Finding Plans with Branches, Loops, and Preconditions

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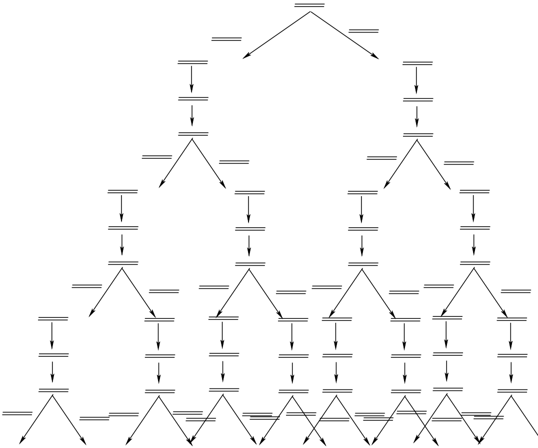
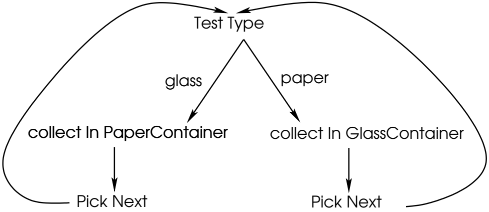
Overview

- Introduction
- Our Framework
- Planning Algorithms
- Results

Conditional Planning



Conditional Planning



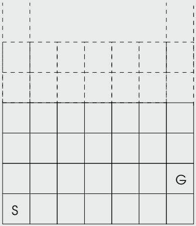
- Serious problems with applicability test, instantiation:
  - Loop termination, progress

Plan Preconditions

- One approach: simulated execution.
- Will be wasted if G cannot solve a problem.

NavigateGrids /*Start at bottom left*/

repeat
  while ¬*rightmost* **do**
    mvR()
  end
  mvU()
  while ¬*leftmost* **do**
    mvL()
  end
  mvU()
until *atgoal*



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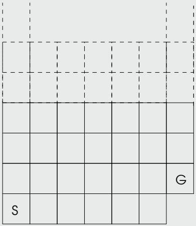


Plan Preconditions (ctd.)

- Historically not common: not required for simple plans $(a_1, \ldots a_n)$.
- Computed plans with loops etc. will typically have a limited applicability.
  - Simulated execution may not even terminate!!

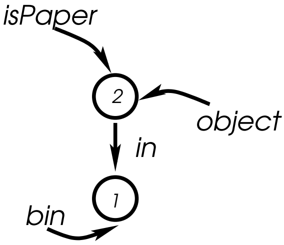
Ideal applicability test: linear in the size of the problem

Our Objective

- Compute algorithm-like “generalized” plans.
  - Efficient applicability tests
  - Efficient generation of generalized plans
- Need to determine progress and termination.

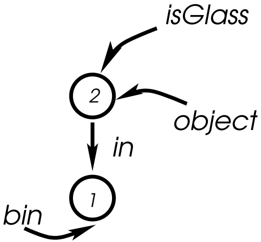
Concrete States as Logical Structures

$$\mathcal{V} = \{object^1, bin^1, isGlass^1, isPaper^1, in^2, empty^1, collected^1, forGlass^1, forPaper^1\}$$



((object(2))) =1
((isPaper(2))) = 1
((bin(1))) = 1
((in(2,1))) = 1

S_1



((object(2))) =1
((isGlass(2))) = 1
((bin(1))) = 1
((in(2,1))) = 1

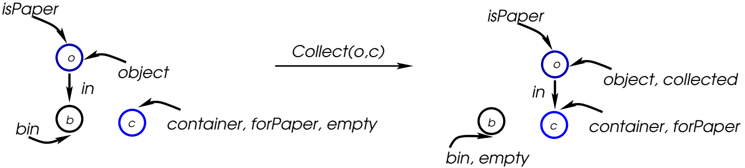
S_2

Example: The Collect Action

Collect(o,c)

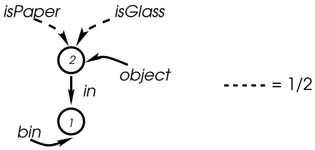
$\text{object}(o) \wedge \text{container}(c) \wedge (\text{isGlass}(o) \leftrightarrow \text{forGlass}(c)) \wedge \exists b(\text{bin}(b) \wedge \text{in}(o,b) \wedge \text{robotAt}(b))$

$$\begin{aligned} in'(u,v) &:= (in(u,v) \wedge u \neq o) \vee \\ &\quad (\neg in(u,v) \wedge u = o \wedge v = c) \\ empty'(u) &:= (empty(u) \wedge u \neq c) \vee in(o,u) \\ collected'(u) &:= collected(u) \vee o = u \end{aligned}$$



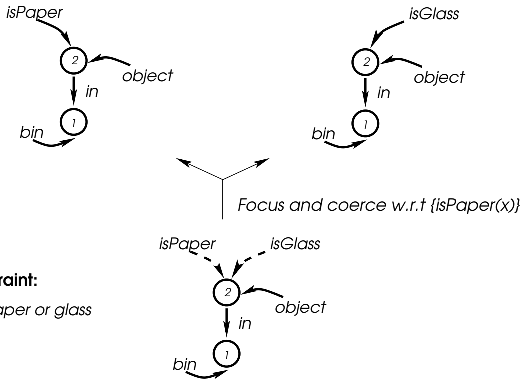
Abstraction Using 3-Valued Logic

Use 3–Valued logic to abstract as:



TVLA: [Sagiv et al., 2002]

Abstraction Using 3-Valued Logic

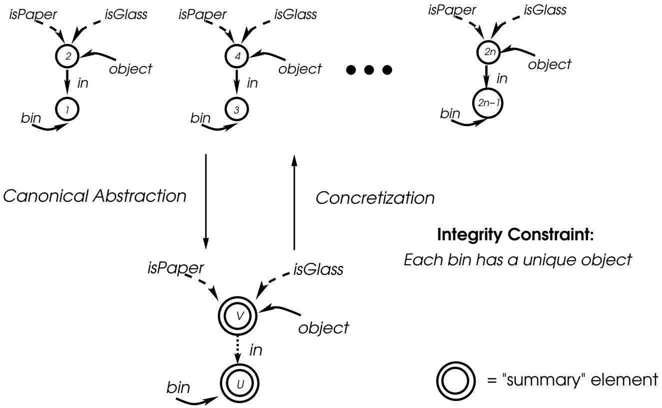


Integrity Constraint:

Objects are either paper or glass

Implementation of "sensing" actions

Abstraction Using 3-Valued Logic



Integrity Constraint:

Each bin has a unique object

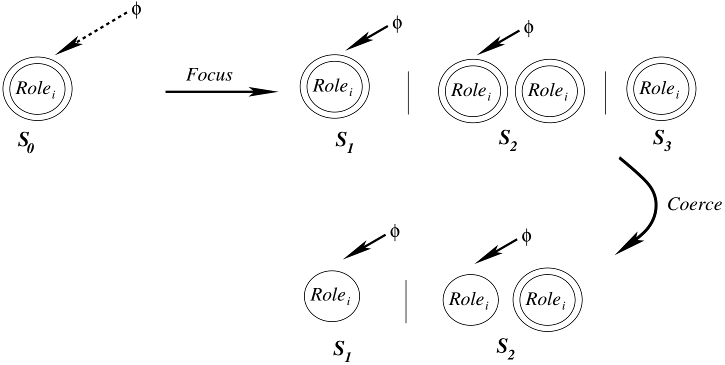
Abstraction Using 3-Valued Logic: Summary

TVLA [Sagiv et al., 2002]: Three Valued Logic Analysis

- Abstraction predicates: unary predicates.
- Element's role = set of abstraction predicates satisfied
- Collapse elements of a role into summary elements.
- Use integrity constraints to retreive concrete states.

Action Application on Belief States

- Make structures precise by creating possible cases: focus (automatic)
- Apply action



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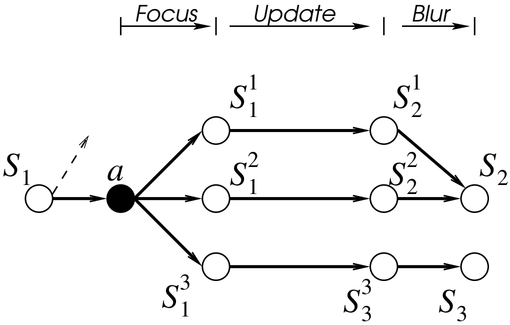
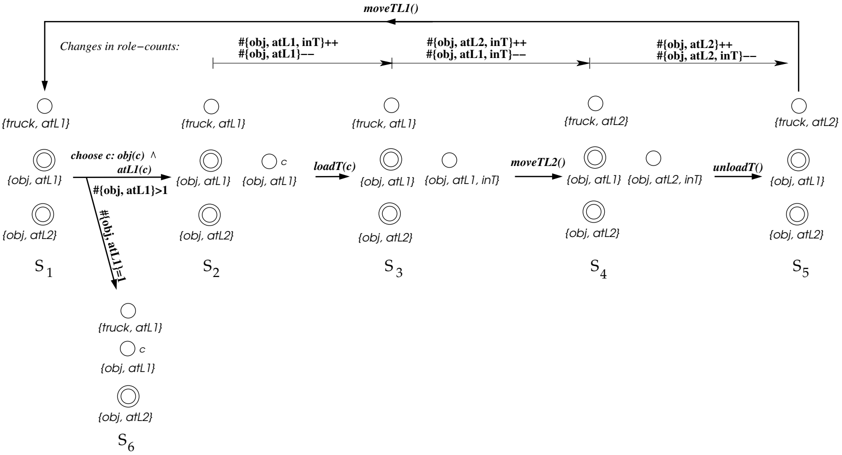
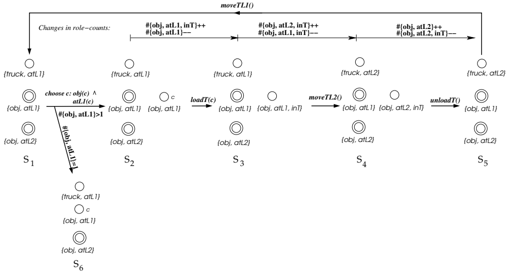


Role-counts, Branches and Plan Preconditions



Role-counts, Branches and Plan Preconditions

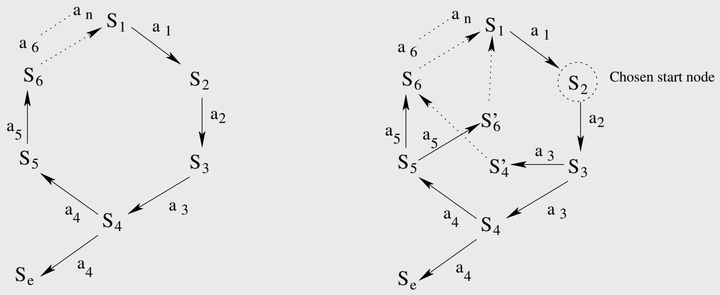


- Goal is provably reachable from the infinitely many structures represented by S_1.
- $\forall s \in S_1$, can compute number of steps required to reach the goal.

Generalized to *extended-LL* domains.

Extension to Complex Loops with Shortcuts

Shortcuts due to sensing actions



(a) A simple loop (b) A simple loop with (non−composable) shortcuts

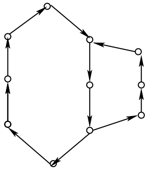
Extension to Nested Loops?

```
for i = 1 to n {
    for j = 1 to k {

    }

}
```

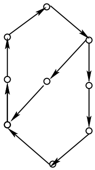
```
for i = 1 to n {

    if (...) {

    }
    if (...) {

    }
}
```

Extension to Nested Loops?

```
for i = 1 to n {
    for j = 1 to k {
        ...
    }
    ...
}
```

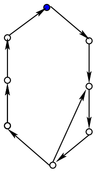


```
for i = 1 to n {
    ...
    if (...) {
        ...
    }
    if (...) {
        ...
    }
}
```

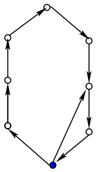


Extension to Nested Loops?

```
for i = 1 to n {
    a1
    for j = 1 to k {
        a2
    }
    a3
}
```



```
i = 1; j = 1
if (i < n+1) { a1 }
for i = 1 to n {
    if (j > k) {
        a3
        i++
        a1
        j = 1
    }
    if (j < k+1) {
        a2
        j++
    }
}
```

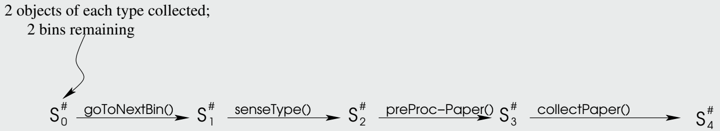


- Execution sequences match.
- Translation of the loop entry point $\implies$ complex loop with a shortcut!
- Methods applicable to many so-called “nested” loops.

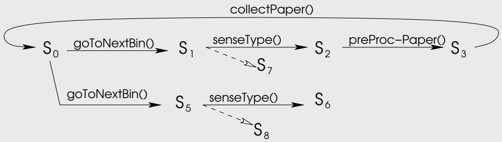
Plan Generalization

Use abstract structures to recognize loop invariants in example concrete plans.

Example Execution



Find Loops



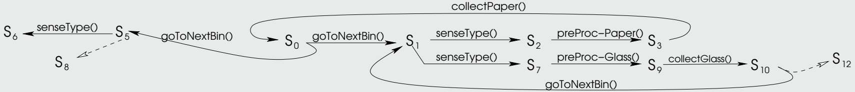
Developed for completely observable settings [Srivastava et al., 2008]

Merging Generalized Plans

Plan for Unhandled Structure

$$S^{\#}_{7} \xrightarrow{\text{preProc-Glass()}} S^{\#}_{9} \xrightarrow{\text{collectGlass()}} S^{\#}_{10} \xrightarrow{\text{goToNextBin()}} S^{\#}_{11} \text{- - - - -}$$

Generalize and Merge

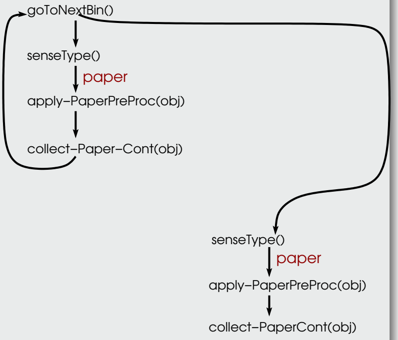


- A single plan may not explore all possibilities.
- Construct problem instances from unsolved belief states.
- Solve them using classical planners.

Example Results

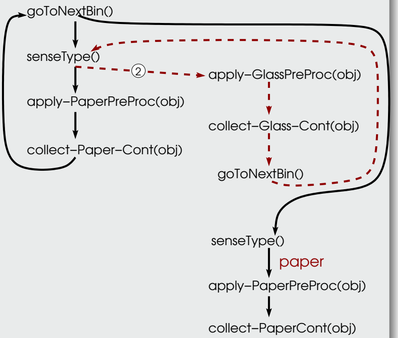
$p_0 = \|\{\text{paper, collected}\}\|; pc_0 = \|\{\text{empty,container,forPaper}\}\|;$
g_0, gc_0 : similar for glass; $b_0 = \|\{\text{bin}\}\|$

Loop 1



- Precons: $pc_0 = l_1; b_0 = l_1$
- Solves 1 out of 2^n

Loops 1 & 2



- Precons:
  $pc_0 = l_1; gc_0 = l_2; b_0 = l_1 + l_2$
- $2^{n-1} + 1$ out of every 2^n

Merging Generalized Plans: Algorithm

Input: Existing plan Π, eg trace trace_i
Output: Extension of Π

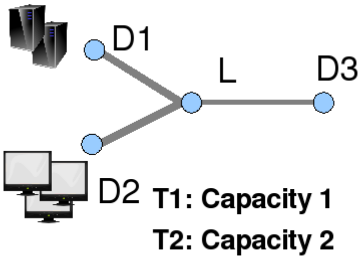
if $\Pi = \emptyset$ **then**
    $\Pi \leftarrow \text{trace}_i$
    return Π
end
$\text{mp}_\Pi, \text{mp}_t \leftarrow$ findMergePoint$(\Pi, \text{trace}_i, \text{bp}_\Pi, \text{bp}_t)$
repeat
    if *mp_Π found* **then**
        $\text{bp}_\Pi, \text{bp}_t \leftarrow$ findBranchPoint$(\Pi, \text{trace}_i, \text{mp}_\Pi, \text{mp}_t)$
    end
    if *bp_Π found* **then**
        $\text{mp}_\Pi, \text{mp}_t \leftarrow$ findMergePoint$(\Pi, \text{trace}_i, \text{bp}_\Pi, \text{bp}_t)$
        addEdges$(\Pi, \text{trace}_i, bp_t, mp_t, mp_\Pi, bp_\Pi)$
    end
until *new bp_Π or mp_Π not found*
return Π

Algorithm 1: ARANDA-Merge

Conclusions

- Approach addressing plan/algorithm synthesis and verification.
  - Advantage of automated synthesis: can choose to keep control structure verifiable.
- Close to program synthesis, but free of associated intractability.
- Efficient precondition tests and measures of progress.

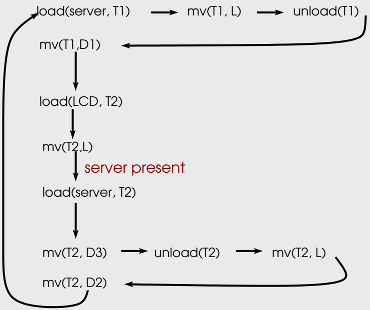
Transport Domain



Transport Domain: Results

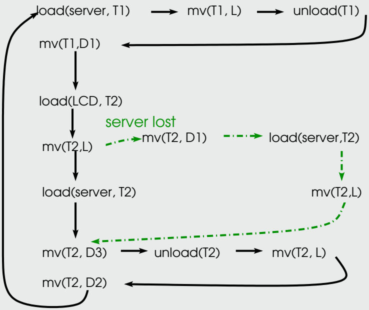
$$m_0 = \|\{\text{monitor, atD2}\}\|; s_0 = \|\{\text{server, atD1}\}\|$$

Loop 1



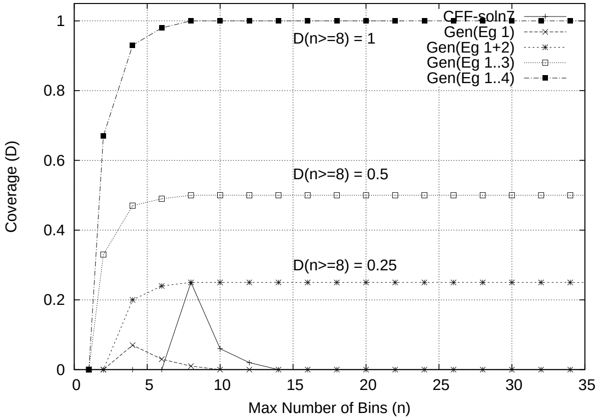
- Precons: $m_o = l_1; s_0 = l_1$

Loops 1 & 2



- Precons:
  $m_0 = l_1; s_o = l_1 + k_1$

Example Results: Domain Coverage



$$D_\pi(n) = |\mathcal{S}_\pi(n)|/|\mathcal{T}(n)|$$

Related Work

- Plans with Loops
  - [Winner and Veloso, 2007]: no preconditions or sensing actions, but use partial ordering.
  - [Levesque, 2005]: single planning parameter, limited preconditions.
  - [Cimatti et al., 2003]: “hard” loops.
- Planning with unknown quantities:
  - [Milch et al., 2005]: action operators not provided.

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