1. This question introduces an example, concerning World War 2 capital ships. It involves the following relations:

    Classes(class, type, country, numGuns, bore, displacement)
    Ships(name, class, launched)
    Battles(name, date)
    Outcomes(ship, battle, result)

Ships are built in “classes” from the same design, and the class is usually named for the first ship of that class. The relation Classes records the name of the class, the type (‘bb’ for battleship or ‘bc’ for battlecruiser), the country that build the ship, the number of main guns, and the displacement(weight, in tons). Relation Ships records the name of the ship, the name of its class, and the year in which the ship was launched. Relation Battles gives the name and date of battles involving these ships, and relation Outcomes gives the result (sunk, damaged, or ok) for each in each battle. Write the following declarations:

a) (5) A suitable schema for relation Classes (including type of each attribute).

```sql
CREATE TABLE Classes (  
class CHAR(20),  
type CHAR(5),  
country CHAR(20),  
umGuns INTEGER,  
bore DECIMAL(3,1),  
displacement INTEGER
);
```

b) (3) An alteration to Ships relation to include the attribute yard giving the shipyard where the ship was built.

```sql
ALTER TABLE Ships ADD yard CHAR(30);
```
2. Write the expression of relational algebra to answer the following questions based on the schema of question 1.

   a) \((3)\) Give the class names and countries of the classes that carried guns of at least 16-inch bore.

   \[ \pi_{\text{class},\text{country}} (\sigma_{\text{bore} \geq 16} (\text{Classes})) \]

   b) \((4)\) Find the ships sunk in the battle of the Denmark Strait.

   \[ \Pi_{\text{name}} (\sigma_{\text{battle}=\text{Denmark Strait AND result}=\text{sunk}} (\text{Outcomes})) \]

   c) \((4)\) The treaty of Washington in 1921 prohibited capital ships heavier than 35,000 tons. List the ships that violated the treaty of Washington.

   \[ \pi_{\text{name}} (\sigma_{\text{launched} > 1921 \text{ AND displacement} > 35000} (\text{Classes} \bowtie \text{Ships})) \]

   d) \((6)\) Find those countries that had both battleships and battlecruisers

   \[ \pi_{\text{country}} (\sigma_{\text{type}=\text{bb}} (\text{Classes})) \cap \pi_{\text{country}} (\sigma_{\text{type}=\text{bc}} (\text{Classes})) \]

   e) \((9)\) Find those ships that “lived to fight another day”; they were damaged in one battle, but later fought in another

   \[ \pi_{\text{ship}} (\pi_{\text{ship},\text{result},\text{date}} (\text{Battles} \bowtie (\text{battle}=\text{name}) \text{Outcomes})) \bowtie (\text{ship}=\text{ship2 AND result}=\text{damaged AND date} < \text{date2}) \rho_{2}(\text{ship2},\text{result2},\text{date2}) \pi_{\text{ship},\text{result},\text{date}} (\text{Battles} \bowtie (\text{battle}=\text{name}) \text{Outcomes})) \]
3. Express the following constraints in relational algebra. The constraints are based on the relations of question 1. You may write your constraints either as containments or by equating an expression to the empty set.

a) \( (4) \) If a class of ships has more than 9 guns, then their bore must be no larger than 14 inches.

\[
\pi_{\text{class}}(\sigma_{\text{numGuns} > 9 \text{ AND bore} > 14}(\text{Classes})) = \emptyset
\]

b) \( (4) \) No country may have both battleships and battlecruisers

\[
\pi_{\text{country}}(\sigma_{\text{type} = \text{bb}}(\text{Classes})) \cap \pi_{\text{country}}(\sigma_{\text{type} = \text{bc}}(\text{Classes})) = \emptyset
\]

4. Design a database for a bank, including information about customer and their accounts. Information about a customer includes their name, address, phone, and Social Security number. Accounts have numbers, types (e.g., saving, checking) and balances. Also record the customer(s) who own an account. Draw the E/R diagram for this database. Be sure to include arrows where appropriate, to indicate the multiplicity of a relationship.

(3)

\[ \begin{array}{c}
\text{ssNo} \\
\text{Name} \\
\text{phone} \\
\text{address} \\
\text{owners} \\
\text{Customers} \\
\hline
\text{number} \\
\text{balance} \\
\text{type} \\
\text{Accounts} \\
\end{array} \]

a) \( (4) \) Change your diagram so an account can have only one customer.

\[ \begin{array}{c}
\text{ssNo} \\
\text{Name} \\
\text{phone} \\
\text{address} \\
\text{owners} \\
\text{Customers} \\
\hline
\text{number} \\
\text{balance} \\
\text{type} \\
\text{Accounts} \\
\end{array} \]
b) *(5)* Further change your diagram so a customer can have only one account.

![Diagram showing a modified database model where a customer can have only one account.](image)


c) *(8)* Change your original diagram so that a customer can have a set of address (which are street-city-state triples) and a set of phones. Remember that we do not allow attributes to have non-primitive types, such as sets, in the E/R model.

![Diagram showing a database model with customer addresses and phones.](image)

d) *(8)* Further modify your diagram so that customers can have a set of address, and at each address there is a set of phones.

![Diagram showing a database model with customer addresses, phones, and their relationships.](image)