CS4244 Project1 Report

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Einstein's puzzle

Meaning of variables

We use `H[house number]_[attribute(color, nationality, pet, ...)]` to encode the CNF. For example, `H1_dogs` means the owner of first house keeps dogs as pets, `H3_green` means the third house is green.

Puzzle Hints

There are generally four types of hints:

- **Direct hint**

This is the type of hint that directly points out which house has which attribute. There are two hints belonging to this type:

1. The man living in the center house drinks milk.
2. The Norwegian lives in the first house.

This type of hint is easy to encode, which consists of only one clause with one literal:

1. `H3_milk`
2. `H1_norwegian`

- **Attribute binding**

This type of hint binds two attributes together. For example, "The Brit lives in the red house." binds color red and Britain nationality to the same house. There are hints belonging to this type:

1. The Brit lives in the red house.
2. The Swed keeps dogs as pets.
3. The Dane drinks tea.
4. The green house's owner drinks coffee.
5. The person who smokes Pall Mall rears birds.
6. The owner of the yellow house smokes Dunhill.
7. The owner who smokes Bluemasters drinks beer.
8. The German smokes Prince.

This type of hint is also easy to encode if CNF is not required. Take the first hint listed above as example:

```
(H1_red & H1_brit) | (H2_red & H2_brit) | (H3_red & H3_brit) | (H4_red & H4_brit) | (H5_red &
```

However, as it must be CNF form, we have to expand the formula. In class, we discussed a method to convert from DNF to CNF, which is adding new variables. Apply that method here we will have:

```
(X_1 | X_2 | X_3 | X_4 | X_5) &

(!X_1 | H1_red) & (!X_1 | H1_brit) & (X_1 | !H1_red | !H1_brit) &

(!X_2 | H2_red) & (!X_2 | H2_brit) & (X_2 | !H2_red | !H2_brit) &

(!X_3 | H3_red) & (!X_3 | H3_brit) & (X_3 | !H3_red | !H3_brit) &

(!X_4 | H4_red) & (!X_4 | H4_brit) & (X_4 | !H4_red | !H4_brit) &

(!X_5 | H5_red) & (!X_5 | H5_brit) & (X_5 | !H5_red | !H5_brit)
```

- **Live next to**

This type of hint has the form of "`[attribute 1] lives next to/has a neighbor of [attribute 2]`". There are hints that belong to this type:

1. The man who smokes Blends lives next to the one who keeps cats.
2. The man who keeps the horse lives next to the man who smokes Dunhill.
3. The Norwegian lives next to the blue house.
4. The man who smokes Blends has a neighbor who drinks water.

Take the first hint listed above as example, it can be interpreted as "if the man smoking Blends lives in house X, then the one keeping pets lives in house (X-1) or (X+1)". So we have the formula(do not forget to consider the boundary):

```
(H1_blends & H2_cats) |

(H2_blends & H1_cats) |

(H2_blends & H3_cats) |

(H3_blends & H2_cats) |

(H3_blends & H4_cats) |

(H4_blends & H3_cats) |

(H4_blends & H5_cats) |

(H5_blends & H4_cats)
```

Also, we can expand the formula with the same method of **Attribute binding** hints.

- **On the left of**

There is only one hint belonging to this type:

1. The green house is on the left of the white house.

This is actually a special form of **Live next to** hint. Therefore we can interprete it as:

```
(H1_green & H2_white) | (H2_green & H3_white) | (H3_green & H4_white) | (H4_green & H5_white)
```

Constraints

There are two types of constraints:

- **Each type belongs to exactly one house**

This constraint states that one and only one house has one kind of attribute. For example, one and only one of the fives houses is painted green:

```
ExactlyOne(H1_green, H2_green, H3_green, H4_green, H5_green)
```

- **Each house takes exactly one type**

This constraints states that one and only one attribute is assigned to one house. For example, the first house has one and only one color of the five colors:

```
ExactlyOne(H1_red, H1_green, H1_white, H1_yellow, H2_blue)
```

In class, we have also discussed how to represent "exactly one" in CNF formula. For exmaple, can be represented as:

```
(H1_green | H2_green | H3_green | H4_green | H5_green) &

(!H1_green | !H2_green) & (!H1_green | !H3_green) & (!H1_green | !H4_green) &

(!H1_green | !H5_green) & (!H2_green | !H3_green) & (!H2_green | !H4_green) &

(!H2_green | !H5_green) & (!H3_green | !H4_green) & (!H3_green | !H5_green) &

(!H4_green | !H5_green)
```

Full encoding

Due to space constraints, we have included both the full formula and its answer in the appendix.
We have also attached the source files puzzle.txt and puzzle_answer.txt.

Puzzle answer

Represent in table:

House	Color	Nationality	Pet	Beverage	Cigar
1	yellow	Norwegian	cats	water	Dunhill

House	Color	Nationality	Pet	Beverage	Cigar
2	blue	Dane	horse	tea	Blends
3	red	Brit	birds	milk	Pall Mall
4	green	German	fish	coffee	Prince
5	white	Swed	dogs	beer	Bluemasters

Check it with the puzzle, it is right answer. So the answer is, the German living in the fourth house keeps fish as pet (who smokes Prince and drinks coffee in the meanwhile).

Summary

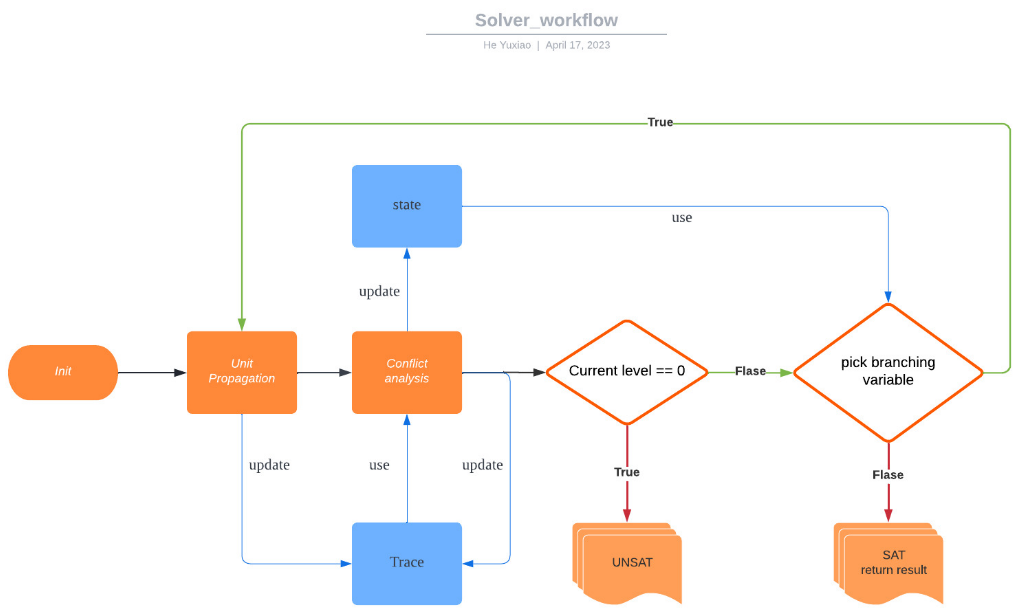
In this project, we developed a SAT solver using the CDCL algorithm. Firstly, we built our basic data structures - *Literal*, *Clause*, and *CNF* - from the ground up. We then used these structures to create *Trace* and *State*, which are used in conflict analysis and branching variable selection. Finally, we constructed the *Solver* and the algorithm to solve the SAT problem by utilizing *CNF*, *Trace*, and *State*.

- In conflict analysis, we use the UIP (Unique Implication Point) method to learn better clauses. This approach enables us to effectively backtrack when a conflict occurs.
- When selecting branching variables, we use the VSIDS (Variable State Independent Decaying Sum) heuristic to focus on the most critical propositions.

Below is the pseudo-code for our SAT solver:

```
while(true) {
 // do unit propagation first
 unitPropagation();
 // check whether there is conflict
 if(findConflict()) {
  if(this.currentLevel == 0) {
   // UNSAT
   return UNSAT;
  }
  else {
   // do conflict analysis
   conflict_analysis();
   continue;
  }
 }
 // if run to here means there is no conflict
 // choose a branching variable
 if(have unassigned proposition) {
  pickBranchingVariable();
  continue;
 }
 else {
  // have no unassigned literal --> SAT solved
  solution = getSolution();
  return SAT, solution;
 }
}
```

The workflow of the solver is shown in the diagram below:



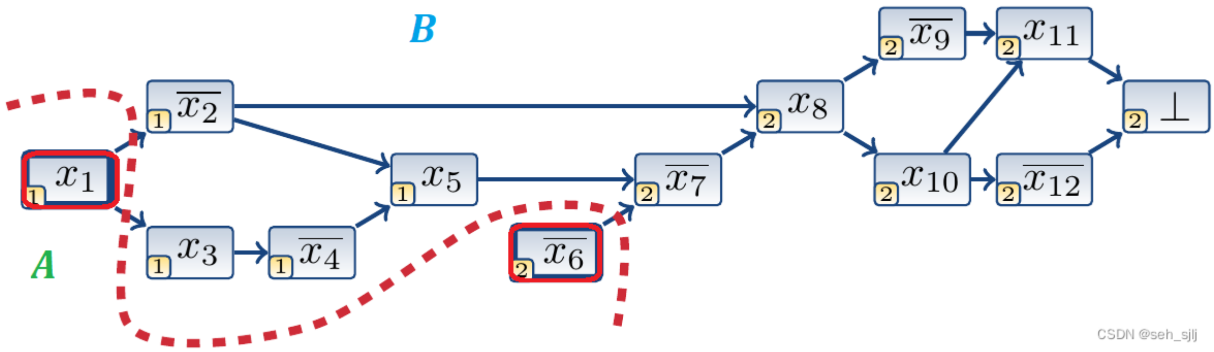
Findings

Conflict analysis

In conflict analysis, we utilize the Unique Implication Point (UIP) heuristic to learn new clauses. We have found it to be more effective than the heuristic discussed in our lecture. But why does the UIP improve the performance of the solver in conflict analysis?

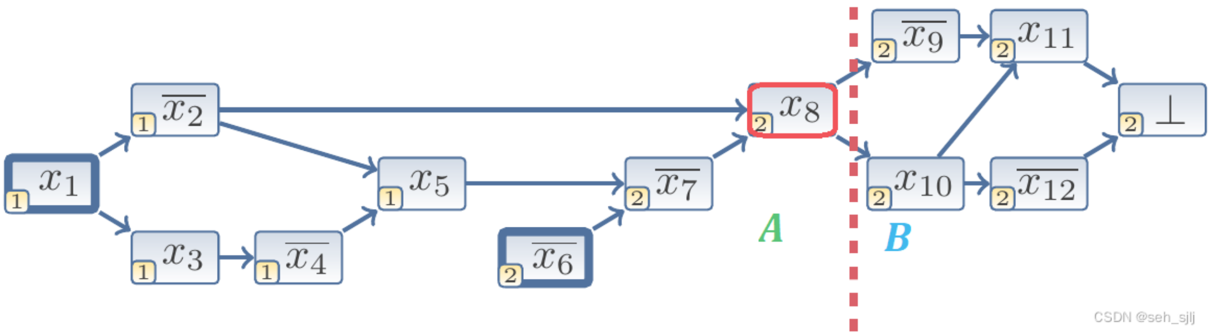
By definition, a Unique Implication Point (UIP) is any node at the current decision level through which any path from the decision variable to the conflict node must pass. As previously mentioned, we record the assignment process in the Trace as a directed acyclic graph (the implication graph). During conflict analysis, we identify a cut (the conflict cut) on this graph and its corresponding reason set. The disjunction of the propositions in the reason set, with their negation reversed, forms the new clause we aim to learn.

In this process, our goal is to identify the most crucial cause of the conflict so that we can learn a new clause that will prevent us from repeating the same conflict. For example, consider the following conflict cut:



The cut identified in the previous step yields the new learned clause $\neg x_1 \lor x_6$, but this may not necessarily be the most crucial cause of the conflict. For instance, even if we add the new clause $\neg x_1 \lor x_6$ but assign 1 to x_8, we will still encounter the same conflict. Therefore, adding the new clause $\neg x_1 \lor x_6$ only guarantees that we will not reach the same conflict in the same manner. However, we may still encounter this conflict through a different path later on.

To address this issue, we need to cut the implication graph in a different way. For example, consider the following cut:



This new conflict cut leverages the UIP x_8, and the newly learned clause is $\neg x_8$. By adding this new clause, we can fully avoid encountering the same conflict again. This demonstrates how the UIP heuristic can improve the solver's performance in conflict analysis by preventing repeated conflicts. As a result, the solver can concentrate its search on more promising regions of the search space.

Pick branching variable

We utilized the VSIDS algorithm to select the branching variable and found it to be a more effective heuristic than random choice. The general concept of VSIDS is to assign a score to each literal, and then choose the unassigned literal with the highest score as the branching variable.

Initially, the score for each literal is set to its frequency of occurrence. This means that literals with a high occurrence frequency are more likely to be selected first. After a literal is assigned and unit propagation is performed, it is more likely to encounter a conflict. We can then learn a new clause to narrow the search space.

During conflict analysis, we increase the score of literals in the newly learned clause. Additionally, we periodically divide all scores by a constant. These operations share a common objective: to focus the solver on literals involved in conflicts. We believe that those literals involved in a conflict are critical. That is why we increase the score of literals in the new learned clause. And the decaying behavior of the scores can be thought of as a moving average, which filters out literals that are only occasionally involved in conflicts, and allows the solver to concentrate on those with a high frequency of conflict involvement.

Self-Evaluation

In this project, we built a SAT solver using the CDCL algorithm.
The advantages of our work:

- we selected a good data structure to represent the formula
- we found better heuristics for conflict analysis and picking branching variables.
  The disadvantages of our work:
- Compared to a program written in C/C++, the Java implementation runs more slowly.
- The division between modules can be improved.

Outcomes

Through this project, we now have a better understanding of the CDCL SAT solver.
We learned some algorithms used in modern SAT solvers and appreciated the ideas behind them.
Also, we improved our ability in software engineering.

Appendix

Encoding

- The full encoding of Einstein's puzzle:

```
(X_1|X_2|X_3|X_4|X_5)&(!X_1|H1_red)&(!X_1|H1_brit)&(X_1|!H1_red|!H1_brit)&(!X_2|H2_red)&
(!X_2|H2_brit)&(X_2|!H2_red|!H2_brit)&(!X_3|H3_red)&(!X_3|H3_brit)&
(X_3|!H3_red|!H3_brit)&(!X_4|H4_red)&(!X_4|H4_brit)&(X_4|!H4_red|!H4_brit)&
(!X_5|H5_red)&(!X_5|H5_brit)&(X_5|!H5_red|!H5_brit)&(X_6|X_7|X_8|X_9|X_10)&
(!X_6|H1_dogs)&(!X_6|H1_swed)&(X_6|!H1_dogs|!H1_swed)&(!X_7|H2_dogs)&
(!X_7|H2_swed)&(X_7|!H2_dogs|!H2_swed)&(!X_8|H3_dogs)&(!X_8|H3_swed)&
(X_8|!H3_dogs|!H3_swed)&(!X_9|H4_dogs)&(!X_9|H4_swed)&(X_9|!H4_dogs|!H4_swed)&
(!X_10|H5_dogs)&(!X_10|H5_swed)&(X_10|!H5_dogs|!H5_swed)&(X_11|X_12|X_13|X_14|X_15)&
(!X_11|H1_tea)&(!X_11|H1_dane)&(X_11|!H1_tea|!H1_dane)&(!X_12|H2_tea)&
(!X_12|H2_dane)&(X_12|!H2_tea|!H2_dane)&(!X_13|H3_tea)&(!X_13|H3_dane)&
(X_13|!H3_tea|!H3_dane)&(!X_14|H4_tea)&(!X_14|H4_dane)&(X_14|!H4_tea|!H4_dane)&
(!X_15|H5_tea)&(!X_15|H5_dane)&(X_15|!H5_tea|!H5_dane)&(X_16|X_17|X_18|X_19)&
(!X_16|H1_green)&(!X_16|H2_white)&(X_16|!H1_green|!H2_white)&(!X_17|H2_green)&
(!X_17|H3_white)&(X_17|!H2_green|!H3_white)&(!X_18|H3_green)&(!X_18|H4_white)&
(X_18|!H3_green|!H4_white)&(!X_19|H4_green)&(!X_19|H5_white)&(X_19|!H4_green|!H5_white)&
(X_20|X_21|X_22|X_23|X_24)&(!X_20|H1_green)&(!X_20|H1_coffee)&(X_20|!H1_green|!H1_coffee)&
(!X_21|H2_green)&(!X_21|H2_coffee)&(X_21|!H2_green|!H2_coffee)&(!X_22|H3_green)&
(!X_22|H3_coffee)&(X_22|!H3_green|!H3_coffee)&(!X_23|H4_green)&(!X_23|H4_coffee)&
(X_23|!H4_green|!H4_coffee)&(!X_24|H5_green)&(!X_24|H5_coffee)&(X_24|!H5_green|!H5_coffee)&
(X_21|X_21|X_22|X_23|X_24)&(!X_20|H1_green)&(!X_20|H1_coffee)&(X_20|!H1_green|!H1_coffee)&
(!X_21|H2_green)&(!X_21|H2_coffee)&(X_21|!H2_green|!H2_coffee)&(!X_22|H3_green)&
(!X_22|H3_coffee)&(X_22|!H3_green|!H3_coffee)&(!X_23|H4_green)&(!X_23|H4_coffee)&
(X_23|!H4_green|!H4_coffee)&(!X_24|H5_green)&(!X_24|H5_coffee)&(X_24|!H5_green|!H5_coffee)&
```

```
(X_25|X_26|X_27|X_28|X_29)&(!X_25|H1_pallmall)&(!X_25|H1_birds)&(X_25|!H1_pallmall|!H1_birds)&
(!X_26|H2_pallmall)&(!X_26|H2_birds)&(X_26|!H2_pallmall|!H2_birds)&(!X_27|H3_pallmall)&
(!X_27|H3_birds)&(X_27|!H3_pallmall|!H3_birds)&(!X_28|H4_pallmall)&(!X_28|H4_birds)&
(X_28|!H4_pallmall|!H4_birds)&(!X_29|H5_pallmall)&(!X_29|H5_birds)&(X_29|!H5_pallmall|!H5_bird
(X_30|X_31|X_32|X_33|X_34)&(!X_30|H1_yellow)&(!X_30|H1_dunhill)&(X_30|!H1_yellow|!H1_dunhill)&
(!X_31|H2_yellow)&(!X_31|H2_dunhill)&(X_31|!H2_yellow|!H2_dunhill)&(!X_32|H3_yellow)&
(!X_32|H3_dunhill)&(X_32|!H3_yellow|!H3_dunhill)&(!X_33|H4_yellow)&(!X_33|H4_dunhill)&
(X_33|!H4_yellow|!H4_dunhill)&(!X_34|H5_yellow)&(!X_34|H5_dunhill)&(X_34|!H5_yellow|!H5_dunhil
(H3_milk)&(H1_norwegian)&(X_35|X_36|X_37|X_38|X_39|X_40|X_41|X_42)&(!X_35|H1_blends)&
(!X_35|H2_cats)&(X_35|!H1_blends|!H2_cats)&(!X_36|H2_blends)&(!X_36|H1_cats)&
(X_36|!H2_blends|!H1_cats)&(!X_37|H2_blends)&(!X_37|H3_cats)&(X_37|!H2_blends|!H3_cats)&
(!X_38|H3_blends)&(!X_38|H2_cats)&(X_38|!H3_blends|!H2_cats)&(!X_39|H3_blends)&
(!X_39|H4_cats)&(X_39|!H3_blends|!H4_cats)&(!X_40|H4_blends)&(!X_40|H3_cats)&
(X_40|!H4_blends|!H3_cats)&(!X_41|H4_blends)&(!X_41|H5_cats)&(X_41|!H4_blends|!H5_cats)&
(!X_42|H5_blends)&(!X_42|H4_cats)&(X_42|!H5_blends|!H4_cats)&(X_43|X_44|X_45|X_46|X_47|X_48|X_
(!X_43|H1_dunhill)&(!X_43|H2_horse)&(X_43|!H1_dunhill|!H2_horse)&(!X_44|H2_dunhill)&
(!X_44|H1_horse)&(X_44|!H2_dunhill|!H1_horse)&(!X_45|H2_dunhill)&(!X_45|H3_horse)&
(X_45|!H2_dunhill|!H3_horse)&(!X_46|H3_dunhill)&(!X_46|H2_horse)&(X_46|!H3_dunhill|!H2_horse)&
(!X_47|H3_dunhill)&(!X_47|H4_horse)&(X_47|!H3_dunhill|!H4_horse)&(!X_48|H4_dunhill)&
(!X_48|H3_horse)&(X_48|!H4_dunhill|!H3_horse)&(!X_49|H4_dunhill)&(!X_49|H5_horse)&
(X_49|!H4_dunhill|!H5_horse)&(!X_50|H5_dunhill)&(!X_50|H4_horse)&(X_50|!H5_dunhill|!H4_horse)&
(X_51|X_52|X_53|X_54|X_55)&(!X_51|H1_bluemasters)&(!X_51|H1_beer)&(X_51|!H1_bluemasters|!H1_be
(!X_52|H2_bluemasters)&(!X_52|H2_beer)&(X_52|!H2_bluemasters|!H2_beer)&(!X_53|H3_bluemasters)&
(!X_53|H3_beer)&(X_53|!H3_bluemasters|!H3_beer)&(!X_54|H4_bluemasters)&(!X_54|H4_beer)&
(X_54|!H4_bluemasters|!H4_beer)&(!X_55|H5_bluemasters)&(!X_55|H5_beer)&(X_55|!H5_bluemasters|!
(X_56|X_57|X_58|X_59|X_60)&(!X_56|H1_german)&(!X_56|H1_prince)&(X_56|!H1_german|!H1_prince)&
(!X_57|H2_german)&(!X_57|H2_prince)&(X_57|!H2_german|!H2_prince)&(!X_58|H3_german)&
(!X_58|H3_prince)&(X_58|!H3_german|!H3_prince)&(!X_59|H4_german)&(!X_59|H4_prince)&
(X_59|!H4_german|!H4_prince)&(!X_60|H5_german)&(!X_60|H5_prince)&(X_60|!H5_german|!H5_prince)&
(X_61|X_62|X_63|X_64|X_65|X_66|X_67|X_68)&(!X_61|H1_norwegian)&(!X_61|H2_blue)&(X_61|!H1_norwe
(!X_62|H2_norwegian)&(!X_62|H1_blue)&(X_62|!H2_norwegian|!H1_blue)&(!X_63|H2_norwegian)&
(!X_63|H3_blue)&(X_63|!H2_norwegian|!H3_blue)&(!X_64|H3_norwegian)&(!X_64|H2_blue)&
(X_64|!H3_norwegian|!H2_blue)&(!X_65|H3_norwegian)&(!X_65|H4_blue)&(X_65|!H3_norwegian|!H4_blu
(!X_66|H4_norwegian)&(!X_66|H3_blue)&(X_66|!H4_norwegian|!H3_blue)&(!X_67|H4_norwegian)&
(!X_67|H5_blue)&(X_67|!H4_norwegian|!H5_blue)&(!X_68|H5_norwegian)&(!X_68|H4_blue)&
(X_68|!H5_norwegian|!H4_blue)&(X_69|X_70|X_71|X_72|X_73|X_74|X_75|X_76)&(!X_69|H1_blends)&(!X_
(X_69|!H1_blends|!H2_water)&(!X_70|H2_blends)&(!X_70|H1_water)&(X_70|!H2_blends|!H1_water)&
(!X_71|H2_blends)&(!X_71|H3_water)&(X_71|!H2_blends|!H3_water)&(!X_72|H3_blends)&
(!X_72|H2_water)&(X_72|!H3_blends|!H2_water)&(!X_73|H3_blends)&(!X_73|H4_water)&
(X_73|!H3_blends|!H4_water)&(!X_74|H4_blends)&(!X_74|H3_water)&(X_74|!H4_blends|!H3_water)&
(!X_75|H4_blends)&(!X_75|H5_water)&(X_75|!H4_blends|!H5_water)&(!X_76|H5_blends)&
(!X_76|H4_water)&(X_76|!H5_blends|!H4_water)&(H1_red|H2_red|H3_red|H4_red|H5_red)&(!H1_red|!H2
(!H1_red|!H3_red)&(!H1_red|!H4_red)&(!H1_red|!H5_red)&(!H2_red|!H3_red)&
(!H2_red|!H4_red)&(!H2_red|!H5_red)&(!H3_red|!H4_red)&(!H3_red|!H5_red)&
(!H4_red|!H5_red)&(H1_green|H2_green|H3_green|H4_green|H5_green)&(!H1_green|!H2_green)&(!H1_gr
(!H1_green|!H4_green)&(!H1_green|!H5_green)&(!H2_green|!H3_green)&(!H2_green|!H4_green)&
(!H2_green|!H5_green)&(!H3_green|!H4_green)&(!H3_green|!H5_green)&(!H4_green|!H5_green)&
(H1_white|H2_white|H3_white|H4_white|H5_white)&(!H1_white|!H2_white)&(!H1_white|!H3_white)&(!H
(!H1_white|!H5_white)&(!H2_white|!H3_white)&(!H2_white|!H4_white)&(!H2_white|!H5_white)&
(!H3_white|!H4_white)&(!H3_white|!H5_white)&(!H4_white|!H5_white)&(H1_yellow|H2_yellow|H3_yell
(!H1_yellow|!H2_yellow)&(!H1_yellow|!H3_yellow)&(!H1_yellow|!H4_yellow)&(!H1_yellow|!H5_yellow
```

```
(!H2_yellow|!H3_yellow)&(!H2_yellow|!H4_yellow)&(!H2_yellow|!H5_yellow)&(!H3_yellow|!H4_yellow
(!H3_yellow|!H5_yellow)&(!H4_yellow|!H5_yellow)&(H1_blue|H2_blue|H3_blue|H4_blue|H5_blue)&(!H1
(!H1_blue|!H3_blue)&(!H1_blue|!H4_blue)&(!H1_blue|!H5_blue)&(!H2_blue|!H3_blue)&
(!H2_blue|!H4_blue)&(!H2_blue|!H5_blue)&(!H3_blue|!H4_blue)&(!H3_blue|!H5_blue)&
(!H4_blue|!H5_blue)&(H1_brit|H2_brit|H3_brit|H4_brit|H5_brit)&(!H1_brit|!H2_brit)&(!H1_brit|!H
(!H1_brit|!H4_brit)&(!H1_brit|!H5_brit)&(!H2_brit|!H3_brit)&(!H2_brit|!H4_brit)&
(!H2_brit|!H5_brit)&(!H3_brit|!H4_brit)&(!H3_brit|!H5_brit)&(!H4_brit|!H5_brit)&
(H1_swed|H2_swed|H3_swed|H4_swed|H5_swed)&(!H1_swed|!H2_swed)&(!H1_swed|!H3_swed)&(!H1_swed|!H
(!H1_swed|!H5_swed)&(!H2_swed|!H3_swed)&(!H2_swed|!H4_swed)&(!H2_swed|!H5_swed)&
(!H3_swed|!H4_swed)&(!H3_swed|!H5_swed)&(!H4_swed|!H5_swed)&(H1_dane|H2_dane|H3_dane|H4_dane|H
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(!H2_dunhill|!H5_dunhill)&(!H3_dunhill|!H4_dunhill)&(!H3_dunhill|!H5_dunhill)&(!H4_dunhill|!H5
```

```
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(!H1_bluemasters|!H5_bluemasters)&(!H2_bluemasters|!H3_bluemasters)&(!H2_bluemasters|!H4_bluem
(!H3_bluemasters|!H4_bluemasters)&(!H3_bluemasters|!H5_bluemasters)&(!H4_bluemasters|!H5_bluem
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(!H3_prince|!H5_prince)&(!H4_prince|!H5_prince)&(H1_blends|H2_blends|H3_blends|H4_blends|H5_bl
(!H1_blends|!H3_blends)&(!H1_blends|!H4_blends)&(!H1_blends|!H5_blends)&(!H2_blends|!H3_blends
(!H2_blends|!H4_blends)&(!H2_blends|!H5_blends)&(!H3_blends|!H4_blends)&(!H3_blends|!H5_blends
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(!H1_green|!H1_blue)&(!H1_white|!H1_yellow)&(!H1_white|!H1_blue)&(!H1_yellow|!H1_blue)&
(H2_red|H2_green|H2_white|H2_yellow|H2_blue)&(!H2_red|!H2_green)&(!H2_red|!H2_white)&(!H2_red|
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(!H2_white|!H2_yellow)&(!H2_white|!H2_blue)&(!H2_yellow|!H2_blue)&(H3_red|H3_green|H3_white|H3
(!H3_red|!H3_green)&(!H3_red|!H3_white)&(!H3_red|!H3_yellow)&(!H3_red|!H3_blue)&
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(!H3_white|!H3_blue)&(!H3_yellow|!H3_blue)&(H4_red|H4_green|H4_white|H4_yellow|H4_blue)&(!H4_r
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(!H1_tea|!H1_milk)&(!H1_tea|!H1_beer)&(!H1_tea|!H1_water)&(!H1_coffee|!H1_milk)&
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- In DIMACS format:

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-1 7 0
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-2 8 0
-2 9 0
2 -8 -9 0
-3 10 0
-3 11 0
3 -10 -11 0
-4 12 0
-4 13 0
4 -12 -13 0
-5 14 0
-5 15 0
5 -14 -15 0
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-16 21 0
-16 22 0
16 -21 -22 0
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-20 30 0
20 -29 -30 0
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60 -54 -65 0
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-101 110 0
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-102 112 0
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126 -98 -130 0
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Answer

Here is the answer:

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