Planning as Model Checking Tasks

Yi Li [1] Jing Sun [2] Jin Song Dong [3] Yang Liu [3] Jun Sun [4]

[1]University of Toronto

[2]The University of Auckland

[3]National University of Singapore

[4]Singapore University of Technology and Design

Oct 13, 2012

Outline

Two Problems

Model Checking

Given a system model $\mathcal{M}$, an initial state s_0, and a formula φ which specifies the property, Model Checking can be viewed as $\mathcal{M}, s_0 \models \varphi$.

Planning

Classical Planning is defined as a three-tuple (S_0, G, A) where S_0 represents the initial state, G represents the set of goal states and A represents a finite set of deterministic actions.

Intuition: construct a safety property $\mathbf{G}\neg\varphi$ that requires the formula φ never to hold.

Motivation

- Performance of model checkers are comparable to that of the state-of-the-art planners.
- Domain specific control knowledge can be exploited to improve the performance of model checkers on planning problems.
- Model checkers are good at handling large state spaces.
- Model checking can be used as underlying planning service for upper layer applications.

Tools

- PAT: Process Analysis Toolkit (demo)
- NuSMV: an extension of the symbolic model checker SMV
- Spin: established model checker, modeling language Promela similar to CSP# of PAT
- SatPlan: an award winning planner for *optimal deterministic planning*
- Metric-FF: domain independent planning system

The sliding game problem

- The *8-tiles problem* is the largest puzzle of its type that can be completely solved.
- The game is simple, and yet obeys a combinatorially large problem space of $9!/2$ states.
- The $N \times N$ extension of the problem is NP-hard.

0	1	2
3	4	5
6	7	8

The sliding game problem cont'd

8	7	6
0	4	1
2	5	3

(a) Hard1

8	0	6
5	4	7
2	3	1

(b) Hard2

8	5	6
7	2	3
4	1	0

(c) Most1

8	5	4
7	6	3
2	1	0

(d) Most2

8	2	1
3	6	4
0	5	7

(e) Rand1

4	1	7
8	0	3
5	6	2

(f) Rand2

Figure: Initial configurations of *the sliding game problem* instances

Experimental Results

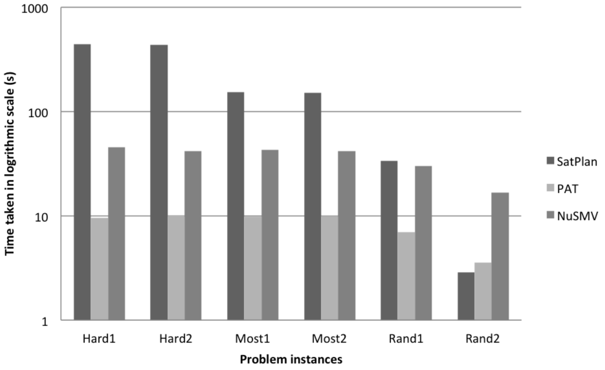


Figure: Execution time comparison of PAT, NuSMV and SatPlan on *the sliding game problem*, shown on a logarithm scale

Case Study: Transport4You

- Transport4You won the Formal Methods Award in SCORE contest out of 56 submissions
- Presented at ICSE 2011 in Hawaii
- Specifically designed municipal transportation management solution
- Simplify the fare collection process and provide customized services to subscribers

Route Planning Module

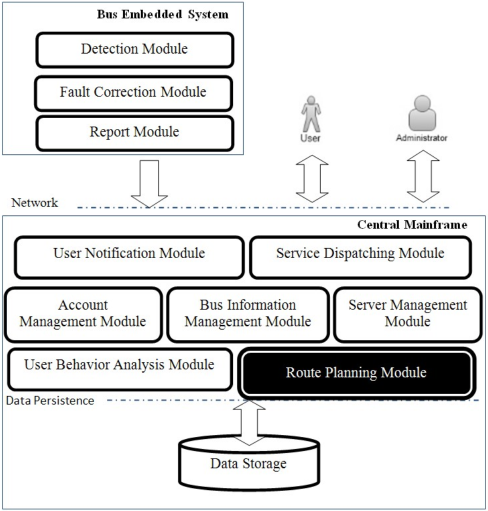


Figure: System architecture diagram of the "Transport4You" IPTM system

Route Planning Module

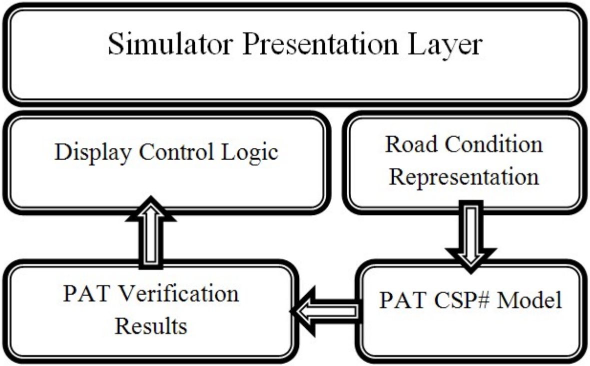


Figure: Simulator architecture diagram

Why Using PAT?

- The searching algorithms of PAT is highly efficient and ready to be used out-of-box.
- CSP# is a highly expressive language for modeling various kind of systems.
- PAT is constructed in a modularized fashion. Modules for specific purposes can be built to give better support for the domains that are considered.

Definition

A Route Planning task is defined by a 5-tuple (S,B,t,c,L) with the following components:

- S: the set of bus stops
- B: the set of bus lines
- $t : S \rightarrow B_S$: a function mapping s to the set of available bus lines at stop s
- $c : S \rightarrow S$: the stop one can get to by crossing the road at stop s.
- L(s) is true when the current location of user is at stop s.

Definition cont'd

A Route Planning problem is mapped to a classical planning problem as follows:

States: Each state is represented as a literal $s \in S$, where L(s) holds.

Initial State: s_0

Goal States: s_g

Actions: 1. $(TakeBus(b_i, s)$,
PRECOND: $b_i \in t(s)$,
EFFECT: $\neg L(s) \wedge L(b_i(s)))$
2. $(Cross(s)$,
PRECOND: $s \in dom(c)$,
EFFECT: $\neg L(s) \wedge L(c(s)))$

Basic Model

Environment Variables

enum{ TerminalA, Stop5, Stop7, Stop9 ... Stop26, Stop11, Stop35, Stop34};

var sLine1 = [TerminalA, Stop5, Stop7, Stop9, Stop58, Stop31, Stop33, Stop53, Stop57, TerminalC];
var<BusLine> Line1 = new BusLine(sLine1,1);
var sLine2 = [TerminalC, Stop56, Stop52, Stop32, Stop30, Stop59, Stop10, Stop8, Stop6, TerminalA];
var<BusLine> Line2 = new BusLine(sLine2,2);
...
var sLine14 = [TerminalC, Stop34, Stop32, Stop30, Stop16, TerminalB];
var<BusLine> Line14 = new BusLine(sLine14,14);

Basic Model cont'd

Initial State

var currentStop = Stop5;
var B0 = [-2];
var<BusLine> currentBus = new BusLine(B0,-1);

Transition Functions

takeBus()=case{
currentStop==TerminalA:BusLine1[]BusLine3[]BusLine5[]BusLine7
currentStop==Stop5:BusLine1[]BusLine5
currentStop==Stop7:BusLine1[]BusLine5
...
currentStop==Stop11:BusLine12
currentStop==Stop35:BusLine13
currentStop==Stop34:BusLine14
};

Basic Model cont'd

Transition Functions

BusLine1=
TakeBus.1{currentStop=Line1.NextStop(currentStop);
currentBus=Line1;} ->plan;
...
BusLine14=
TakeBus.14{currentStop=Line14.NextStop(currentStop);
currentBus=Line14;} ->plan;

crossRoad()=case{
currentStop==Stop5: crosscurrentStop=Stop6 ->plan
currentStop==Stop7: crosscurrentStop=Stop8 ->plan
...
currentStop==Stop35: crosscurrentStop=Stop34 ->plan
currentStop==Stop34: crosscurrentStop=Stop35 ->plan
};

Basic Model cont'd

Transition Functions

plan=takeBus()[]crossRoad();

Goal States

#define goal currentStop==Stop53;

Cost Function Approach

Modified Transition Functions

- $takeBus()$=$tau\{cost = cost + 10\}$->$case\{\ldots$
- $crossRoad()$=$tau\{cost = cost + 2\}$->$case\{\ldots$
- $BusLine1$=$tau\{if(!currentBus.isEqual(LineX))\{cost = cost + 5\}\}$ ->$TakeBus.1\ldots$

- New assertion: *#assert plan reaches goal with min(cost);*
- $cost = 10 \times \sharp takeBus + 5 \times \sharp crossRoad + 2 \times \sharp busChange$
- Original problem can be solved by a simple breadth-first search.
- To find the goal state with minimum cost, the whole state space has to be searched?

Cost Function Approach cont'd

Algorithm 1 newBFSVerification()

```
initialize queue: working;
current ← InitialStep; τ ← ∞;
repeat
   value ← EvaluateExpression(current);
   if current.ImplyCondition() then
      if value < τ then
         τ ← value;
      end if
   end if
   if value > τ then
      continue;
   end if
   for all step ∈ current.MakeOneMove() do
      working.Enque(step);
   end for
until working.Count() ⩽ 0
```

Search Space Pruning

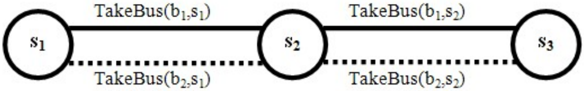


Figure: An example bus line configuration

Figure: A solution produced by the basic model

Search Space Pruning cont'd

Given the current bus line is b_k, an action $TakeBus(b_i, s_j)$ is not redundant if one of the followings holds:

1. $b_i = b_k$
2. $b_i \in t(s_j) \wedge b_k \in t(s_j) \wedge b_i(s_j) \neq b_k(s_j) \wedge \exists m \in \mathbb{N}_1,$
   $b_i(s_j)^{-m} \neq b_k(s_j)^{-m}$
3. 1 and 2 do not hold and $b_i(s_j) \neq b_k(s_j) \wedge b_i^{-1}(s_j) \neq b_k^{-1}(s_j)$

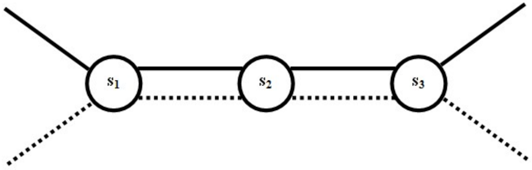
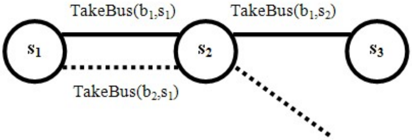
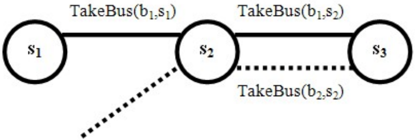


Figure: Special pattern of two overlapping bus lines

Search Space Pruning cont'd



(a) Same Previous Stop



(b) Same Next Stop

Figure: Redundant bus changes

Future Work

- Extend the comparisons to a larger range of model checking as well as planning tools.
- By fine tuning the way of modeling or exploiting domain specific knowledge, some models can be further optimized.
- An automated translator for the translation from PDDL to CSP# can be implemented.
- The applications of PAT as planning service should be extended to a larger range on real problems in various fields.

The End