CS 228 : Logic in Computer Science

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- Combine all these proofs, and give a proof for ψ starting with no premises

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- This gives a proof of ψ with no premises.

Normal Forms

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  each $L_{i,j}$ is a literal.
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- A formula F is in DNF if it is a disjunction of a conjunction of literals.

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Every formula F is equivalent to some formula F_1 in CNF and some formula F_2 in DNF.

CNF Algorithm

Given a formula F, $(x \rightarrow [\neg(y \vee z) \wedge \neg(y \rightarrow x)])$

- Replace all subformulae of the form $F \rightarrow G$ with $\neg F \vee G$, and all subformulae of the form $F \leftrightarrow G$ with $(\neg F \vee G) \wedge (\neg G \vee F)$. When there are no more occurrences of $\rightarrow, \leftrightarrow$, proceed to the next step.

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- Get rid of all double negations : Replace all subformulae
  - $\neg\neg G$ with G,
  - $\neg(G \wedge H)$ with $\neg G \vee \neg H$
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  When there are no more such subformulae, proceed to the next step.
- Distribute $\vee$ wherever possible.

The resultant formula F_1 is in CNF and is provably equivalent to F.
$[(\neg x \vee \neg y) \wedge (\neg x \vee \neg z)] \wedge [(\neg x \vee y) \wedge (\neg x \vee \neg x)]$

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- How hard is checking satisfiability, in general?

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- $p \wedge (\neg p \vee \neg q \vee r) \wedge (\neg a \vee \neg b)$ is Horn, but $a \vee b$ is not Horn.
- A basic Horn formula is one which has no $\wedge$. Every Horn formula is a conjunction of basic Horn formulae.

positive literal is just an atom (e.g., x).

A negative literal is the negation of an atom (e.g., \lnot x).

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- Thus, a Horn formula is written as a conjunction of implications.

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- Consider subformulae of the form $(p_1 \wedge \cdots \wedge p_m) \to \bot$. If there is one such subformula with all p_i marked, then say Unsat, otherwise say Sat.

An Example

$$(\top \to A) \wedge (C \to D) \wedge ((A \wedge B) \to C) \wedge ((C \wedge D) \to \bot) \wedge (\top \to B).$$

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- Assume H is satisfiable. Then there is an assignment α of $\mathcal{S}$ such that $\alpha \models H$. For each basic Horn formula B of H, $\alpha(B) = 1$. Also, $\alpha(\bot) = 0$ and $\alpha(\top) = 1$.

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- If B has the form $\top \to C_i$, then $\alpha(C_i) = 1$. If B has the form $(C_1 \wedge \cdots \wedge C_n) \to D$, where each $\alpha(C_i) = 1$, then $\alpha(D) = 1$. Hence, $\alpha(C_i)$ agrees with the marking of the algo.

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- Assume the algo says H is unsat. Then there is a subformula B of the form $(A_1 \wedge \cdots \wedge A_m) \to \perp$, where each A_i is marked. Hence, $\alpha(A_i) = 1$ for each A_i. Then $\alpha(B) = 0$, a contradiction to our assumption that $\alpha(B) = 1$ for each B.

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- Conversely, assume that the algo says *Sat*. Show that there exists a satisfying assignment α, using the markings made by the algo. Let α be the assignment of $\mathcal{S}$ defined by $\alpha(C_i) = 1$ iff C_i is marked. We claim that $\alpha \models H$.

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- Conversely, assume that the algo says *Sat*. Show that there exists a satisfying assignment α, using the markings made by the algo. Let α be the assignment of $\mathcal{S}$ defined by $\alpha(C_i) = 1$ iff C_i is marked. We claim that $\alpha \models H$.
- Show that $\alpha \models B$ for each basic Horn formula B of H.

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- Assume all the A_i's were marked. Then $\alpha(A_i) = 1$ for all i. Since the algo said *Sat*, $G \neq \perp$. Then G is also marked (step 2 of algo). Hence, $\alpha(G) = 1$, and we have $\alpha(B) = 1$.

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- Thus, the markings of the algorithm gives rise to a satisfying assignment α if the algorithm said *Sat*.

Complexity of Horn

- Given a Horn formula ψ with *n* propositions, how many times do you have to read ψ?
- Step 1: Read once
- Step 2: Read atmost *n* times
- Step 3: Read once