Problem 1 [15 points]: Consider a relation \( R \) with five attributes \( ABCDE \). You are given the following dependencies: \( A \rightarrow D, A \rightarrow E, DE \rightarrow BC, B \rightarrow A, D \rightarrow C \).

1. List all keys for \( R \).
   \( A, B, DE \)

2. Is \( R \) in 3NF?
   No. \( D \rightarrow C \) is non-trivial, but \( D \) is not a superkey, while \( C \) is not part of some key.

3. Is \( R \) in BCNF?
   No. \( D \rightarrow C \) is non-trivial, but \( D \) is not a superkey.

Problem 2 [20 points]:
See Figure 1.

Problem 3 [25 points]: Consider a relation \( R \) with five attributes \( ABCDXYZ \) and the FD set \( F = \{AB \rightarrow X, AC \rightarrow D, Y \rightarrow C, YZ \rightarrow X, XB \rightarrow D, BD \rightarrow Z\} \). Let \( F^+ \) denote the closure set of \( F \).

1. For each of the following attribute sets, do the following: (i) write down a minimal cover of the subset of \( F^+ \) that holds over the set; (ii) name the strongest normal form that is not violated by the relation containing these attributes; (iii) decompose it into a collection of BCNF relations if it is not already in BCNF.
   (a) \( ABC \)
   (i) \( \emptyset \); (ii) BCNF, trivially; (iii) already in BCNF, trivially
   (b) \( ABCD \)
   (i) \( \{AB \rightarrow D, AC \rightarrow D\} \); (ii) 1NF; (iii) \( \{ABC, ACD\} \)

2. For each of the following decompositions of \( R = ABCDXYZ \), with the same set of functional dependencies \( F \), say whether the decomposition is (i) dependency preserving, and (ii) lossless join.
   (a) \( \{ABXYD, ABCYZ\} \)
   (i) no; (ii) yes
Problem 4 [20 points]: Suppose you are given a relation \( R(A, B, C, D) \). For each of the following (complete) sets of FDs, (i) identify the candidate key(s) for \( R \), and (ii) state whether or not the proposed decomposition of \( R \) into smaller relations is a “good” decomposition and briefly explain why or why not.

1. \( A \rightarrow B, B \rightarrow C, C \rightarrow D \). Decompose into \( AB \), \( BC \), and \( CD \).
   (i) \( A \); (ii) “good” because decomposition is both lossless-join and dependency-preserving

2. \( C \rightarrow A, B \rightarrow D \). Decompose into \( AC \) and \( BD \).
   (i) \( BC \); (ii) “bad” because not a lossless-join decomposition

Problem 5 [15 points]: Let \( R \) be a relation on attributes \( ABCD \), and let \( F = \{ B \rightarrow A, B \rightarrow CD \} \) be a set of FDs on \( R \). Prove that \( S = \{ AB, BC, BD \} \) is a lossless join decomposition of \( R \) under \( F \). (Hint: construct a binary tree for the decomposition, then apply Theorem 3 from Chapter 19 in the text.)

\[ \text{Proof.} \] Clearly \( B \) is a key for \( R \), since we can infer \( B \rightarrow ABCD \) from the FDs given. Now consider the following derivation tree for \( S \):

\[
\begin{array}{c}
ABCD \\
\hline
AB \\
BCD \\
\hline
BC \\
BD
\end{array}
\]

It suffices to show that the decomposition is lossless at each step. In the first step, we have the decomposition of \( ABCD \) into \( AB \) and \( BCD \). But \( AB \cap BCD = B \), and \( B \) is a key for \( R \). So by Theorem 3 from Chapter 19 in the text, the decomposition is lossless. Likewise, in the second step, since \( BC \cap BD = B \), the decomposition there is lossless as well. \( \square \)
Figure 1: ER-diagram for Problem 2.

Constraints:
Trial-User AND Paying-Customer COVER User
Beta-Tester OVERLAPS Trial-User
Beta-Tester OVERLAPS Paying-Customer

Note: Keys indicated by double solid line around attribute. Partial keys indicated by double dashed line around attribute. (DOT doesn’t know how to do underlining.)