CS 3100, Fall 2021, Asg-9, 100 pts

Please fill the notebook `u000000_asg09.ipynb` within `21_NPC_Lambda/ASSIGNMENT-9`, finish that,and submit that. You are also required to submit a `.png` file called `bdd1.png`.

1. **(25 points)** The topic of this assignment problem is *Running the BDD tools.*

   These are now found as follows

   Git pull Jove

   At the top level, click into the folder pbl and select BDD.ipynb

   Send BDD.ipynb to Colab

   Follow instructions in BDD.ipynb as well as below

   Someone wants to implement the following functions:

   - The magnitude comparison function `<` (written **lt**) defined over bits `a3,a2,a1,a0` and `b3,b2,b1,b0`. In particular, `a3 a2 a1 a0 < b3 b2 b1 b0` must be true exactly when the magnitude of the unsigned binary nibble `a3 a2 a1 a0` is less than that of the nibble `b3 b2 b1 b0`.

     Examples: `0100 < 1100`, `0100 < 0101`, etc.
   - The magnitude comparison function `>` (written **gt** in the BDD file) defined over bits `a3,a2,a1,a0` and `b3,b2,b1,b0`. It is defined similar to how `<` was defined.

     Examples: `1100 > 0100`, `0101 > 0100`, etc.
   - The equality function `=` (written **eq** in the BDD file) defined over bits `a3,a2,a1,a0` and `b3,b2,b1,b0`.

     Examples: `1100 = 1100`, `0101 = 0101`, etc.
   - Someone using our BDD tool has come up with the following definitions. Your task is to help the person debug his/her construction. Due to the symmetry of their construction, they trust `lt1` and `gt1` to be both right or wrong. Similarly, they trust `lt2` and `gt2` to be both right or wrong. They also trust `eq`'s definition. They need help with which pair `lt1,gt1` or `lt2,gt2` to trust. They also need help with size-control of the BDD:

```
#1 Var_Order : a3, a2, a1, a0, b3, b2, b1, b0
#2 Var_Order : something else

lt1 = (~a3 & b3) | (~a2 & b2) | (~a1 & b1) | (~a0 & b0)
gt1 = (a3 & ~b3) | (a2 & ~b2) | (a1 & ~b1) | (a0 & ~b0)

lt2 = ~a3 & b3 | (a3<=>b3) & (~a2 & b2 | ((a2<=>b2) & (~a1 & b1 | (a1<=>b1) & ~a0 & b0)))
gt2 = a3 & ~b3 | (a3<=>b3) & (a2 & ~b2 | ((a2<=>b2) & (a1 & ~b1 | (a1<=>b1) & a0 & ~b0)))

eq = (a3 <=> b3) & (a2 <=> b2) & (a1 <=> b1) & (a0 <=> b0)
```

```
#3 Main_Exp  : lt1 & gt1
#4 Main_Exp  : lt2 & gt2
#5 Main_Exp  : (lt1 & ~gt1) <=> lt1
#6 Main_Exp  : (lt2 & ~gt2) <=> lt2
```

(a) **(5 pts)** Which `Var_Order` (`#1` or `#2`) do you recommend, and why? What is a good criterion for picking a variable ordering that results in smaller BDD sizes? (about 2 bullets)

(b) **(5 pts)** When you enable `#3` as the `Main_Exp`, does the resulting BDD suggest that `lt1` and `gt1` are correct? Also, when you enable `#4` as the `Main_Exp`, does the resulting BDD suggest that `lt2` and `gt2` are correct? Explain in clear bullets (about 2) by reading the resulting BDDs, saying which of the expressions are correct (`lt1,gt1` or `lt2,gt2`).

(c) **(5 pts)** When you enable `#5` as the `Main_Exp`, does the resulting BDD suggest that `lt1` and `gt1` are correct? Also, when you enable `#6` as the `Main_Exp`, does the resulting BDD suggest that `lt2` and `gt2` are correct? Explain in clear bullets (about 2) by reading the resulting BDDs, saying which of the expressions are correct (`lt1,gt1` or `lt2,gt2`).

(d) **(5 pts)** What is the main flaw in `lt1/gt1`? (about 2 bullets)

(e) **(5 pts)** How is this flaw fixed in `lt2/gt2`? (about 2 bullets)

2. **(25 points)** Refer to Figure 16.9 of our book. Here, a formula called ϕ is given. Drop the last conjunct of ϕ, calling the resulting formula ϕ_1.

(a) **(5 points)** Enter this formula in the syntax of the provided BDD tool. Answer in your notebook, in the space provided, how you entered this formula.

```
Var_Order : x1 x2
...
```

(b) **(5 points)** Submit the PNG file you obtain for this BDD in your ZIP as a file called `bdd1.png`. You can save the image by right-clicking on it.

Next, obtain the satisfying assignment for ϕ_1. Write it in the syntax provided, in the notebook.

```
... variable assignment ...
```

(c) In the NP-completess proof, there is a mapping reduction employed in Figure 16.9. Describe the cliques generated by ϕ_1 according to the construction rules of this mapping reduction. In particular,

- **(5 points)** How many 3-cliques (or *triangles*) are allowed by the image of ϕ_1? Hint on locating these cliques: See that there are three "clause islands" `{x1,x1,x2}`, `{x1,x1,!x2}`, and `{!x1,!x1,x2}` that are to be connected in every possible way. The assignment we obtained for ϕ_1 is rather simple, and suggests the edges that are allowed to be connected. Locate all the allowed triangles. A good way to "chase down" the triangles may be this:
  - Look at the clause islands `Island1: {x1,x1,x2}` and `Island2: {x1,x1,!x2}`. How many 2-cliques (or *lines*) can bridge them?
  - Introduce those 2-cliques, and then try to finish a triangle by picking the third vertex from the clause island `Island3: {!x1,!x1,x2}`.
  - List the triangles as triples in this manner. The first line is an actual solution. Finish the remaining ones yourself:

    List as `‘‘(Island1: node, Island2: node, Island3: node)’’`
    * One solution: `(Island1: first x2, Island2: first x1, Island3: only x2)’’`
    * Another solution: `(Island1: x1, Island2: second x1, Island3: only x2)`
- **(5 points)** List the remaining cliques, one per line.
  SOLUTION: N cliques are allowed! They are:
  - ...
- **(5 pts)** Suppose someone comes up with a P-time solver for cliques. How does this allow you to obtain a P-time solver for 3-SAT? Describe in **two clear sentences** reflecting your understanding. Use any two sentence forms to express: we just want to see how you are thinking.

3. **(25 points)** SAT, while being NP-complete, is a "workhorse of a tool." This problem asks you to get a taste of running a SAT tool and seeing how things are encoded. Specifically, you will be running CryptoMinisat on a SAT formula. You don't need to install this tool: merely go to page 265 of our book, consult Figure 16.10, and presto—there is a link to this tool that you can click! When you do this, the tool comes up with a prefilled formula. There is a Play button that you can click whereupon it solves the SAT instance.

   This assignment asks you to replace this SAT instance with something bigger: specifically, the Pigeonhole problem (`hole6.cnf`) from `https://people.sc.fsu.edu/~jburkardt/data/cnf/cnf.html`. Just click the above link, and get the `hole6.cnf` file, and plunk the CNF into the buffer.

   Hit "play" and report on the execution time (you can look at your phone's clock). If under 2 seconds, say "negligible" for your answer!

   How much time would such a problem take through brute-force enumeration of 2^n combinations on a computer that takes a microsecond per variable combination (the n is the number of variables used in the Pigeonhole problem)? **HINT:** Here is how you read the contents of a CNF file:

```
c File:  hole6.cnf <--- these are comment lines - starts wth a "C"
c...
c
p cnf 42 133     <--- CRUCIAL !! Tells you there are 42 variables and 133 clauses
-1     -7    0   <--- This line says (!x1 + !x7). The "0" is just end-of-a-clause marker!
-1     -13   0   <--- This line says (!x1 + !x13)
...
 12     11     10     9      8      7    0 <--- This clause reads
                                           (x12 + x11 + x10 + x9 + x8 + x7)
...
```

(a) **(5 points)** CryptoMinisat runtime: **SOLUTION: some time OR Negligible.**

(b) **(5 points)** 2^n runtime estimation. (Your solution here.)

(c) **(15 points)** List six facts that you found interesting about Boolean SAT in these articles:

`https://cacm.acm.org/magazines/2009/8/34498-boolean-satisfiability-from-theoretical-hardness-to-practical-success/fulltext`

and

`https://en.wikipedia.org/wiki/Boolean_satisfiability_problem`

Anything that interested you is fine – theoretical or practical. Please offer 1-2 sentences per point that interested you.

4. **(25 points)** Euclid's method to compute the greatest common divisor of two natural numbers can be specified in the Lambda syntax as:

```
gcd = lambda x: lambda y: y if (x==y) else gcd(x-y)(y) if (x>y) else gcd(x)(y-x)
```

(a) **(5 points)** Much like we computed `fact` to be `Ye(prefact)` (see Chapter 18), compute the following: `pregcd` using a `Ye` application. Notice that `pregcd` is *curried* (Page 311 defines *curried functions*); but that does not matter yet (computing `gcd` from `pregcd` works the same despite having a curried function of two arguments).

Define `pregcd` in this manner, and then `gcd`

(b) **(5 points)** Evaluate these:

- `gcd(450)(6000)`
- `gcd(450)(6001)`
- `gcd(450)(6002)`
- `gcd(450)(6003)`
- `gcd(453)(6003)`

(c) **(15 points)** (In this problem, we use () or [] interchangeably, for visual clarity.) Show that Y_e is indeed a fixed-point combinator. That is, show that for any G, we get

$$Y_e\, G = G(Y_e\, G)$$

Here are a few steps of the derivation; finish this:

- $Y_eG = (\lambda f.(\lambda x.(xx)[\lambda y.f(\lambda v.((yy)v))])G$
- *(Apply Beta reduction to pull in G, and get)*
- $= (\lambda x.(xx)[\lambda y.G(\lambda v.((yy)v))])$
- … finish the remaining steps; it will involve two more Beta reductions and one Eta reduction.