Conformant Planners: Approximations vs. Representation

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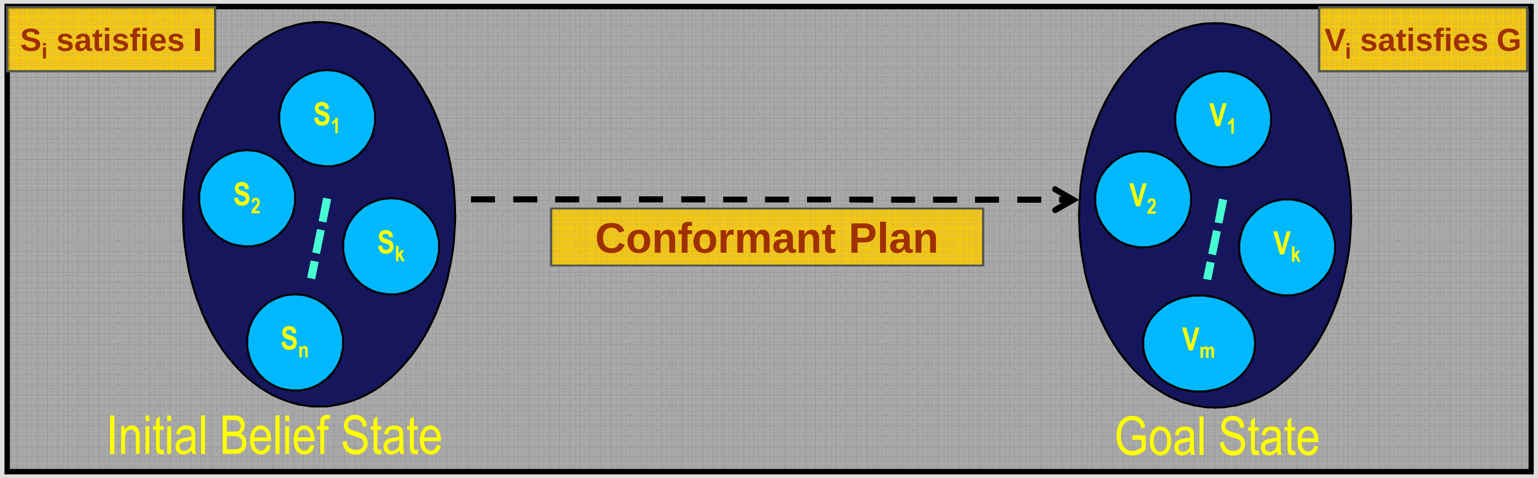
Conformant Planning Problem

- Given: planning problem $P = \langle F, O, I, G \rangle$ where
  - F is a set of propositions
  - O is a set of operators
  - I is the initial state – often incomplete
  - G is the goal
- Problem: Computing a plan that achieves G from all possible initial states of the world satisfying I



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Goal, Motivated Questions, and Facts

- **Goal**: develop state-of-the-art conformant planners
- **Motivated questions**:
  - How does the definition of a progression function influence the performance of a conformant planner?
  - How does the representation of belief states influence the performance of a conformant planner?
- **Motivated facts**:
  - CpA^{PH}, an *approximation-based conformant planner*, uses an incomplete progression function & a compact belief state representation performs very well in its first implementation
  - CpA^{PH} differs from all of its counterparts when it was introduced
  - CpA^{PH} needs complete initial belief state in benchmark problems with disjunctive information about the initial state

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Considerations in Conformant Planners

- How to encode a belief state? Many possibilities
  - OBDD
  - DNF
  - CNF
  - …

  each might have its own desirable properties (e.g. minimal)
- How to progress? By a function Φ
  - Given an action *a* and a belief state *S* in the corresponding representation, compute the belief state *U* resulting from executing *a* in *S*, written as $U = \Phi(a, S)$
  - Certain operations on a representation might lead to a formula which no longer satisfies the desirable properties and require some overhead after the computation (e.g., updating minimal CNF might not result in a minimal CNF)

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Main Characteristics of CpA

- Approximation-based progression function
- Encoding of belief state enable easy computation of successor belief state
- Search for plan in the space of 3^n partial states instead of the space of 2^{2^n} belief states as most other conformant planners (for problems with conjunction of literals as initial state)
- Maintain completeness through special reasoning technique
  - CpA incurs significant overhead in the computation of the representation of the initial belief state
  - CpA uses DNF-formulae to encode belief states and can potentially require a lot of memory
- CpA uses a combination of the cardinality and the number of satisfied subgoals heuristic as its heuristic function

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Main Characteristics of DNF

- ❑ A middle-ground between approximation and complete reasoning
- ❑ Search for plan in the space of 2^{2^n} belief states
- ❑ Use minimal DNF-formulae to represent belief states, also enable easy computation of successor belief state
- ❑ Progression function defined over minimal DNF-formulae
  - ❑ DNF incurs overhead for the transformation of successor belief state into minimal DNF-formulae
- ❑ DNF uses a combination of the cardinality, the number of satisfied subgoals, and the square distance to the goal heuristic as its heuristic function

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Main Characteristics of CNF

- Search for plan in the space of 2^{2^n} belief states
- Use minimal CNF-formulae to represent belief states, a departure of easy computation of successor belief state
- Progression function defined over minimal CNF-formulae
  - CNF also incurs overhead for the transformation of successor belief state into minimal CNF-formulae
- CNF uses the number of satisfied subgoals as its heuristic function

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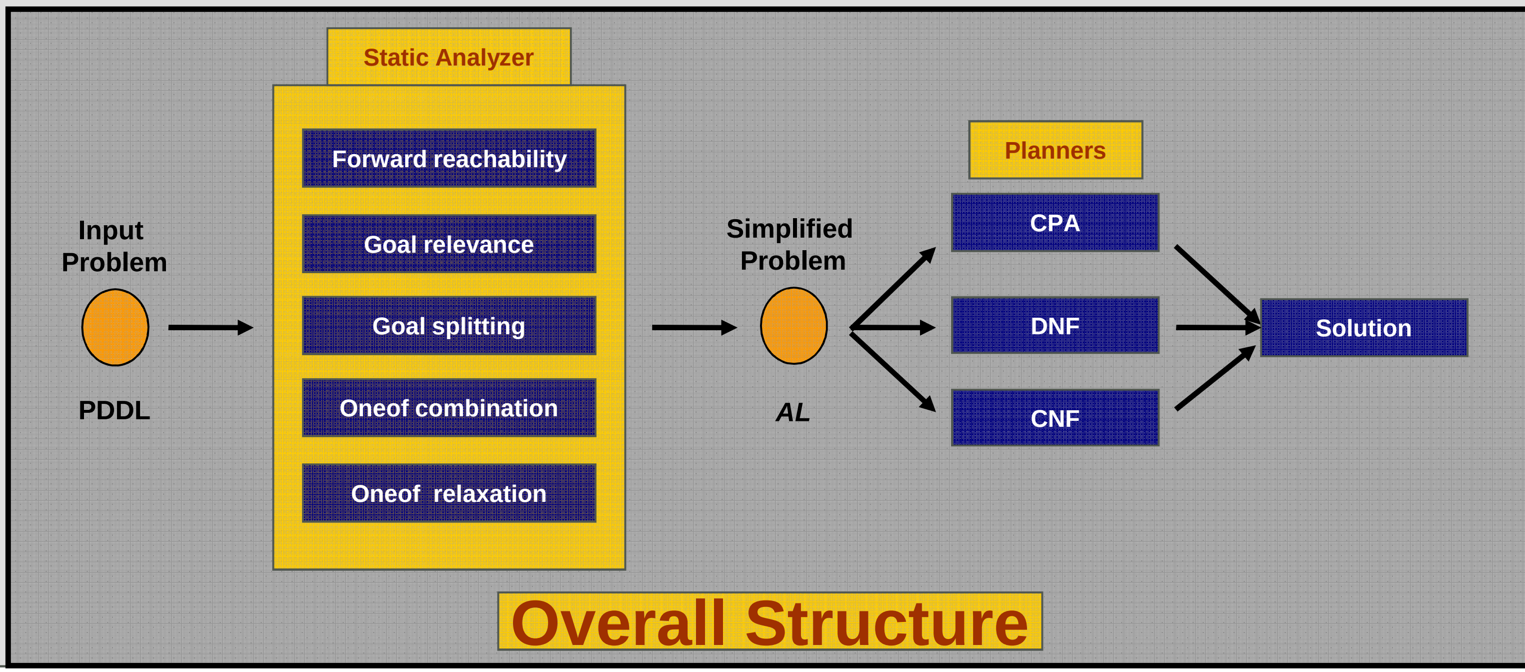
Simplification Techniques for Scalability and Performance

- Forward reachability: eliminating redundant actions and propositions
- Goal relevance: identifying necessary information in the initial belief state to guarantee completeness
- Goal splitting: divide-and-conquer using subgoals
- Oneof-combination: reducing the size of the initial belief state
- Oneof-relaxation: replacing mutual exclusive or by disjunctive or



Overall Structure

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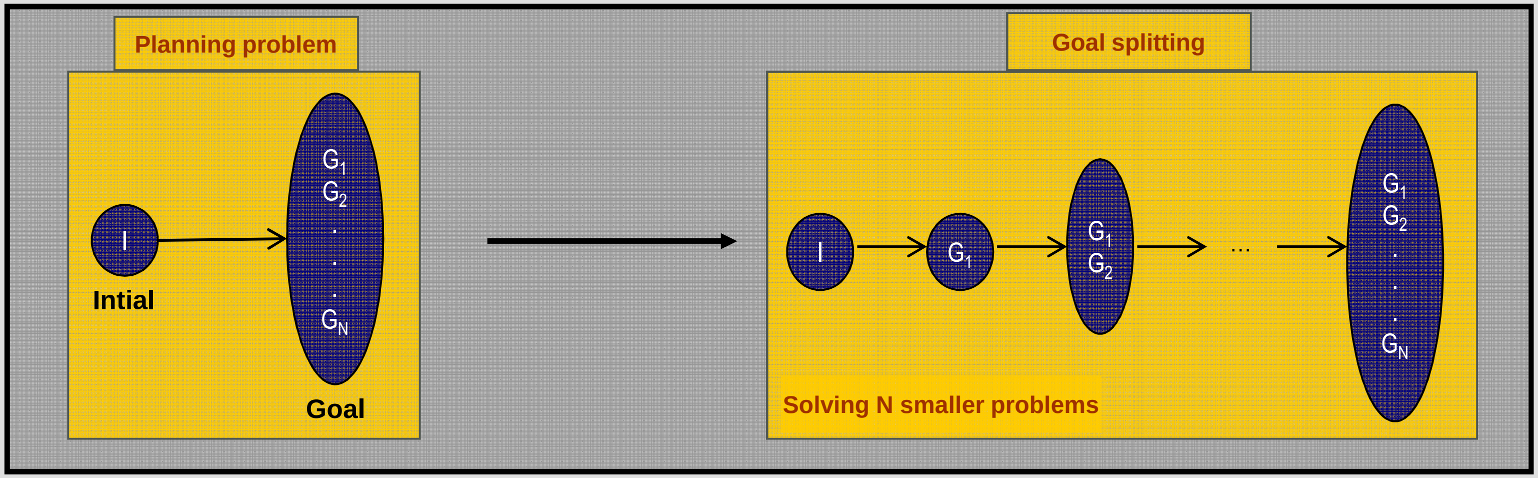
Simplification Techniques: Goal Splitting

- If a problem *P* contains a subgoal whose truth value cannot be negated by the actions used to reach the other goals, then the problem can be decomposed into a sequence of smaller problems
- Improve scalability



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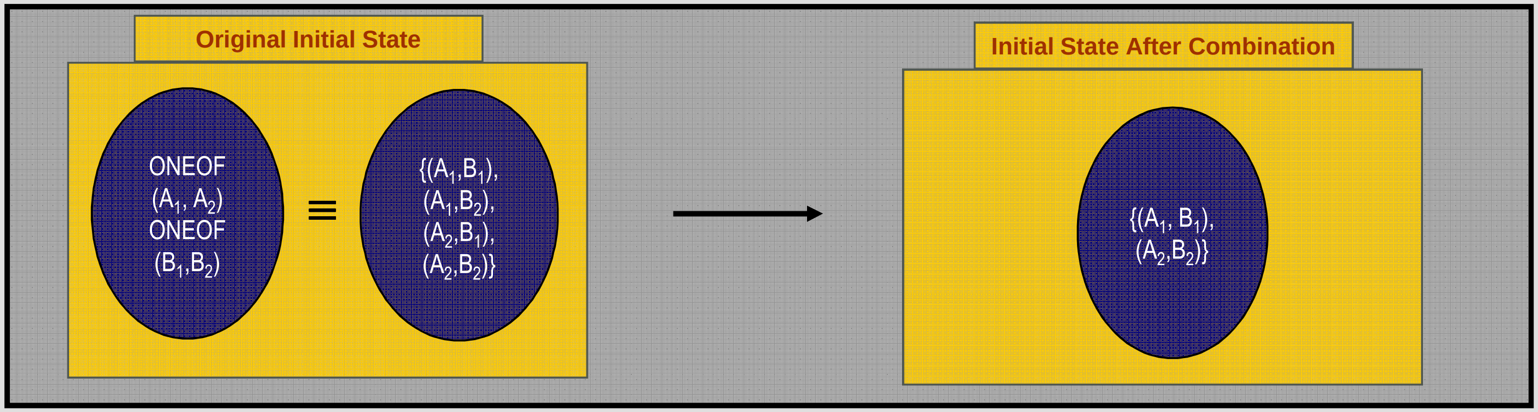
Simplification Techniques: oneof-combination

- If actions and propositions in different **oneof**'s have no interaction then we do not need to consider all possible permutations of the **oneof**'s.
- Reducing the size of the initial belief state
- Improve scalability
- Suitable for DNF and CpA



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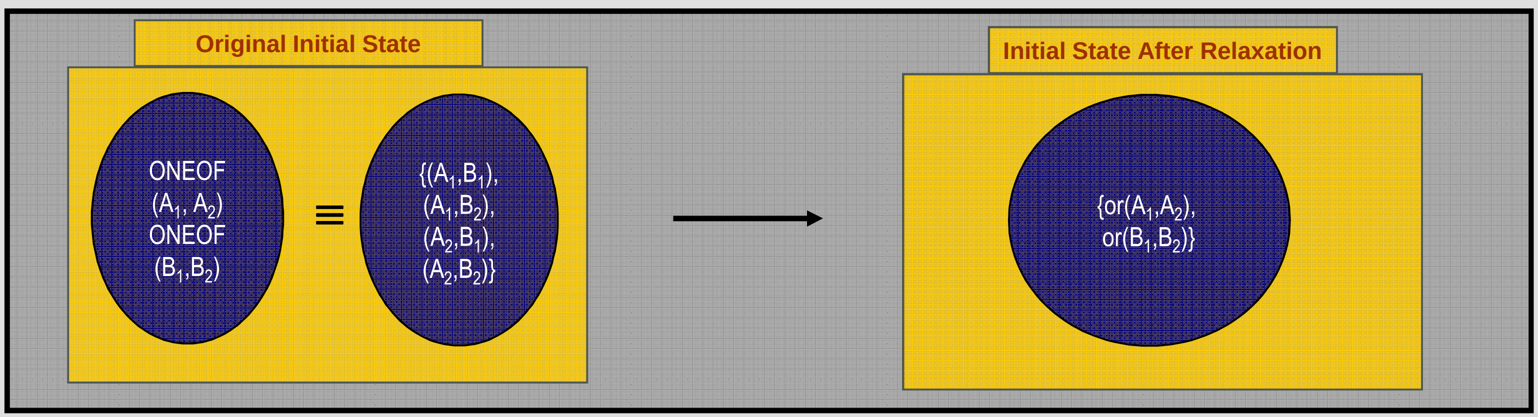
Simplification Techniques: `oneof`-relaxation

- If actions and propositions in an **`oneof`**–clause satisfy certain properties then an **`oneof`**–clause can be replaced by an **`or`**–clause
- Increasing the size of the initial belief state
- Improve scalability
- Suitable for CNF



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Conclusions

- Presentation of three conformant planners: CpA, DNF, and CNF
- There exists no “one size fits all” representation for all domains
- The choice of belief state representation impacts
  - performance of conformant planner
  - choice of simplification techniques
  - algorithm for computing successor belief state

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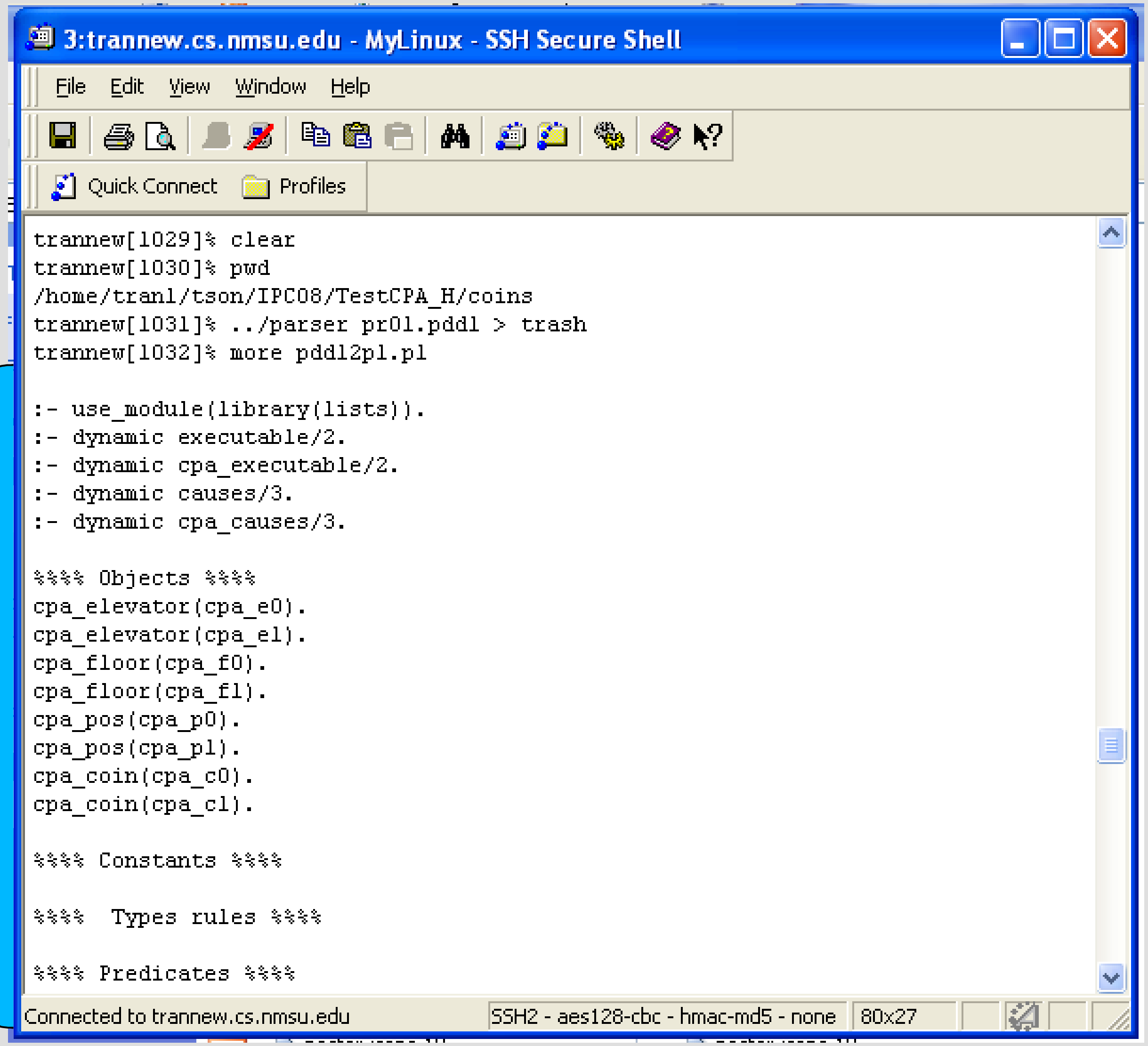
A Sample Run – CpA - Preprocessor

Translating from PDDL to Prolog



Prolog Representation of PDDL (segment)

Preprocessor

Calling the Preprocessor

3:trannew.cs.nmsu.edu - MyLinux - SSH Secure Shell

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```
trannew[1036]% sicstus -l prob.pl --goal 'main,halt.' > trash
% compiling /home/tranl/tson/IPC08/TestCPA_H/coins/prob.pl...
%  loading /local/sicstus-3.12.2/lib/sicstus-3.12.2/library/lists.po...
%  module lists imported into user
%  loaded /local/sicstus-3.12.2/lib/sicstus-3.12.2/library/lists.po in module li
sts, 0 msec 13696 bytes
%  loading /local/sicstus-3.12.2/lib/sicstus-3.12.2/library/ordsets.po...
%  module ordsets imported into user
%  loaded /local/sicstus-3.12.2/lib/sicstus-3.12.2/library/ordsets.po in module
ordsets, 0 msec 13912 bytes
NAME CLASH: remove_duplicates/2 is already imported into module user from module
 lists
Do you really want to override this definition with the one in user? (y, n, p, s
, a, b, or ?) y
* [NewFluents] - singleton variables in user:create_independent_theories/3
* Approximate lines: 581-589, file: '/home/tranl/tson/IPC08/TestCPA_H/coins/prob
.pl'
* [NewFluents] - singleton variables in user:create_dependent_theories/3
* Approximate lines: 590-598, file: '/home/tranl/tson/IPC08/TestCPA_H/coins/prob
.pl'
* [NI] - singleton variables in user:compose_in/4
* Approximate lines: 946-953, file: '/home/tranl/tson/IPC08/TestCPA_H/coins/prob
.pl'
NAME CLASH: remove_duplicates/2 is already defined in module user
Do you really want to override this definition with the one in lists? (y, n, p,
s, a, b, or ?) y
% compiled /home/tranl/tson/IPC08/TestCPA_H/coins/prob.pl in module user, 200 ms
```

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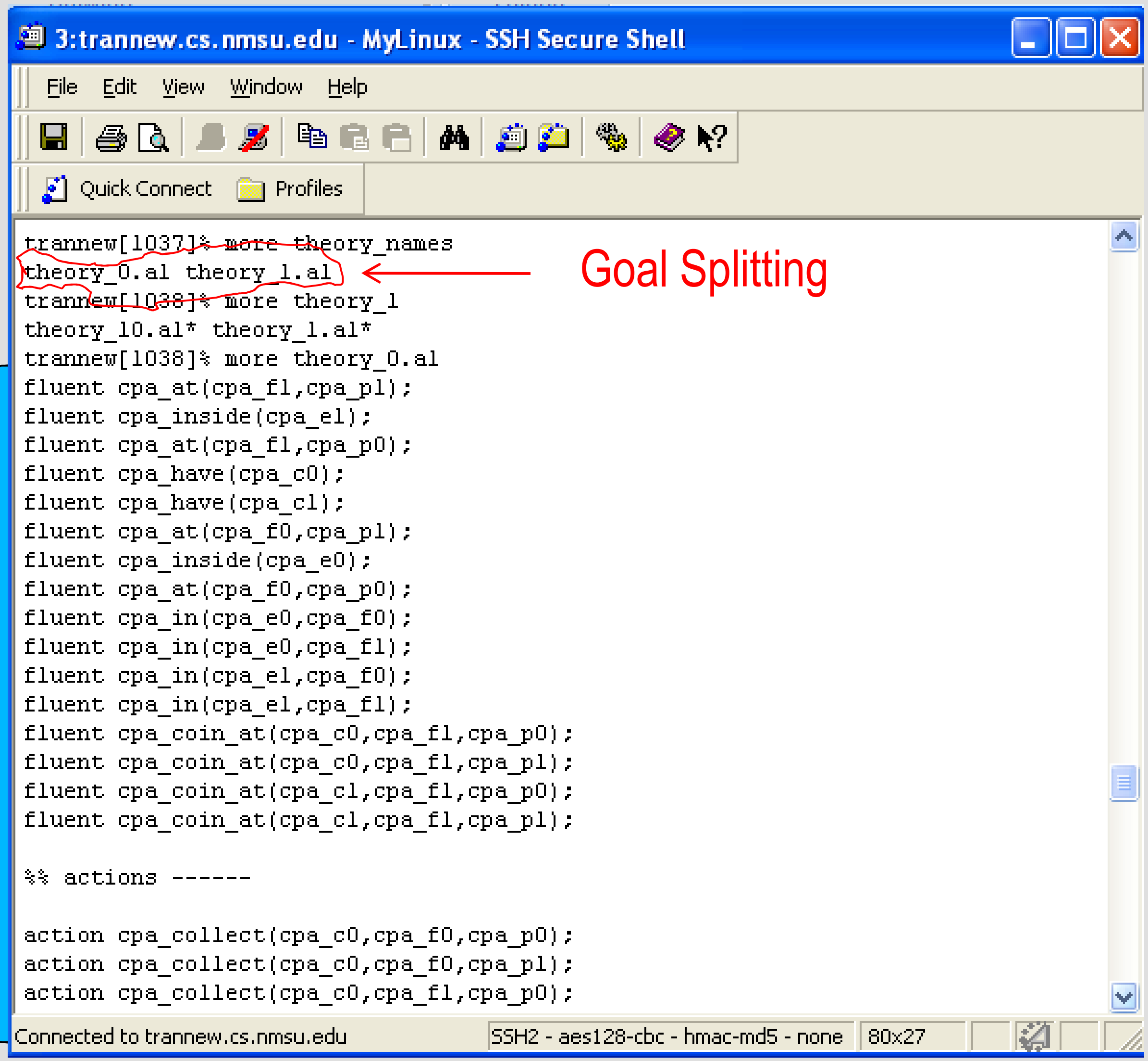
Output of Preprocessor

Output of the Preprocessor

Goal Splitting

First theory in AL




```
trannew[1037]% more theory_names
theory_0.al theory_1.al
trannew[1038]% more theory_1
theory_10.al* theory_1.al*
trannew[1038]% more theory_0.al
fluent cpa_at(cpa_f1,cpa_p1);
fluent cpa_inside(cpa_e1);
fluent cpa_at(cpa_f1,cpa_p0);
fluent cpa_have(cpa_c0);
fluent cpa_have(cpa_c1);
fluent cpa_at(cpa_f0,cpa_p1);
fluent cpa_inside(cpa_e0);
fluent cpa_at(cpa_f0,cpa_p0);
fluent cpa_in(cpa_e0,cpa_f0);
fluent cpa_in(cpa_e0,cpa_f1);
fluent cpa_in(cpa_e1,cpa_f0);
fluent cpa_in(cpa_e1,cpa_f1);
fluent cpa_coin_at(cpa_c0,cpa_f1,cpa_p0);
fluent cpa_coin_at(cpa_c0,cpa_f1,cpa_p1);
fluent cpa_coin_at(cpa_c1,cpa_f1,cpa_p0);
fluent cpa_coin_at(cpa_c1,cpa_f1,cpa_p1);

%% actions ------

action cpa_collect(cpa_c0,cpa_f0,cpa_p0);
action cpa_collect(cpa_c0,cpa_f0,cpa_p1);
action cpa_collect(cpa_c0,cpa_f1,cpa_p0);
```

Calling the planner

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```
%% goal state ----------
goal  cpa_have(cpa_c0);
trannew[1039]% ../cpa
cpa*          cpa+bfs+card* cpa+bfs+rgp*  cpa.pddl2pl*
cpa+*         cpa+bfs+gc*   cpa+dfs*
trannew[1039]% ../cpa+bfs+gc theory_names
0
%%

11 cpa_go_down(cpa_e0,cpa_f1,cpa_f0) cpa_go_up(cpa_e1,cpa_f0,cpa_f1) cpa_step_in
(cpa_e0,cpa_f0,cpa_p0) cpa_go_up(cpa_e0,cpa_f0,cpa_f1) cpa_step_out(cpa_e0,cpa_f
1,cpa_p0) cpa_collect(cpa_c0,cpa_f1,cpa_p0) cpa_move_right(cpa_f1,cpa_p0,cpa_p1)
 cpa_collect(cpa_c0,cpa_f1,cpa_p1) cpa_collect(cpa_c1,cpa_f1,cpa_p1) cpa_move_le
ft(cpa_f1,cpa_p1,cpa_p0) cpa_collect(cpa_c1,cpa_f1,cpa_p0)
%%
linear 12 0 1 2 3 4 5 0 6 7 8 9 10
STATISTICS
---------------------
Total time: 0.011 (sec)
  Reading: 0.002 (sec) [17.37 %]
  Preprocessing: 0.001 (sec) [9.63 %]
  Search: 0.008 (sec) [73.01 %]
Total states allocated: 0
Total cstate(s): 0
Total cstate(s) remaining in the queue: 0
trannew[1040]%
```

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Plan

Statistic