1. **Propositional Logic:** Given the interpretation $W = \{a, b, c\}$. For each of the following formulas, determine if W is a model for it:

$$(a \wedge b) \tag{1}$$
$$(b \rightarrow d) \tag{2}$$
$$b \wedge ((c \rightarrow e) \rightarrow d) \tag{3}$$
$$e \vee (c \wedge \neg d) \tag{4}$$
$$\neg d \rightarrow \neg e \tag{5}$$

2. **Propositional Logic:** Define an interpretation W which is a model for *all* of the following formulas:

$$(a \wedge \neg b) \tag{6}$$
$$(b \rightarrow c) \tag{7}$$
$$(c \vee d \vee \neg a) \tag{8}$$
$$(a \rightarrow e) \tag{9}$$
$$(e \rightarrow (\neg a \vee \neg b \vee \neg c \vee \neg d)) \tag{10}$$

3. **Predicate Logic:** Given the interpretation

$$\begin{aligned} W = \{ & Lannister(Tywin), Lannister(Tyrion), \\ & Lannister(Cersei), Lannister(Jaime), \\ & owes(Tyrion, Bronn), owes(Jaime, Brienne), \\ & owes(Brienne, Catelyn), \\ & paidDebt(Tyrion, Bronn), \\ & paidDebt(Jaime, Brienne)\} \end{aligned}$$

over the Domain $D = \{Tywin, Tyrion, Cersei, Jaime, Bronn, Brienne, Catelyn\}$. For each of the following formulas, determine if W is a model for it:

$$\forall x \forall y \in Lannister : owes(y, x) \rightarrow paidDebt(y, x) \tag{11}$$
$$\exists x \forall y : \neg owes(x, y) \tag{12}$$
$$\exists x \forall y : \neg owes(y, x) \tag{13}$$
$$\forall y \exists x : \neg owes(y, x) \tag{14}$$
$$\forall x : owes(x, Catelyn) \rightarrow \neg Lannister(x) \tag{15}$$

4. **Predicate Logic:** Define an interpretation W which is a model for *none* of the following formulas.

$$\forall x : bird(x) \tag{16}$$
$$\forall x \exists y : eats(x, y) \tag{17}$$
$$\neg \exists x : cat(x) \tag{18}$$
$$\forall x : cat(x) \rightarrow \neg \exists y eats(y, x) \tag{19}$$
$$\neg dog(pluto) \tag{20}$$

5. **Transition Systems:** Below you are given the state s_0 and the effects e_1, e_2, e_3 of three actions. Apply e_1 to s_0 and determine the resulting state s_1. Apply e_2 to s_1 and determine the resulting state s_2. Finally, apply e_3 to s_2 and determine a final state s_3.

$$
\begin{aligned}
s_0 =& \{at(Sherlock, BakerStreet), murderer(Moriarty), victim(ReginaldMusgrave)\}\\
e_1 =& (\forall x : \text{when } (at(Sherlock, x))\ (\neg at(Sherlock, x))) \wedge at(Sherlock, ScotlandYard)\\
e_2 =& (\forall x : \text{when } (victim(x))\ (knowsVictim(Sherlock, x))) \wedge\\
& (\forall x : \text{when } (murderer(x))\ knownsMurderer(Sherlock, x))\\
e_3 =& \text{when } (\exists x : murderer(x) \wedge knownsMurderer(Sherlock, x))\ (solvedCrime(Sherlock))
\end{aligned}
$$

6*. **Bonus Points** Show that the negation of an effect formula (as defined on slide 51 in lecture 1) is not necessarily an effect formula.