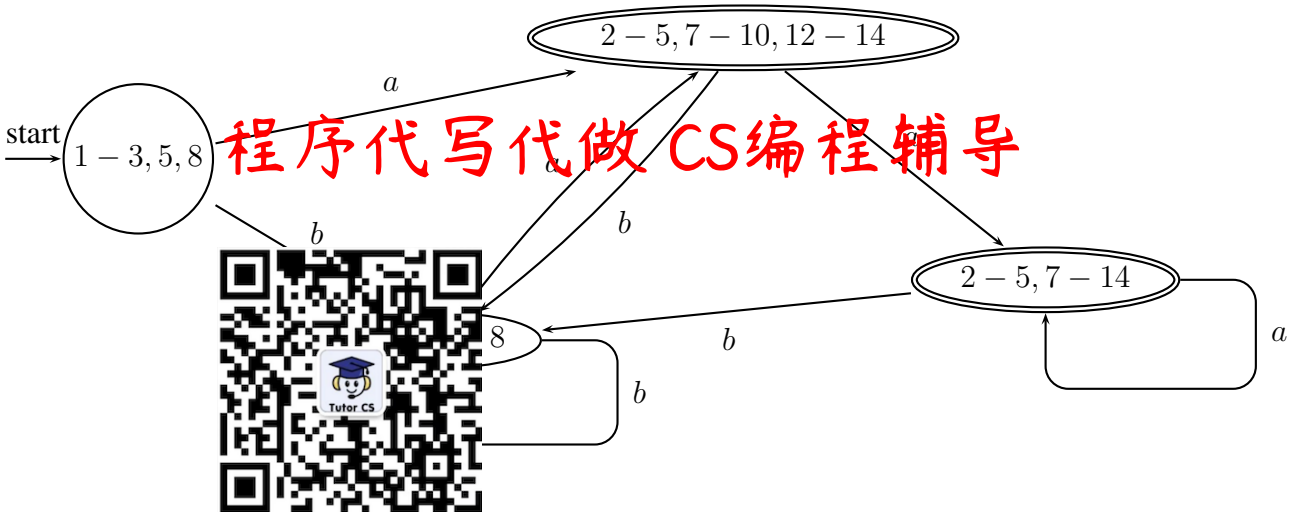
(c) Convert the DFA of (b) into a minimal-state DFA. *[4 marks]*

********* ANSWER *********

(a)

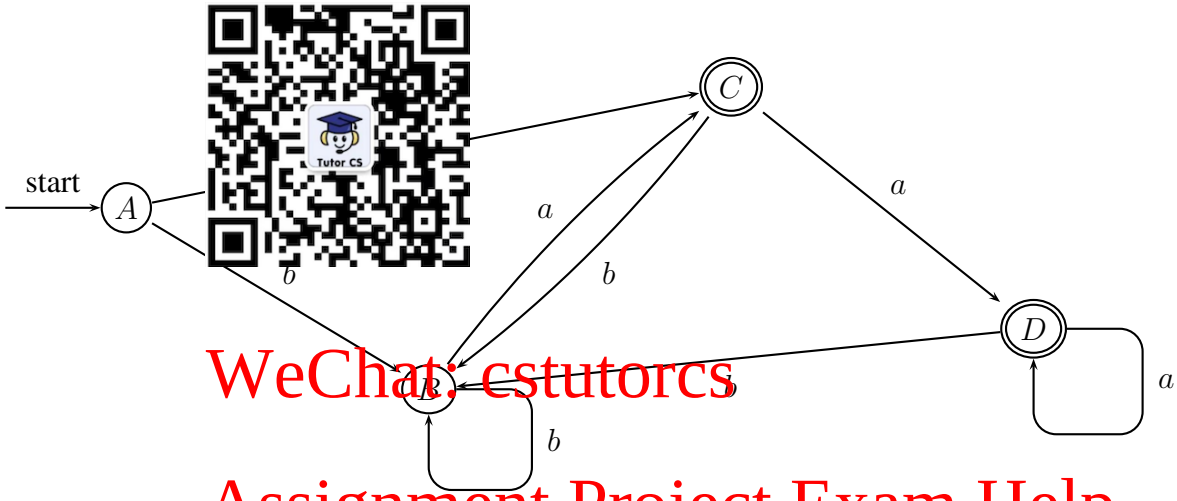


(b)

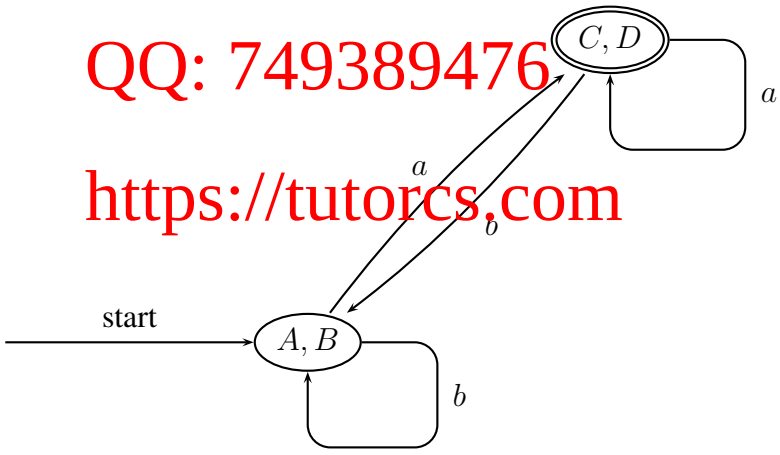


(c)

Renaming the states of the DFA yields:



The minimal-state DFA is:



Question 2. Context-Free Grammars *[15 marks]*

Assume that arithmetic expressions are built up from the following terminals:

- Binary in +, −
- Unary pr
- Variable
- Brackets

Operator ∼ ha nce, followed by @ and #, which have equal precedence. Operators + and − have the lowest precedence. Operators @, # and + are left associative but − is right associative. Brackets are used to group expressions in the usual manner.

Write a context-free grammar for this language.

You are not allowed to use the regular operators, *, +, and ?, in your grammar.

********* ANSWER *********


```
<exp> --> <exp> + <term>
        | <term> - <expr>
        | <term>

<term> --> <term> @ <factor>
         | <term> # <factor>
         | <factor>

<factor> --> ~ <factor>
           | [ <exp> ]
           | <var>

<var> --> X | Y | Z
```

Question 3. Recursive Descent Parsing *[20 marks]*

Consider the following context-free grammar:

$$
\begin{array}{rlcl}
1. & S & \rightarrow & BA \\
2. & A & \rightarrow & aBA \\
3. & & | & \epsilon \\
4. & B & \rightarrow & DC \\
5. & C & \rightarrow & cDC \\
6. & & | & \epsilon \\
7. & D & \rightarrow & xSf \\
8. & & | & gCg
\end{array}
$$

where the set of nonterminals is $\{S, A, B, C, D\}$ and the set of terminals is $\{a, c, x, f, g\}$.

(a) Compute the FIRST sets for all nonterminal symbols.

[4 marks]

(b) Compute the FOLLOW sets for all nonterminal symbols.

[6 marks]

(c) Construct the LL(1) parsing table for the grammar.

[4 marks]

(d) Is the grammar LL(1)? Justify your answer in a few sentences.

[2 marks]

(e) The string gx is NOT syntactically legal (since it is NOT in the language defined by the grammar). Explain concisely how this can be detected by an LL(1) table-driven parser for the language.

[4 marks]

Note: In your answer, you can write E or e as an abbreviation for ϵ.

Accepted file to submit via give or Webcms3: *.txt.

********* ANSWER *********

********* ANSWER *********

(a)

FIRST(S)	$\{x, g\}$
FIRST(A)	$\{a, \epsilon\}$
FIRST(B)	$\{x, g\}$
FIRST(C)	$\{c, \epsilon\}$
FIRST(D)	$\{x, g\}$

(b)

FOLLOW(S)	$\{f, \$\}$
FOLLOW(A)	$\{f, \$\}$
FOLLOW(B)	$\{a, f, \$\}$
FOLLOW(C)	$\{a, f, g, \$\}$
FOLLOW(D)	$\{a, c, f, g, \$\}$

(c)

	a	c	d	x	f	g	\$
S				P1		P1	
A	P2				P3		P3
B				P4		P4	
C	P6	P5			P6	P6	P6
D				P7		P8	

(d) Yes. Each entry contains at most one production.

(e)

```
Stack     Input       Production          Left Derivation
$         gx
$         gx          S->BA               S=>BA
$AB       gx          B->DC               S=>DCA
$ACD      gx          D->gCg              S=>gCgCA
$ACgCg    advance
#ACgC     x           blank ===> error
```

Question 4. Attribute Grammars *[15 marks]*

Consider the following context-free grammar that generates regular expressions:

$$
\begin{array}{rcl}
R & \rightarrow & a \\
& | & b \\
& | & \epsilon \\
& | & R_1 R_2 \\
& | & R_1 \mid R_2 \\
& | & (R_1)^* \\
& | & (R_1)
\end{array}
$$

(a) Define an attribute grammar that records the maximum number of **nested** Kleene star operators of a regular expression R in its attribute $R.depth$. For example, ab has depth 0, a^* has depth 1 and $a^*|(b^*|a)^*$ has depth 2.

[14 marks]

(b) Is $R.depth$ inherited or synthesized? Explain your answer.

[3 marks]

Note: In your answer, you can write R_1, R_2 and * as $R1$, $R2$ and $*$, respectively.

This is straightforward except that adding an inherited attribute can be tricky.

********* ANSWER *********

(a)

			$\{R.depth = 0;\}$
			$\{R.depth = 0;\}$
			$\{R.depth = 0;\}$
4.		$R_1 R_2$	{ **if** $R_1.depth > R_2.depth$ $R.depth = R_1.depth$ **else** $R.depth = R_2.depth$ }
5.		$R_1 \mid R_2$	{ **if** $R_1.depth > R_2.depth$ $R.depth = R_1.depth$ **else** $R.depth = R_2.depth$ }
6.		$(R_1)^*$	$R.depth = R_1.depth + 1$
7.		(R_1)	$R.depth = R_1.depth$

(b) Synthesised as it is propagated to a node from its children

Question 5. Code Generation *[30 marks]*

Consider the following attribute grammar for generating "short-circuit" code, where

- The semantic rules associated with a production are evaluated sequentially in a top-down ma
- "#" stan catenation operator.

$S \rightarrow$ **while** B **do** S_1
  $S.begin :=$
  $B.true :=$
  $B.false := S.next;$
  $S_1.next := S.begin;$
  $S.code := emit(S.begin\ ':') \ \#\ B.code\ \#\ emit(B.true\ ':')\ \#\ S_1.code\ \#\ emit('goto'\ S.begin)$

$S \rightarrow$ **ID** $= E$
  $S.code := E.code\ \#\ emit(\textbf{ID}.place\ ':='\ E.place)$

$E \rightarrow E_1 + E_2$
  $E.place := getNewTemp();$
  $E.code := E_1.code\ \#\ E_2.code\ \#\ emit(E.place\ ':='\ E_1.place\ '+'\ E_2.place)$

$E \rightarrow$ **ID**
  $E.place :=$ **ID**$.place$; // **ID**$.place$ is the lexeme of the **ID**
  $E.code :=$ '' // no code generated

$B \rightarrow B_1$ && B_2
  $B_1.true := getNewLabel();$
  $B_1.false := B.false;$
  $B_2.true := B.true;$
  $B_2.false := B.false;$
  $B.code := B_1.code\ \#\ emit(B_1.true\ ':')\ \#\ B_2.code$

$B \rightarrow$! B_1
  $B_1.true := B.false;$
  $B_1.false := B.true;$
  $B.code := B_1.code$

$B \rightarrow$ **ID**$_1 >$ **ID**$_2$
  $B.code := emit('if'\ \textbf{ID}_1.place > \textbf{ID}_2.place\ 'goto'\ B.true)\ \#\ emit('goto' B.false)$

Note that this grammar is ambiguous but that does not affect the following questions.

Consider the following **while** loop:

```
while (! (a > b && x > y) )
    r = p + q;
```

(a) Draw the AST (Abstract Syntax Tree) for the **while** loop. *[5 marks]*

Continued onto next page

Question 5 continued from Page 6

(b) Suppose that $S.next$ = L666, $getNewLabel()$ will return labels L1, L2, ... when called, a will return temporary variables t1, t2, ... when called. Give th e attributes for all the B nodes in the AST of (a).

[7 marks]

(c) Give th the root node S in the AST of (a). In other words, give the cod **hile** loop according to this attribute grammar.

[7 marks]

(d) The production $B \rightarrow B_1 \;\&\&\; B_2$ given in the grammar serves to define conditional AND expressions. Suppose we replace this production with $B \rightarrow B_1 \parallel B_2$ so that conditional OR expressions are considered instead. Give the semantic rules for the new production to generate short-circuit code for conditional OR expressions.

[5 marks]

(e) Give the semantic rules for the new production that defines `do-while` statements:

$$S \rightarrow \textbf{do}\ S_1\ \textbf{while}\ B$$

In a `do-while` statement, S_1 will be executed at least once.

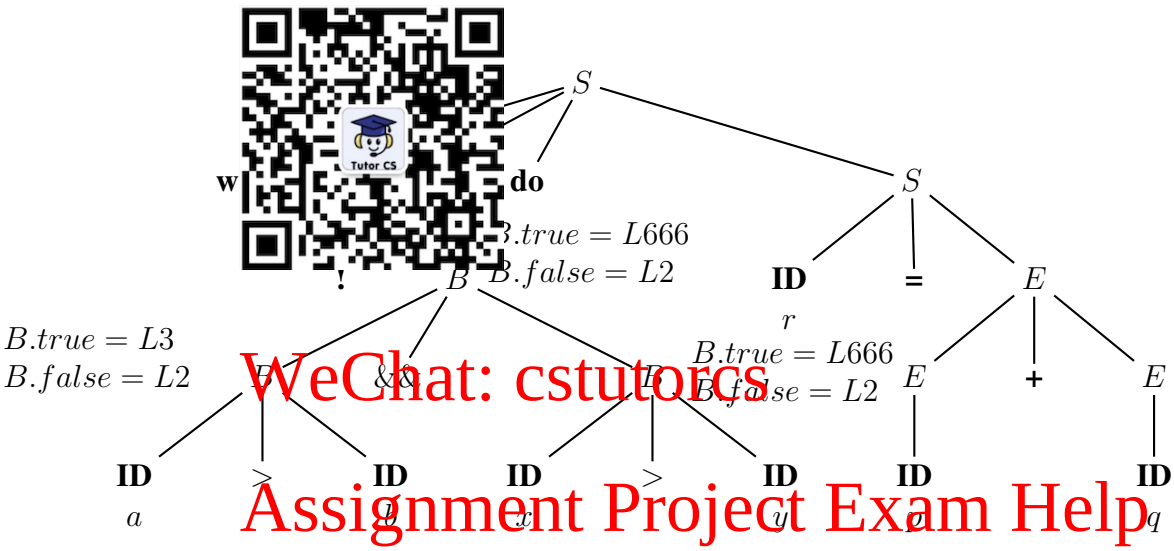
[6 marks]

Note: In your answer, you can write S_1, B_1 and B_2 as $S1$, $B1$ and $B2$, respectively.

Accepted file to submit via give or Webcms3: *.txt.

********* ANSWER *********

(a) and (b)



(c)

```
L1:
     if a > b goto L3
       goto L2
L3:
     if x > y goto L666
       goto L2
L2:
     r = p + q
     goto L1
```

(d)

$B \rightarrow B_1 \parallel B_2$
$B_1.true := B.true;$
$B_1.false := getNewLabel();$
$B_2.true := B.true;$
$B_2.false := B.false;$
$B.code := B_1.code \bowtie emit(B_1.false\,' :') \bowtie B_2.code$

(e)

$S \rightarrow$ **do** S_1 **while** B

$S.begin := getNewLabel();$
$B.true := S.begin();$
$B.false := S.next;$
$S_1.next := S.begin;$
$S.code := (S.begin\ ':') \bowtie S_1.code \bowtie B.code$