Name: ______________________________

1. (1 pt.)
   - **Read all material carefully.**
   - *If in doubt whether something is allowed, ask, don't assume.*
   - You may refer to your books, papers, and notes during this test.
   - E-books may be used *subject to the restrictions* noted in class.
   - Computers are not permitted, except when used strictly as ebooks.
   - Network access of any kind (cell, voice, text, data, ...) is not permitted.
   - Write, and draw, carefully. Ambiguous or cryptic answers receive zero credit.
   - Use class and textbook conventions for notation, algorithmic options, etc.

   Write your name in the space provided above.

WAIT UNTIL INSTRUCTED TO CONTINUE TO REMAINING QUESTIONS.

Do not write in the following table.

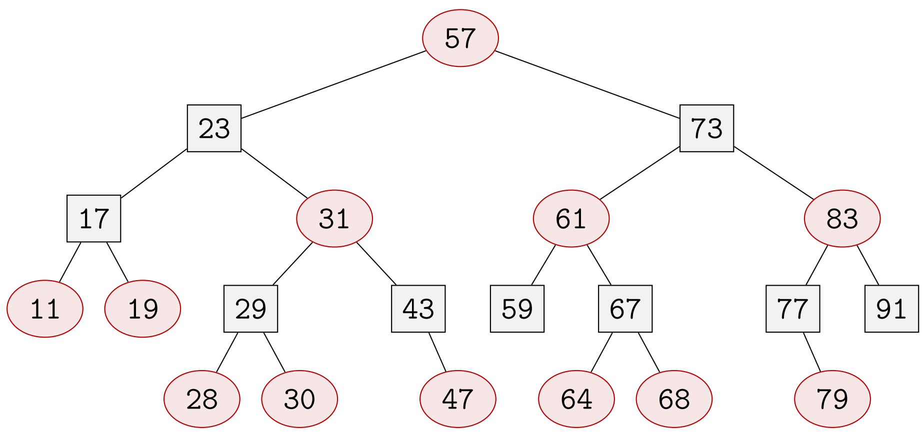
Q	Full	Score
1	1	
2	14	
3	14	
4	16	
total	45	

2. (14 pts.) In the following depiction of a *red-black tree*, the oval nodes are red and rectangular nodes are black, with the mnemonic: ***R****ound is red,* ***B****ox is black.*

   (a) What are the requirements for a tree such as this one to be a *valid red-black tree* data structure? (List the requirements.)

   (b) Does this tree satisfy the requirements? If so, briefly explain your answer; Otherwise, indicate the *simplest* (least changes) modifications that are needed to satisfy the requirements.

   (c) *Augment* this tree to convert it to an *order-statistic* tree. Write the augmenting data to next to each node clearly.



3. (14 pts.) Using a table similar to the one at the bottom of page 342 of the textbook, trace the execution of the OS-RANK algorithm with the argument T set to the red-black tree of Question 2 and the argument x set to node with key 67.

4. (16 pts.) Consider a *directed graph* $G = (V, E)$ with

$$
\begin{aligned}
V &= \{A, B, C, D, E, F, G\} \\
E &= \{(A, B), (A, D), (A, E), (B, C), (B, E), (C, A), (C, D), \\
&\quad (D, C), (D, G), (E, C), (E, F), (F, G), (G, A), (G, E)\}
\end{aligned}
$$

(a) Draw a graphical representation of G following the usual conventions.

(b) Depict the encoding of G in an *adjacency list* data structure.

(c) Depict the encoding of G in an *adjacency matrix* data structure.

(d) Depict the encoding of G in an *incidence matrix* data structure.

[additional space for answering the earlier question]

[additional space for answering the earlier question]