Propositional formula: true or false. **Strict def**: need brackets (outer; not…). Removing some => abbrev. of genuine formulas. Meaningless: not strictly well-formed (def). e.g., p or q and r

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binary connectives: right-associative: p->q->r is p->(q->r). Conj/disj: associative

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Subformulas (!= substrings): subtrees but no repeated occurrences

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Formation tree

Verum/Falsum are atomic formulas but not atoms. An atom p is an atomic formula. Not p, Not falsum, verum etc. are literals and clauses

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XOR:

Modus **ponens**:

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Modus **tollens**:

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Set-notation for CNF: Ø is falsum if “empty clause”, and verum if “empty conjunction”

**Special cases of CNF/DNF**:

1) CNF: conjunction of literals; conjunction with a single clause; not(p or q) is not a clause so not a conjunction;

2) DNF: disjunction with a single conjunction (of clauses, or of one clause);

Note you should NOT use log. equivalent clauses to determine if in CNF/DNF.

A tautology can appear as a clause in a CNF: e.g., “p or not p”

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CNF / DNF:

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Resolution = inference rule taking 2 clauses -> produce the 3rd clause implied

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Use set-notation

in resolution steps

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**PURE RULE**: remove clauses containing pure literals. **UNIT PROP**: remove unit clauses and remove the compl. literal *from* remaining clauses

Resolution is sound:

(**SLD in def.log**

**programs too**)



Davis-Putnam Algo

**PL Resolution**

In **FOL**, **Constant**: name for an object. **Predicate**: properties/rel. between objects. **FS**: map objects to other objects. Can use “=” in FOL formulas.

(BFS)

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**Ground term**: contains no variable (!= unground term).

Terms have NO truth

**FOL syntactic errors** (not formulas): NO predicates or connectives inside predicates/FS; be clear when predicate/FS, as predicate can have truth value, but FS (term) cannot.

Davis-Logemann-Loveland Algo

(DLL or DPLL)

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(DFS)

signature L

L-terms

An occurrence of a variable X is **bound** if it lies under a quantifier in the formation tree (otherwise **free**). **Sentence:** formula with no free variable + has truth in a structure.

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NO predicates

Meaning phi of a predicate p is set of objects/tuples in D that p applies to (if 0-arity, phi(p)=Ø)

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L-formulas

L-structure

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**Variable assignment under M** with sigma function (V: D)

to give **truth** value to FOL formulas with **free** variables.

**X-variant** to give **truth** value to FOL formula with **bound** X

Quantifiers bind as strongly as “not” in PL

(i)-(iii) = atomic

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**FOL resolution:** unification by substitution. Start with a query, replace one of the negated atoms in the query by the body of a rule in P whose head is that atom (% unification). Resolvent of one of P clause w/ query is always a new **query**! derived empty cl. => **refutation of goal <-Q** (not Q), so **P|=Q. OR, use M(P)**

**Substitution and unification for SLD (FOL)**

Direct reasoning

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Verum/falsum: NOT lit.

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atom, lit., clause in Definite Logic Program

\*

**Computed answer substitution (CAS)**: Mgus theta\_1 **o** theta\_m (root to success), **theta\***. **Computed answer**: original query w/ variables substituted using the CAS

**Definite clause (DC):** clause w/ exactly 1 positive literal. DC with no negative lit. (fact), otherwise (rule).

**Def.Log.Program** P = set of DCs

**Logic program. notation**

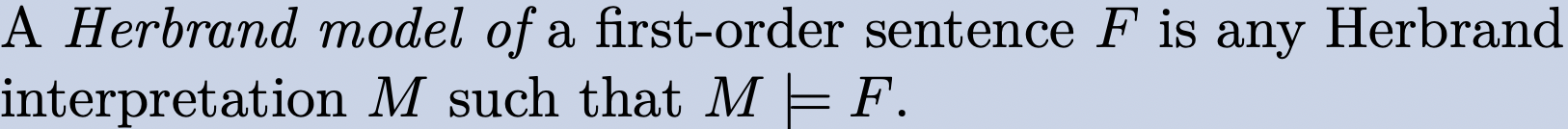
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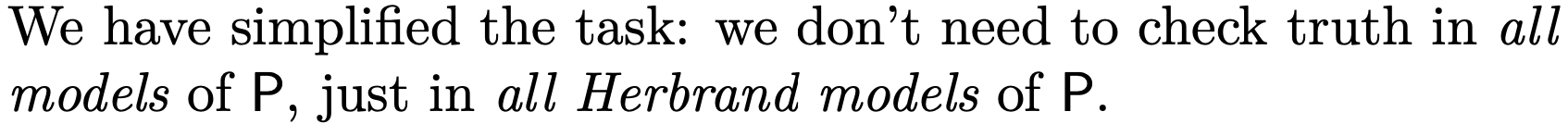
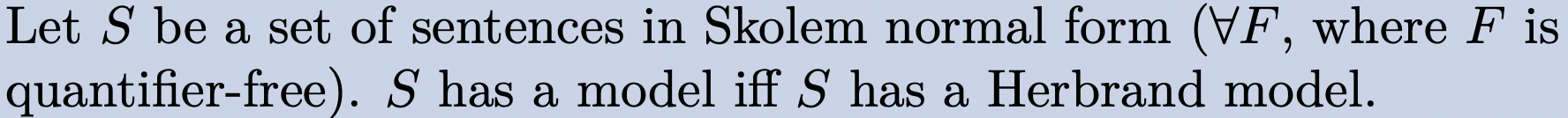
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**NOTE: only substitute variables (w/ other var.), not constants!**

\*

**Herbrand Interprt (HI)** = FOL structure where constants and terms made with FS name *themselves* (phi function), + D is the set of ground L-terms.



**Use of HI** = alternative to FOL SLD: **just** **check if Q in M(P)** 



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Renaming substitution *p*

**SUCCESS**

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H models represented as bases

L-atoms = predicates applied to objects

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The Herbrand base is always a model of P (every P has at least onemodel)

M = *a* Herbrand model of P

IF Q is a ground atom q

Use of M(P):

c = def. clause

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Description générée automatiquementpathcost: root->n; h(n): n->goal (estimated)

d = depth of optimal sol

**TimeC**: GreedyBFS O(b^m); A\* O(b^d)

**SpaceC**: GreedyBFS O(b^m); A\* O(b^d)

**Complete** (tree/graph): GreedyBFS N/Y; A\* Y/Y (w/ consistent h)

**Optimal** (tree/graph): GreedyBFS N/N; A\* Y/Y (**IFF admissible h**) + optimally efficient

4

2

5

6

**Greedy BestFS**: f(n) = h(n)

**A\***: f(n) = pathcost + h(n)

3

Minimax

7

6

5

4

2

1

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3

1

**PO**. belief state b of physical state s <=> the set of s’ s.t. PERCEPT(s) = PERCEPT(s’), s~s’ <=> equivalence class [s]. b satisfies GOAL-TEST if all s in b satisfy GOAL-TEST. RESULT(b,a) = set of belief states bo

**Solve sensorless problem:** any (un)informed SA

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**Solve planning problem:** any un(informed) SA. Search **forward** or **backward (relevant-states search**). **Backward search by regressing actions:** ground goal g, ground action a, then regression from g over a gives state g’

**Planning problems in PDDL => sol is a plan**

**State**: conjunction of fluents (ground, functionless atoms). **Closed-world assumption**: fluents not mentioned false. **Unique names assumption**. **Action schema**: action name, list of var., pre- and post-conditions (conj. of literals); post-condition EFFECT only contains things that changed. **Planning domain**: set of action schemas. **Planning problem**: planning domain + initial state (conj. of ground atoms) + goal (conj. of +/- literals that may contain univ.quant. variables). **Plan**: sequence of ground actions a0 to al. **Ground action**: name(a)(x1/t1, …, xk/tk), where a = action schema. **Induced state sequence (ISS)**: s0, s1, …, sl+1. **Executable** (ISS exists) and **valid** (executable and sl+1 entails goal(P)) plans.

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**Automated heuristics finding from relaxed problems.** Relax problem by adding more transitions (more paths). How? By relaxing actions: drop all or certain preconditions from all actions + drop all effects that are not literals in goal state + ignore delete lists (to make monotonic progress towards the goal)

**Relevant action = action that could be last step in plan leading up to current goal state**

**Cond. plan reaches a goal state in all circum.**

**Recursive DFS type**

**To solve PO problem**

(2)

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**Planning graphs:** data structure for giving better heuristic estimates + searching for sol (GRAPHPLAN). Polynomial-size approx. (constructed quickly). Gives estimate of num steps to reach goal (admissible h). Estimate always correct when unreachable goal reported. Directed graph organised into levels. Level i is an admissible heuristic/estimate of how difficult it is to achieve a literal /perform an action, from initial state S0. **Persistence actions** for all fluents, **mutex links** between fluents or actions, **termination** iff 2 same cons. S levels.

**Time/SpaceC**: if a actions, l literals/fluents, n levels, then O(n(a+l^2)).

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**Cost of a goal literal gi:** level at which it **FIRST** appears in planning graph (**level cost**) => admissible estimate for each goal literal. **Cost of a conj. of goals**:

**To extract a plan directly**

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**Extract by Backward search, w/ intermediate goal states at each level before last one**

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**Admissible heuristic:** never overestimates the estimated cost from state s to goal (obtain from relaxed problems).

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