Towards embedded Answer Set Solving

Torsten Schaub

University of Potsdam

Outline

1 Introduction

2 Foundations

3 Modeling

4 Modeling and Controlling

5 Case-study: Ricochet Robots

6 Case-sketch: Preferences and optimization

7 Potassco

8 Summary

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Answer Set Programming (ASP)

- ASP is an approach to declarative problem solving
  - describe the problem, not how to solve it
- ASP allows for solving hard search and optimization problems
  - Systems Biology
  - Product Configuration
  - Linux Package Configuration
  - Robotics
  - Music Composition
  - ...
- All search-problems in NP (and NP^{NP}) are expressible

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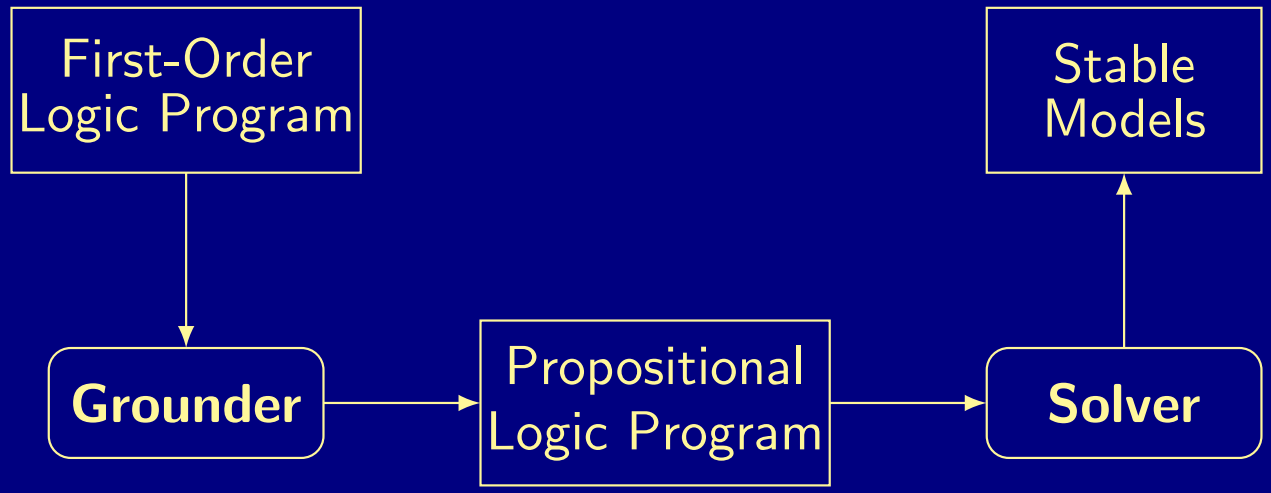
The ASP Solving Process



Expressive modeling language

Powerful grounding and solving tools

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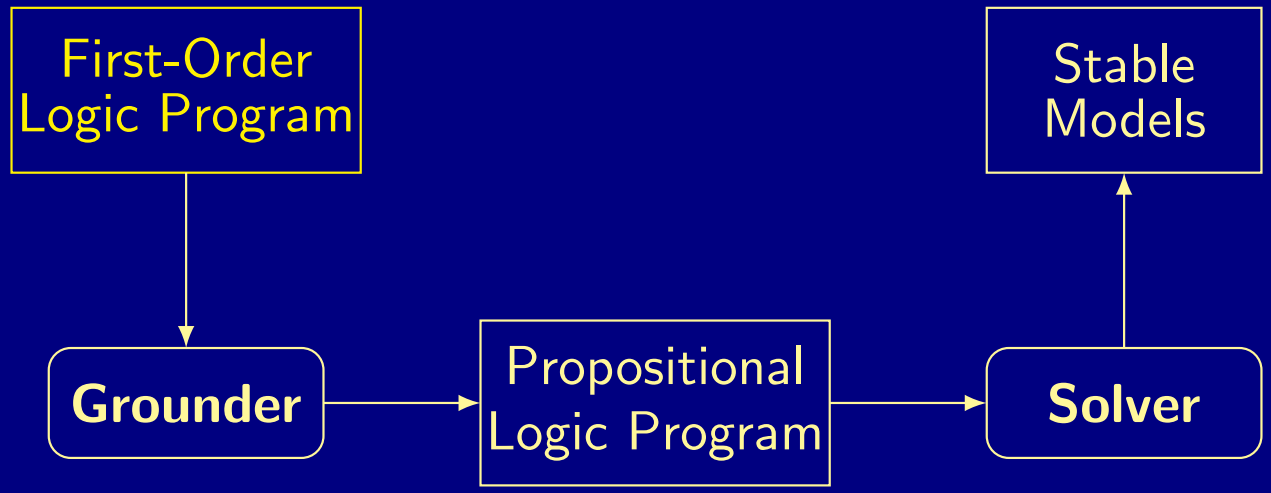

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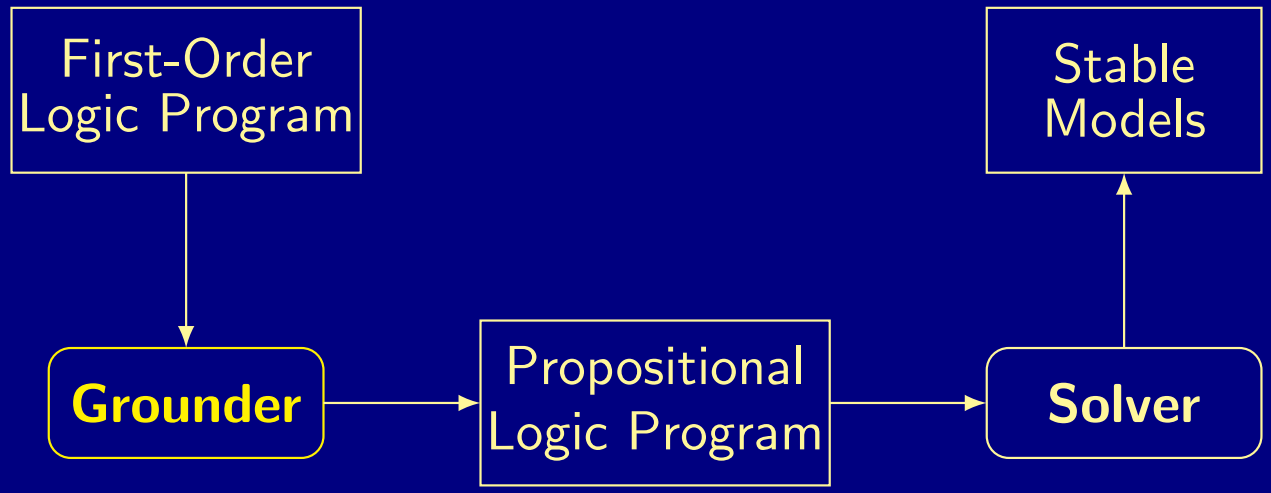

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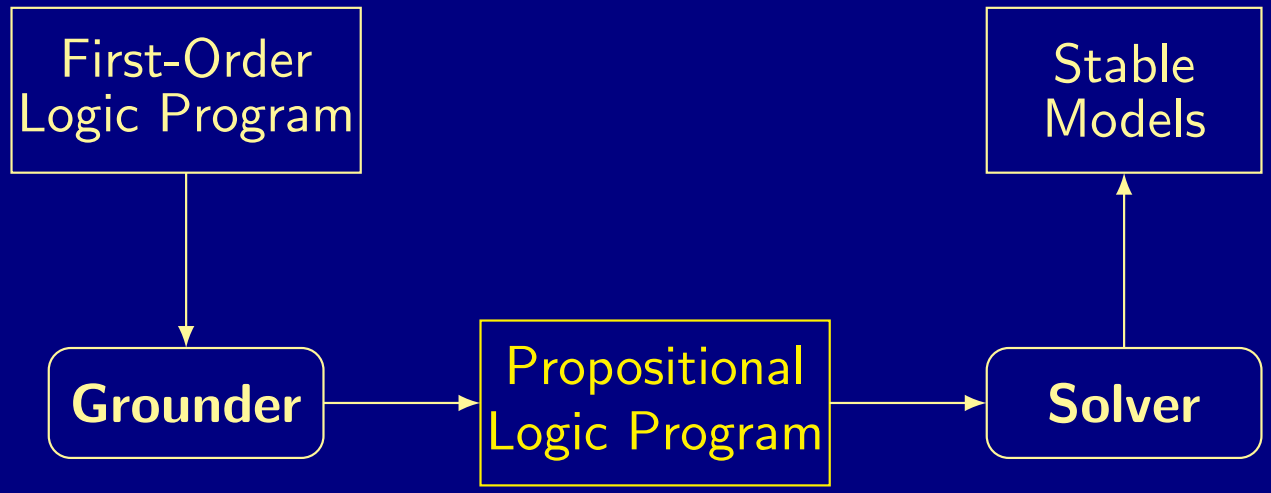

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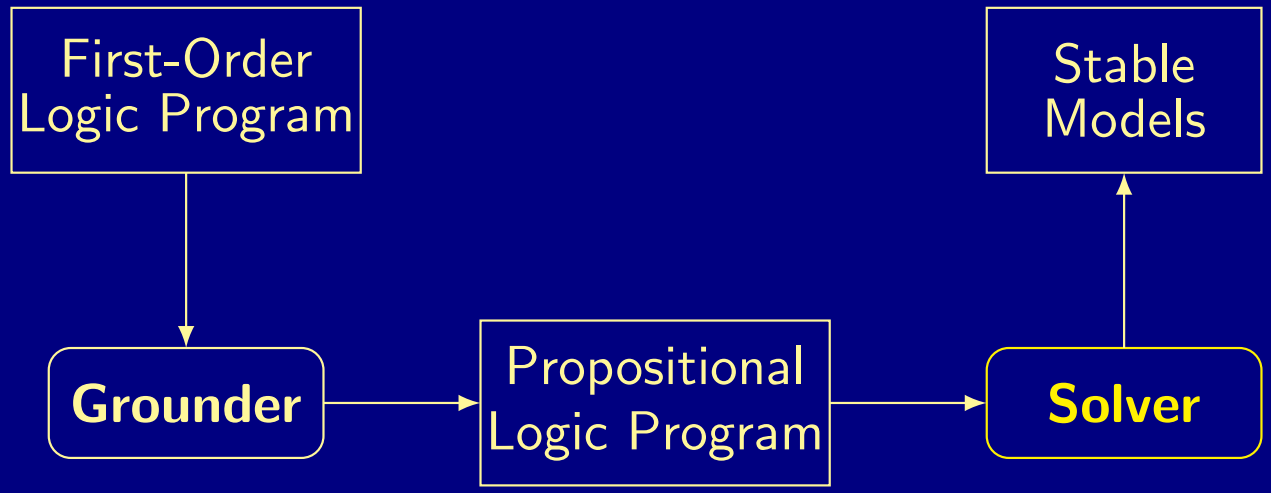

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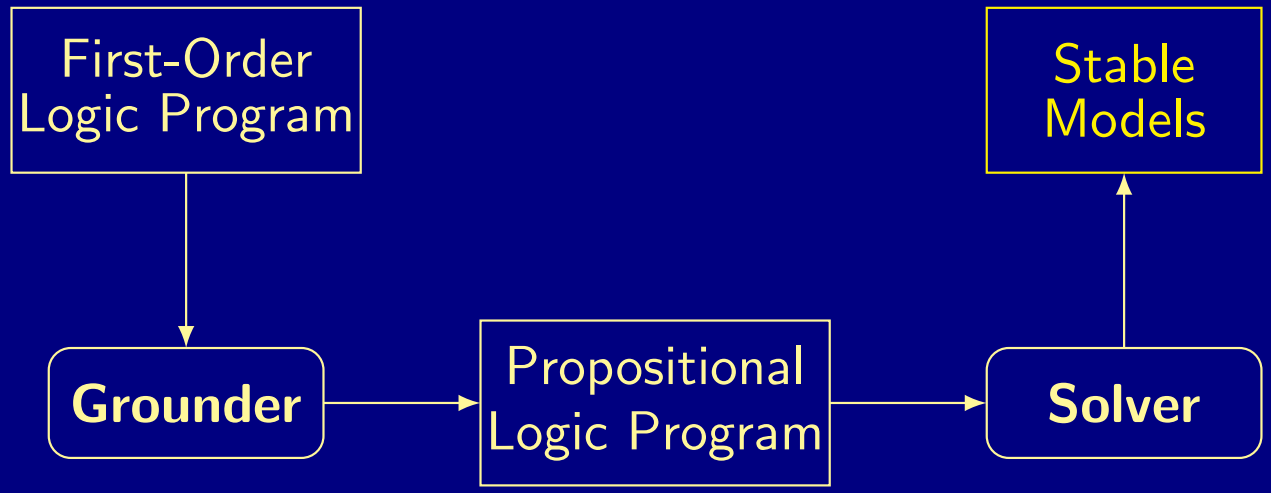

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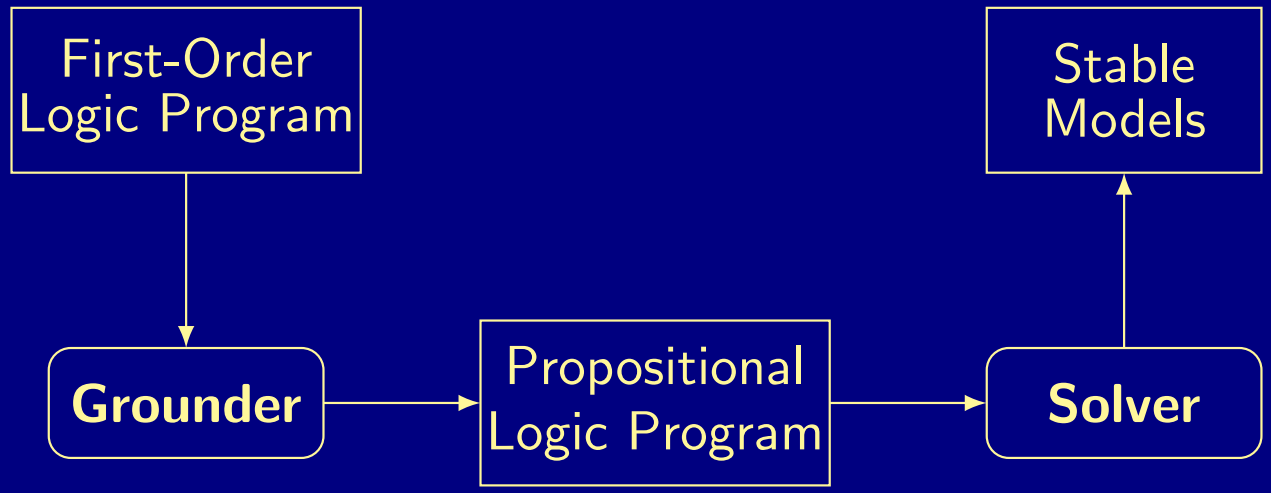

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Propositional Normal Logic Programs

- A logic program Π is a set of rules of the form

$$\underbrace{a}_{\text{head}} \leftarrow \underbrace{b_1, \ldots, b_m, \sim c_1, \ldots, \sim c_n}_{\text{body}}$$

  - a and all b_i, c_j are atoms (propositional variables)
  - $\leftarrow$, ,, $\sim$ denote if, and, and default negation
  - intuitive reading: head must be true if body holds

- Semantics given by stable models, informally, sets X of atoms such that
  - X is a (classical) model of Π and
  - each atom in X is justified by some rule in Π

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Logic Programs

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Logic Programs as Propositional Formulas

$$\Pi = \{a \leftarrow \sim b \quad b \leftarrow \sim a \quad x \leftarrow a, \sim c \quad x \leftarrow y \quad y \leftarrow x, b\}$$

$$CF(\Pi) = \{a \leftarrow \neg b \quad b \leftarrow \neg a \quad x \leftarrow (a \wedge \neg c) \vee y \quad y \leftarrow x \wedge b\} \cup \{c \leftrightarrow \bot\}$$

$$LF(\Pi) = \{(x \vee y) \rightarrow a \wedge \neg c\}$$

Classical models of $CF(\Pi)$:

$\{b\}$, $\{b, c\}$, $\{b, x, y\}$, $\{b, c, x, y\}$, $\{a, c\}$, $\{a, b, c\}$, $\{a, x\}$, $\{a, c, x\}$, $\{a, x, y\}$, $\{a, c, x, y\}$, $\{a, b, x, y\}$, $\{a, b, c, x, y\}$

- Unsupported atoms
- Unfounded atoms

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Logic Programs as Propositional Formulas

$$\Pi = \{a \leftarrow \sim b \quad b \leftarrow \sim a \quad x \leftarrow a, \sim c \quad x \leftarrow y \quad y \leftarrow x, b\}$$

$$RF(\Pi) = \{a \leftarrow \neg b \quad b \leftarrow \neg a \quad x \leftarrow (a \wedge \neg c) \vee y \quad y \leftarrow x \wedge b\}$$
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Classical models of $RF(\Pi)$: (only true atoms shown)

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Classical models of $CF(\Pi) \cup LF(\Pi)$:

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Logic Programs as Propositional Formulas

$$\Pi = \{a \leftarrow \sim b \quad b \leftarrow \sim a \quad x \leftarrow a, \sim c \quad x \leftarrow y \quad y \leftarrow x, b\}$$

$$CF(\Pi) = \{a \leftrightarrow (\bigvee_{(a \leftarrow B) \in \Pi} BF(B)) \mid a \in atom(\Pi)\}$$

$$BF(B) = \bigwedge_{b \in B \cap atom(\Pi)} b \wedge \bigwedge_{\sim c \in B} \neg c$$

$$LF(\Pi) = \{(\bigvee_{a \in L} a) \rightarrow (\bigvee_{a \in L, (a \leftarrow B) \in \Pi, B \cap L = \emptyset} BF(B)) \mid L \in loop(\Pi)\}$$

Classical models of $CF(\Pi) \cup LF(\Pi)$:

Theorem (Lin and Zhao)

Let Π be a normal logic program and $X \subseteq atom(\Pi)$.
Then, X is a stable model of Π iff $X \models CF(\Pi) \cup LF(\Pi)$.

- Size of $CF(\Pi)$ is linear in the size of Π
- Size of $LF(\Pi)$ may be exponential in the size of Π

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Some language constructs

- Variables
  - `p(X) :- q(X)` over constants $\{\texttt{a}, \texttt{b}, \texttt{c}\}$ stands for
    `p(a) :- q(a), p(b) :- q(b), p(c) :- q(c)`
- Conditional Literals
  - `p :- q(X) : r(X)` given `r(a), r(b), r(c)` stands for
    `p :- q(a), q(b), q(c)`
- Disjunction
  - `p(X) ; q(X) :- r(X)`
- Integrity Constraints
  - `:- q(X), p(X)`
- Choice
  - `2 { p(X,Y) : q(X) } 7 :- r(Y)`
- Aggregates
  - `s(Y) :- r(Y), 2 #sum { X : p(X,Y), q(Y) } 7`

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Basic methodology

Methodology

Generate and Test (or: Guess and Check)

Generator: Generate potential stable model candidates (typically through non-deterministic constructs)

Tester: Eliminate invalid candidates (typically through integrity constraints)

Peanutshell

Logic program = Data + Generator + Tester (+ Optimizer)

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Satisfiability testing

$(a \leftrightarrow b) \wedge c$

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$(a \leftrightarrow b) \wedge c$

```
{ a ; b ; c }.

 :- not a, b.
 :- a, not b.
 :- not c.
```

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Maximum satisfiability testing

"$(a \not\leftrightarrow b)$" $+ (a \leftrightarrow b) \wedge c$

```
{ a ; b ; c }.

 :- not a, b.
 :- a, not b.
 :- not c.

 :~ a, b. [42@1]
 :~ not a, not b. [69@2]
```

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n-queens
Basic encoding

```
{ queen(1..n,1..n) }.

 :- { queen(I,J) } != n.
 :- queen(I,J), queen(I,JJ), J != JJ.
 :- queen(I,J), queen(II,J), I != II.
 :- queen(I,J), queen(II,JJ), (I,J) != (II,JJ), I-J = II-JJ.
 :- queen(I,J), queen(II,JJ), (I,J) != (II,JJ), I+J = II+JJ.
```

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n-queens

Advanced encoding

```
{ queen(I,1..n) } = 1 :- I = 1..n.
{ queen(1..n,J) } = 1 :- J = 1..n.

 :- { queen(D-J,J) } >= 2, D =   2..2*n.
 :- { queen(D+J,J) } >= 2, D = 1-n..n-1.
```

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n-queens

(Experimental) constraint encoding

```
1 $<= $queen(1..n) $<= n.

#disjoint { X : $queen(X) $+ 0 : X=1..n }.
#disjoint { X : $queen(X) $+ X : X=1..n }.
#disjoint { X : $queen(X) $- X : X=1..n }.
```

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Traveling salesperson
Basic encoding (no instance)

```
1 { cycle(X,Y) : edge(X,Y) } 1 :- node(X).
1 { cycle(X,Y) : edge(X,Y) } 1 :- node(Y).

reached(X) :- X = #min { Y : node(Y) }.
reached(Y) :- cycle(X,Y), reached(X).

:- node(Y), not reached(Y).

#minimize { C,X,Y : cycle(X,Y), cost(X,Y,C) }.
```

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Company Controls

```
controls(X,Y) :-
        #sum+ { S: owns(X,Y,S);
                S,Z: controls(X,Z), owns(Z,Y,S) } > 50,
        company(X), company(Y), X != Y.


company(c_1).    owns(c_1,c_2,60).
                 owns(c_1,c_3,20).
company(c_2).    owns(c_2,c_3,35).
company(c_3).    owns(c_3,c_4,51).
company(c_4).
```

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From One- to Multi-shot ASP solving

- Claim ASP is an under-the-hood technology

  That is, in practice, it mainly serves as a solving engine within an encompassing software environment

- Single-shot solving: *ground* | *solve*

  Multi-shot solving: *ground* | *solve*

  ➥ **continuously changing logic programs**

Agents, Assisted Living, Robotics, Planning, Query-answering, etc

clingo 4 — providing operative solving processes dealing with continously changing logic programs

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Clingo = ASP + Control

- ASP

```
#program <name> [ (<parameters>) ]
          #program play(t).
#external <atom> [ :  <body> ]
          #external mark(X,Y,P,t) :  field(X,Y), player(P).
```

- Control

Lua (www.lua.org)

```
          prg:solve(), prg:ground(parts), ...
```

Python (www.python.org)

```
          prg.solve(), prg.ground(parts), ...
```

- Integration

in ASP: embedded scripting language (#script)
in Lua/Python: library import (import gringo)

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    `prg.solve(), prg.ground(parts), ...`
- Integration
  - in ASP: embedded scripting language (`#script`)
  - in Lua/Python: library import (`import gringo`)

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Clingo = ASP + Control

- ASP
  - `#program <name> [ (<parameters>) ]`
    - Example `#program play(t).`
  - `#external <atom> [ : <body> ]`
    - Example `#external mark(X,Y,P,t) : field(X,Y), player(P).`
- Control
  - Lua (`www.lua.org`)
    - Example `prg:solve(), prg:ground(parts), ...`
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Vanilla *Clingo*

- Emulating *Clingo* in *Clingo* 4

```
#script (python)
def main(prg):
    parts = []
    parts.append(("base", []))
    prg.ground(parts)
    prg.solve()
#end.
```

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Vanilla *Clingo*

- Emulating *Clingo* in *Clingo* 4

```
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Potassco

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```

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Towers of Hanoi Instance

- Emulating *iClingo* (an incremental ASP solver) in *Clingo* 4
  - Incremental grounding
  - Incremental solving

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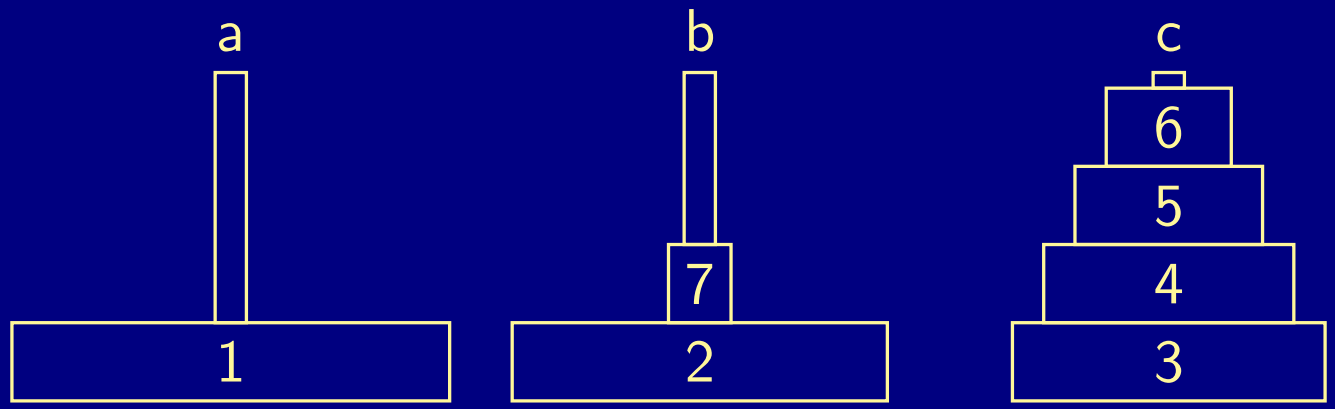
Towers of Hanoi Instance




```
peg(a;b;c).
init_on(1,a).
init_on((2;7),b).
init_on((3;4;5;6),c).
```

```
disk(1..7).

goal_on((3;4),a).
goal_on((1;2;5;6;7),c).
```

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Towers of Hanoi Encoding (base)

```
#program base.

on(D,P,0) :- init_on(D,P).
```

Towers of Hanoi Encoding (cumulative)

```
#program cumulative(t).

1 { move(D,P,t) : disk(D), peg(P) } 1.

moved(D,t) :- move(D,_,t).
blocked(D,P,t) :- on(D+1,P,t-1), disk(D).
blocked(D,P,t) :- blocked(D+1,P,t), disk(D).
:- move(D,P,t), blocked(D-1,P,t).
:- moved(D,t), on(D,P,t-1), blocked(D,P,t).

on(D,P,t) :- on(D,P,t-1), not moved(D,t).
on(D,P,t) :- move(D,P,t).
:- not 1 { on(D,P,t) : peg(P) } 1, disk(D).
```

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Towers of Hanoi Encoding (volatile)

```
#program volatile(t).
#external query(t).

:- goal_on(D,P), not on(D,P,t), query(t).
```

Exercising control

An `#external atom` can be controlled from Python (or Lua) via

- `assign_external(self,atom,value)`
  where `value` is either `True`, `False`, or `None`
- `release_external(self,atom)`
  sets `atom` permanently to `False`

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Towers of Hanoi Encoding (volatile)

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#external query(t).

:- goal_on(D,P), not on(D,P,t), query(t).
```

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  sets `atom` permanently to `False`

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Incremental Solving (embedded)

```
#script (python)

from gringo import SolveResult, Fun

def main(prg):
    ret, parts, step = SolveResult.UNSAT, [], 1
    parts.append(("base", []))
    while ret == SolveResult.UNSAT:
        parts.append(("cumulative", [step]))
        parts.append(("volatile", [step]))
        prg.ground(parts)
        prg.release_external(Fun("query", [step-1]))
        prg.assign_external(Fun("query", [step]), True)
        ret, parts, step = prg.solve(), [], step+1

#end.
```

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Incremental Solving (library)

```
from sys import stdout
from gringo import SolveResult, Fun, Control

prg = Control()
prg.load("toh.lp")

ret, parts, step = SolveResult.UNSAT, [], 1
parts.append(("base", []))
while ret == SolveResult.UNSAT:
    parts.append(("cumulative", [step]))
    parts.append(("volatile", [step]))
    prg.ground(parts)
    prg.release_external(Fun("query", [step-1]))
    prg.assign_external(Fun("query", [step]), True)
    f = lambda m: stdout.write(str(m))
    ret, parts, step = prg.solve(on_model=f), [], step+1
```

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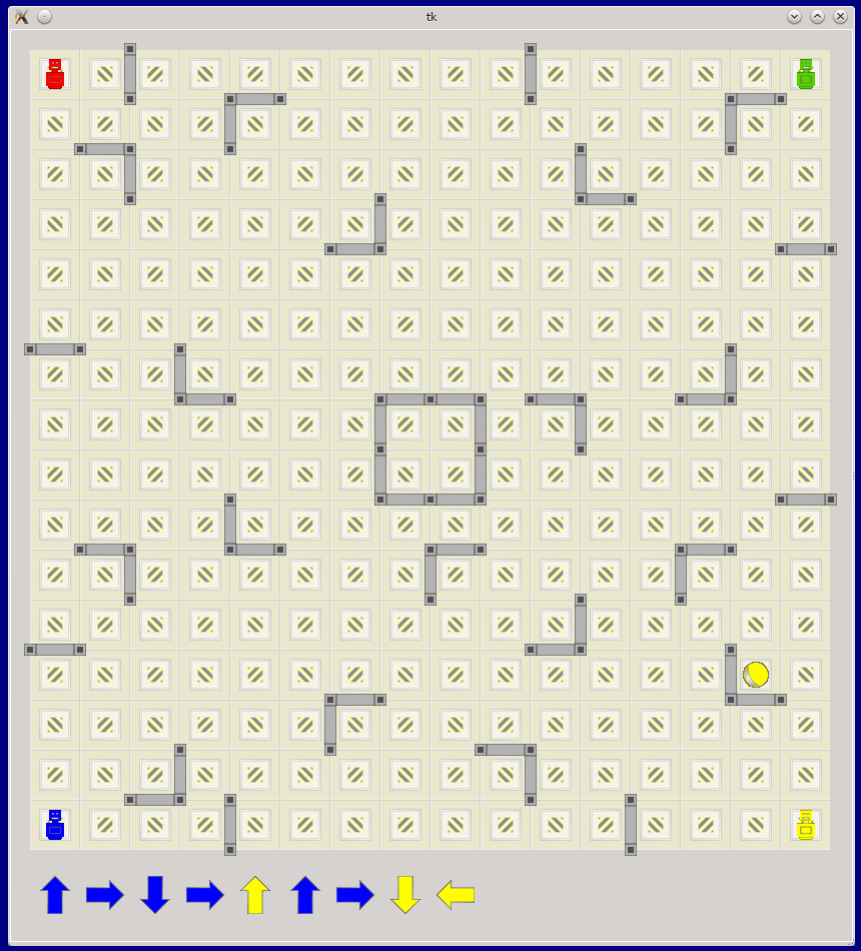
Outline

1 Introduction
2 Foundations
3 Modeling
4 Modeling and Controlling
5 Case-study: Ricochet Robots
6 Case-sketch: Preferences and optimization
7 Potassco
8 Summary

Potassco

Alex Rudolph's Ricochet Robots

Solving goal(13) from cornered robots



- Four robots roaming
  - horizontally
  - vertically

  up to blocking objects, ricocheting (optionally)
- Goal Robot on target (sharing same color)

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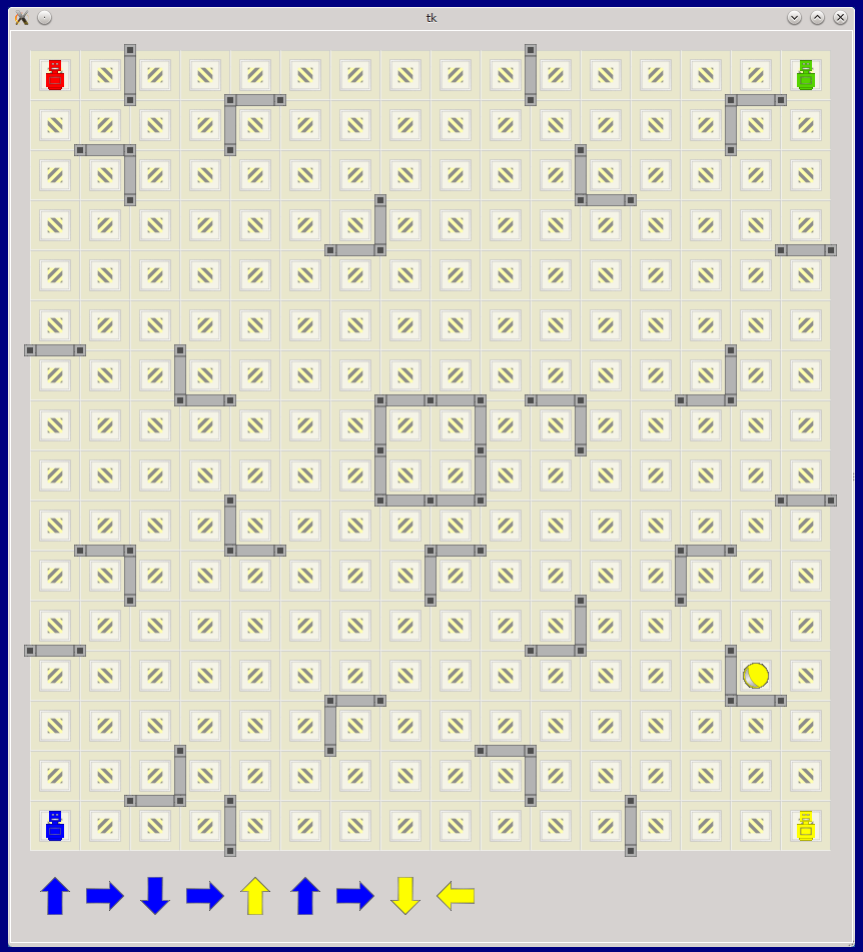
Alex Rudolph's Ricochet Robots

Solving `goal(13)` from cornered robots



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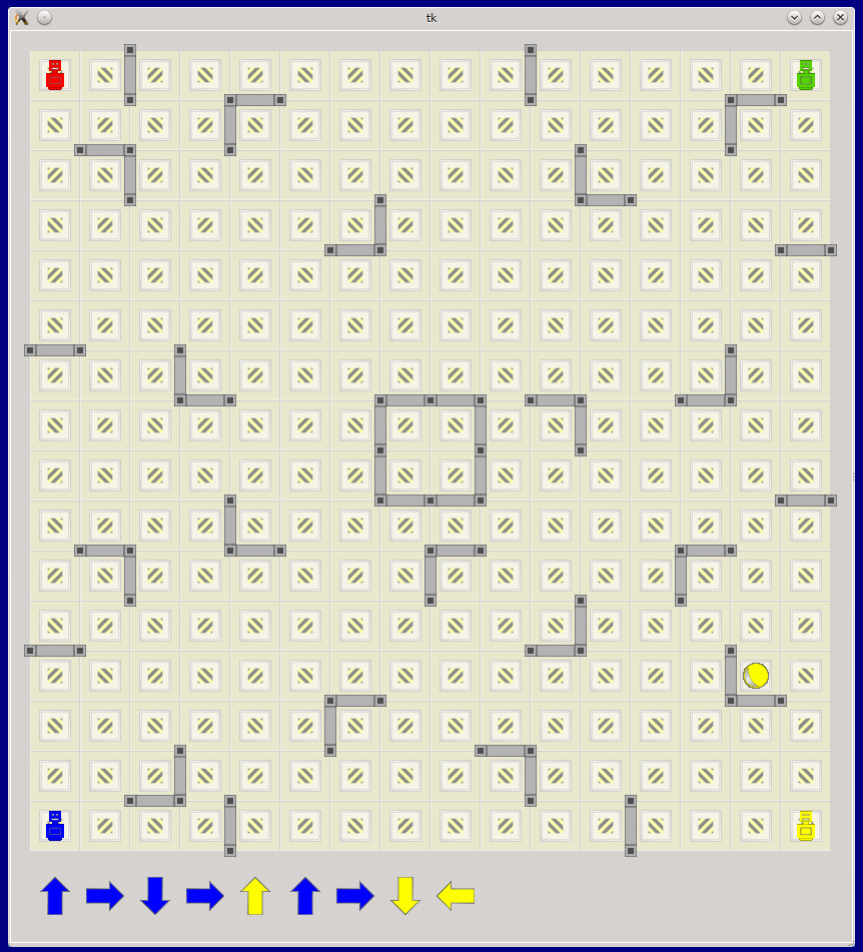

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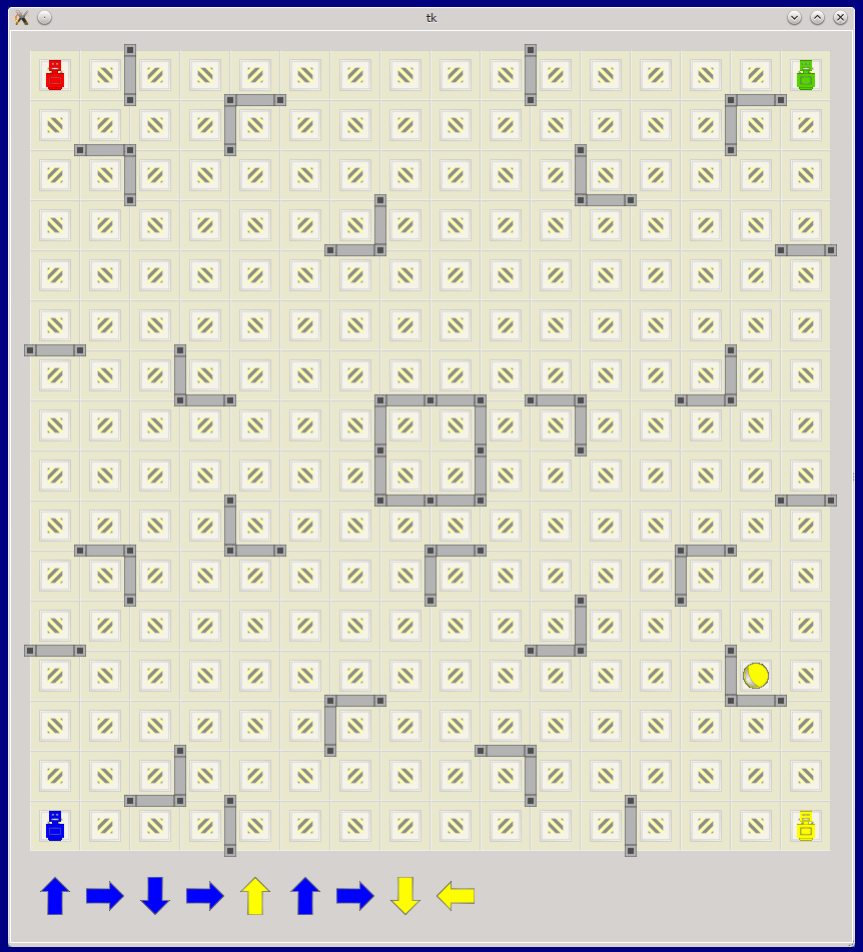

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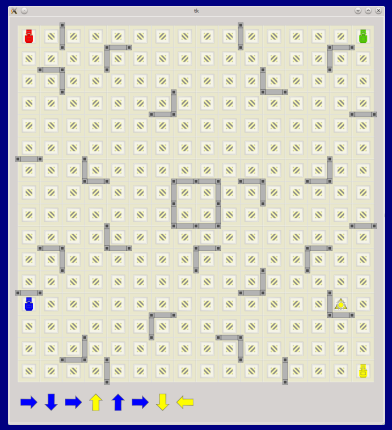
Solving `goal(13)` from cornered robots (ctd)



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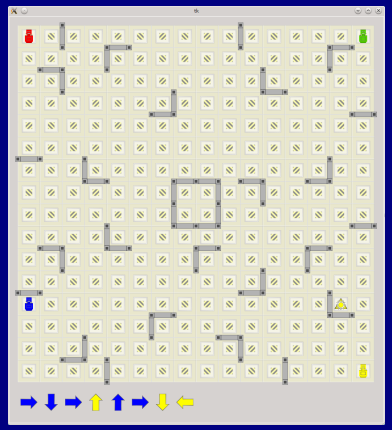

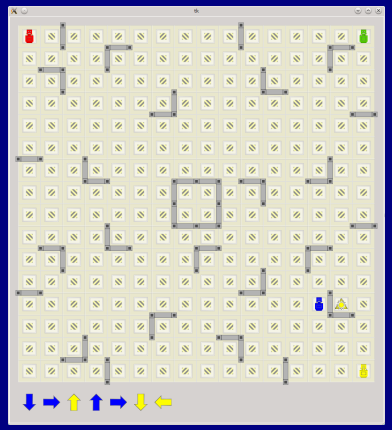

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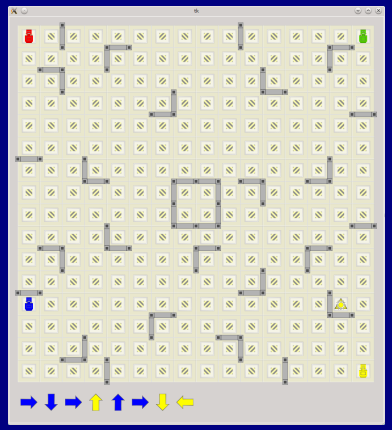
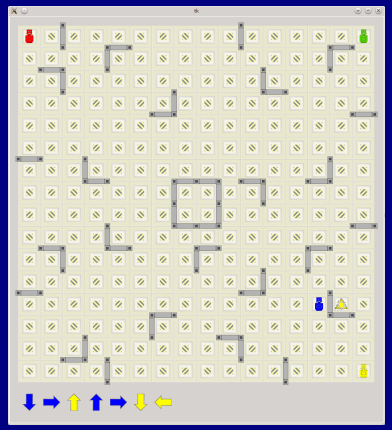
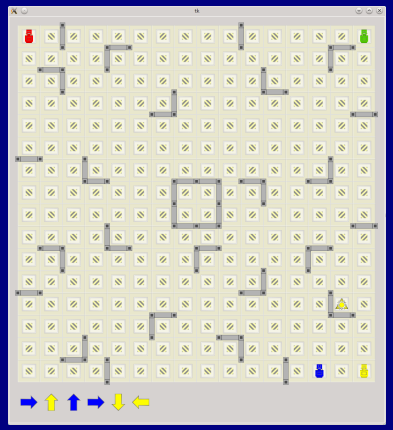

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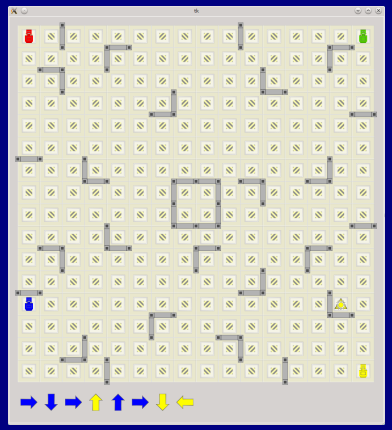
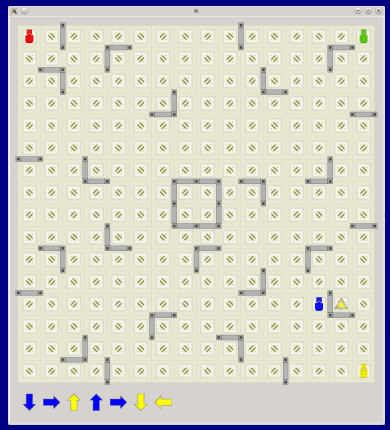
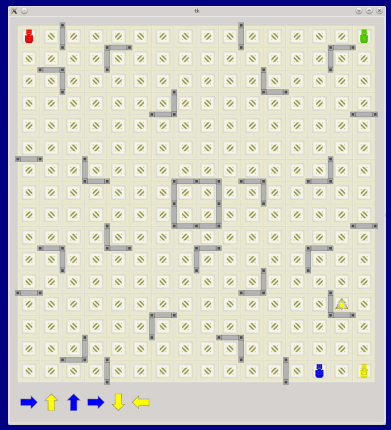
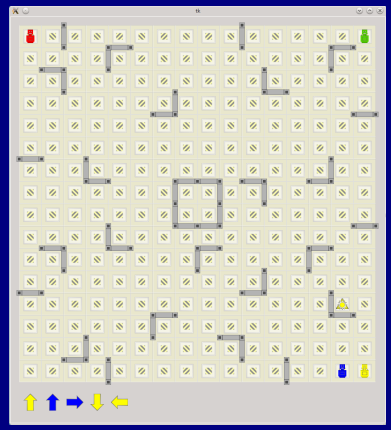

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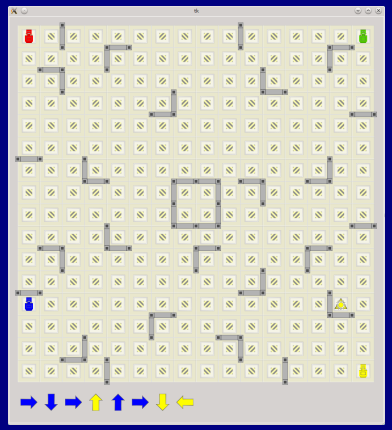
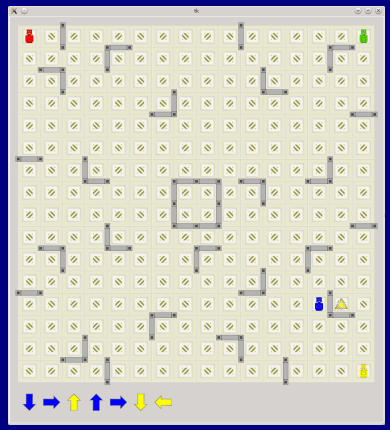
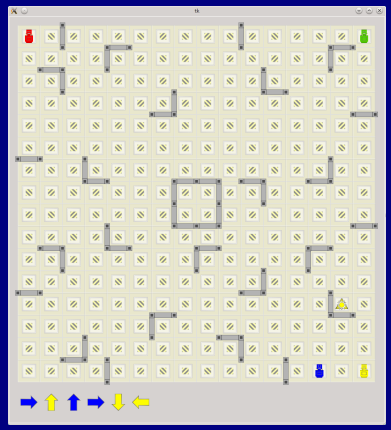
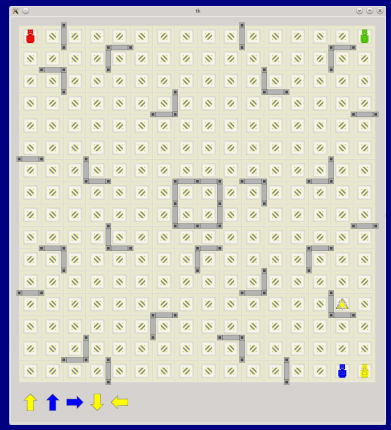
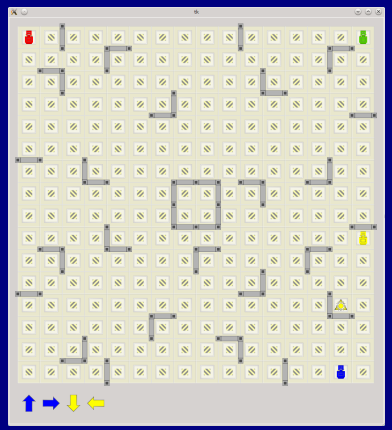

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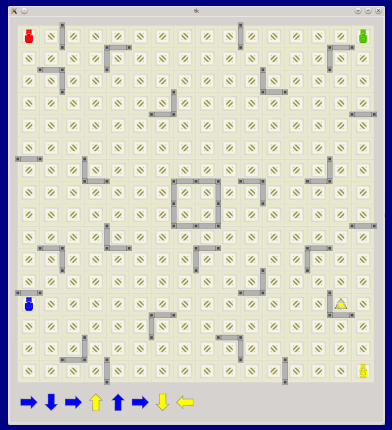
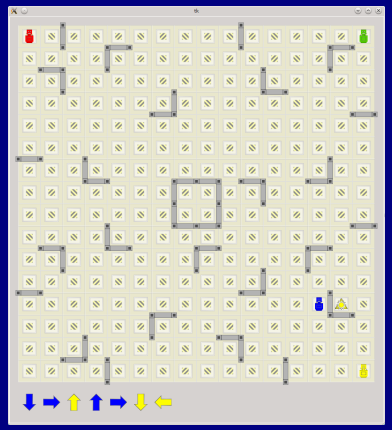
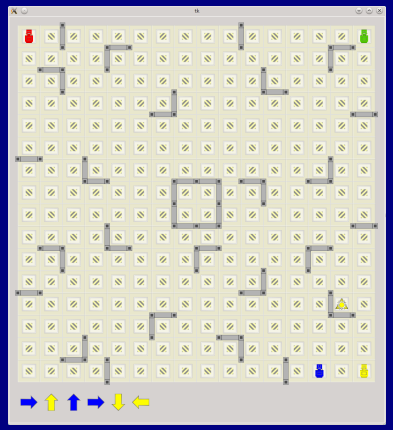
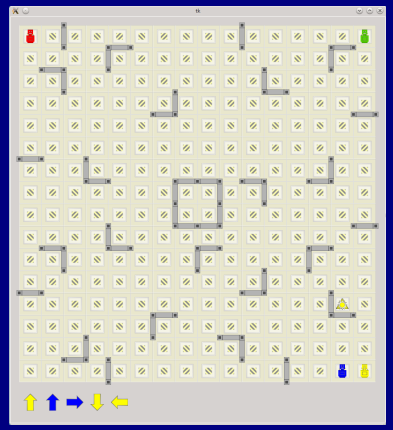
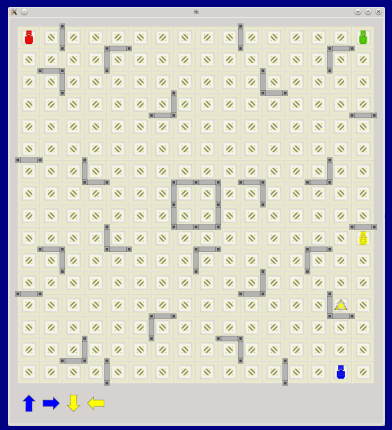
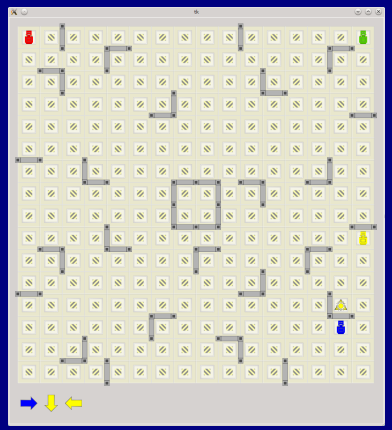
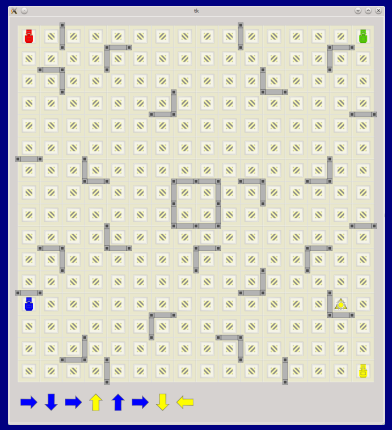
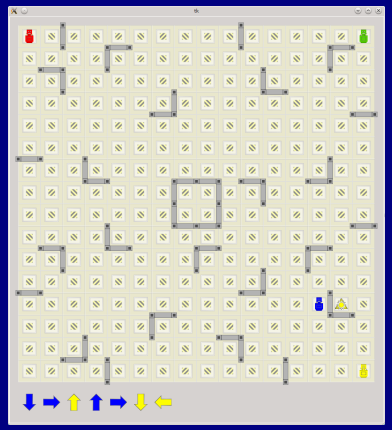
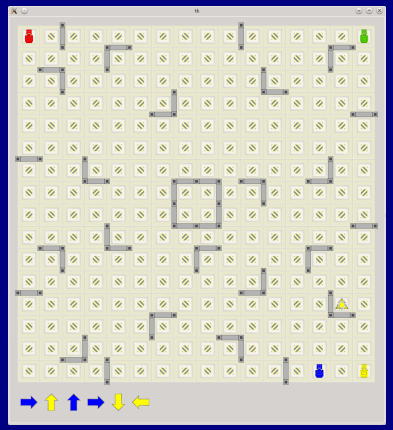
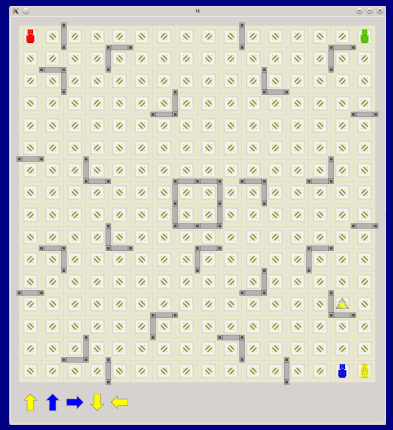
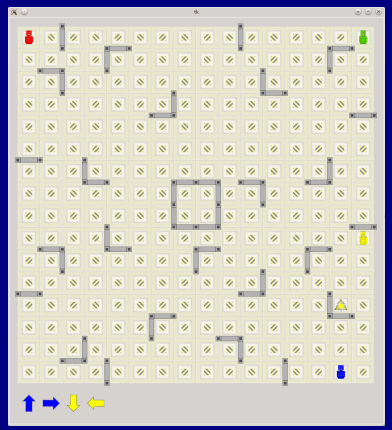
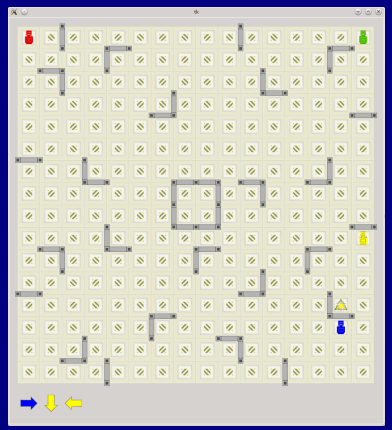
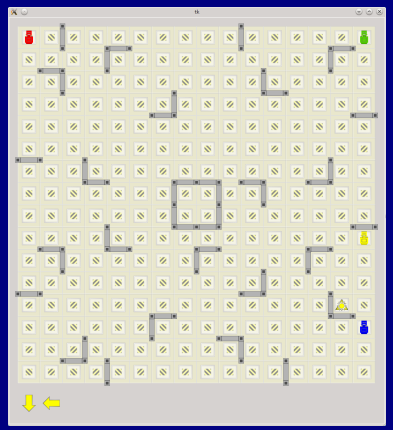
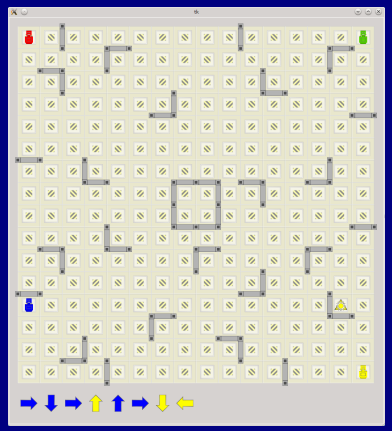
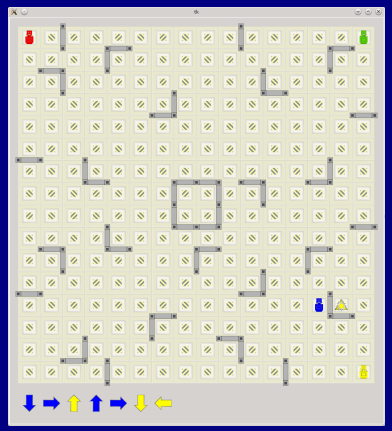
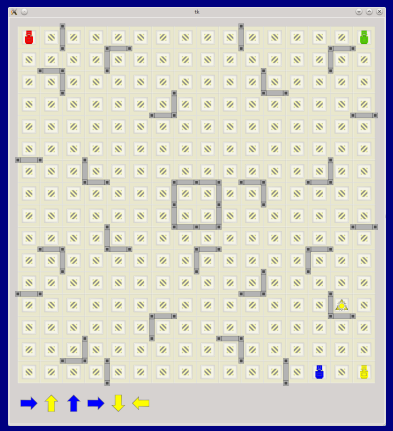
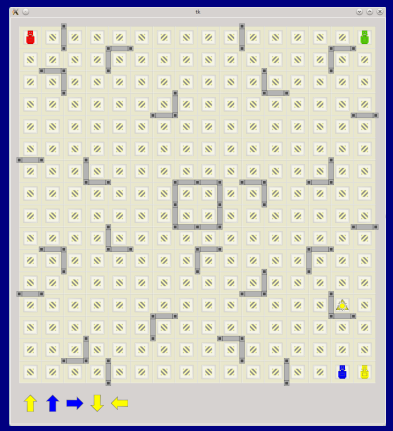
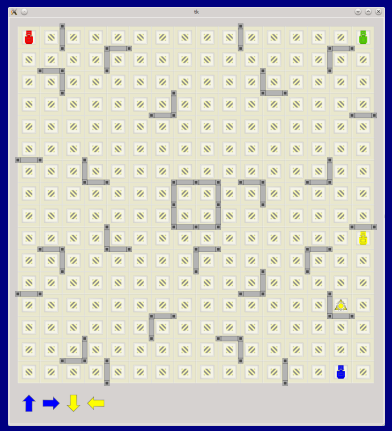
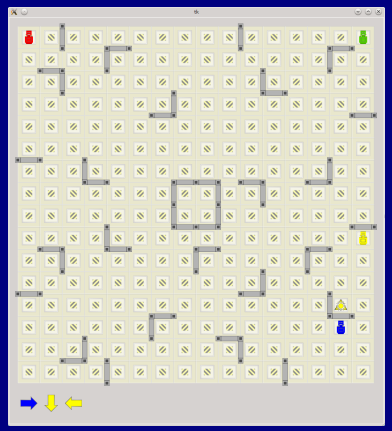
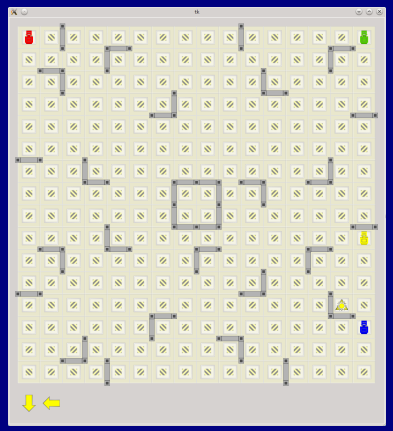
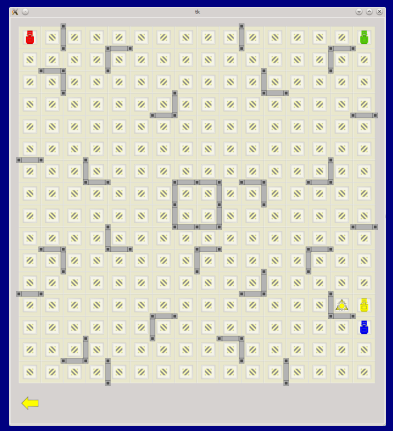







Solving `goal(13)` from cornered robots (ctd)

Solving `goal(13)` from cornered robots (ctd)

Potassco

board.lp

```
dim(1..16).

barrier( 2, 1, 1, 0).  barrier(13,11, 1, 0).  barrier( 9, 7, 0, 1).
barrier(10, 1, 1, 0).  barrier(11,12, 1, 0).  barrier(11, 7, 0, 1).
barrier( 4, 2, 1, 0).  barrier(14,13, 1, 0).  barrier(14, 7, 0, 1).
barrier(14, 2, 1, 0).  barrier( 6,14, 1, 0).  barrier(16, 9, 0, 1).
barrier( 2, 3, 1, 0).  barrier( 3,15, 1, 0).  barrier( 2,10, 0, 1).
barrier(11, 3, 1, 0).  barrier(10,15, 1, 0).  barrier( 5,10, 0, 1).
barrier( 7, 4, 1, 0).  barrier( 4,16, 1, 0).  barrier( 8,10, 0,-1).
barrier( 3, 7, 1, 0).  barrier(12,16, 1, 0).  barrier( 9,10, 0,-1).
barrier(14, 7, 1, 0).  barrier( 5, 1, 0, 1).  barrier( 9,10, 0, 1).
barrier( 7, 8, 1, 0).  barrier(15, 1, 0, 1).  barrier(14,10, 0, 1).
barrier(10, 8,-1, 0).  barrier( 2, 2, 0, 1).  barrier( 1,12, 0, 1).
barrier(11, 8, 1, 0).  barrier(12, 3, 0, 1).  barrier(11,12, 0, 1).
barrier( 7, 9, 1, 0).  barrier( 7, 4, 0, 1).  barrier( 7,13, 0, 1).
barrier(10, 9,-1, 0).  barrier(16, 4, 0, 1).  barrier(15,13, 0, 1).
barrier( 4,10, 1, 0).  barrier( 1, 6, 0, 1).  barrier(10,14, 0, 1).
barrier( 2,11, 1, 0).  barrier( 4, 7, 0, 1).  barrier( 3,15, 0, 1).
barrier( 8,11, 1, 0).  barrier( 8, 7, 0, 1).
```

Potassco

targets.lp

```
#external goal(1..16).

target(red,    5, 2) :- goal(1).
target(red,   15, 2) :- goal(2).
target(green,  2, 3) :- goal(3).
target(blue,  12, 3) :- goal(4).
target(yellow, 7, 4) :- goal(5).
target(blue,   4, 7) :- goal(6).
target(green, 14, 7) :- goal(7).
target(yellow,11, 8) :- goal(8).
target(yellow, 5,10) :- goal(9).
target(green,  2,11) :- goal(10).
target(red,   14,11) :- goal(11).
target(green, 11,12) :- goal(12).
target(yellow,15,13) :- goal(13).
target(blue,   7,14) :- goal(14).
target(red,    3,15) :- goal(15).
target(blue,  10,15) :- goal(16).

robot(red;green;blue;yellow).
#external pos((red;green;blue;yellow),1..16,1..16).
```

Potassco

ricochet.lp

```
time(1..horizon).
dir(-1,0;1,0;0,-1;0,1).

stop( DX, DY,X,   Y   ) :- barrier(X,Y,DX,DY).
stop(-DX,-DY,X+DX,Y+DY) :- stop(DX,DY,X,Y).

pos(R,X,Y,0) :- pos(R,X,Y).

1 { move(R,DX,DY,T) : robot(R), dir(DX,DY) } 1 :- time(T).
move(R,T) :- move(R,_,_,T).

halt(DX,DY,X-DX,Y-DY,T) :- pos(_,X,Y,T), dir(DX,DY), dim(X-DX), dim(Y-DY),
                           not stop(-DX,-DY,X,Y), T < horizon.

goto(R,DX,DY,X,Y,T) :- pos(R,X,Y,T), dir(DX,DY), T < horizon.
goto(R,DX,DY,X+DX,Y+DY,T) :- goto(R,DX,DY,X,Y,T), dim(X+DX), dim(Y+DY),
                         not stop(DX,DY,X,Y), not halt(DX,DY,X,Y,T).

pos(R,X,Y,T) :- move(R,DX,DY,T), goto(R,DX,DY,X,Y,T-1),
                not goto(R,DX,DY,X+DX,Y+DY,T-1).
pos(R,X,Y,T) :- pos(R,X,Y,T-1), time(T), not move(R,T).

:- target(R,X,Y), not pos(R,X,Y,horizon).

#show move/4.
```

Potassco

Solving `goal(13)` from cornered robots

```
$ clingo board.lp targets.lp ricochet.lp -c horizon=9 \
       <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")

clingo version 4.5.0
Reading from board.lp ...
Solving...
Answer: 1
move(red,0,1,1)     move(red,1,0,2) move(red,0,1,3)    move(red,-1,0,4) move(red,0,1,5) \
move(yellow,0,-1,6) move(red,1,0,7) move(yellow,0,1,8) move(yellow,-1,0,9)
SATISFIABLE

Models       : 1+
Calls        : 1
Time         : 1.895s (Solving: 1.45s 1st Model: 1.45s Unsat: 0.00s)
CPU Time     : 1.880s


$ clingo board.lp targets.lp ricochet.lp -c horizon=8 \
       <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")

clingo version 4.5.0
Reading from board.lp ...
Solving...
UNSATISFIABLE

Models       : 0
Calls        : 1
Time         : 2.817s (Solving: 2.41s 1st Model: 0.00s Unsat: 2.41s)
CPU Time     : 2.800s
```

Potassco

Solving `goal(13)` from cornered robots

```
$ clingo board.lp targets.lp ricochet.lp -c horizon=9 \
       <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")

clingo version 4.5.0
Reading from board.lp ...
Solving...
Answer: 1
move(red,0,1,1)     move(red,1,0,2) move(red,0,1,3)    move(red,-1,0,4) move(red,0,1,5) \
move(yellow,0,-1,6) move(red,1,0,7) move(yellow,0,1,8) move(yellow,-1,0,9)
SATISFIABLE

Models       : 1+
Calls        : 1
Time         : 1.895s (Solving: 1.45s 1st Model: 1.45s Unsat: 0.00s)
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$ clingo board.lp targets.lp ricochet.lp -c horizon=8 \
       <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")

clingo version 4.5.0
Reading from board.lp ...
Solving...
UNSATISFIABLE

Models       : 0
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Potassco

Solving `goal(13)` from cornered robots

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$ clingo board.lp targets.lp ricochet.lp -c horizon=9 \
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clingo version 4.5.0
Reading from board.lp ...
Solving...
Answer: 1
move(red,0,1,1)     move(red,1,0,2) move(red,0,1,3)    move(red,-1,0,4) move(red,0,1,5) \
move(yellow,0,-1,6) move(red,1,0,7) move(yellow,0,1,8) move(yellow,-1,0,9)
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Reading from board.lp ...
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UNSATISFIABLE

Models       : 0
Calls        : 1
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Potassco

Solving `goal(13)` from cornered robots

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$ clingo board.lp targets.lp ricochet.lp -c horizon=9 \
        <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")

clingo version 4.5.0
Reading from board.lp ...
Solving...
Answer: 1
move(red,0,1,1)     move(red,1,0,2) move(red,0,1,3)    move(red,-1,0,4) move(red,0,1,5) \
move(yellow,0,-1,6) move(red,1,0,7) move(yellow,0,1,8) move(yellow,-1,0,9)
SATISFIABLE

Models       : 1+
Calls        : 1
Time         : 1.895s (Solving: 1.45s 1st Model: 1.45s Unsat: 0.00s)
CPU Time     : 1.880s


$ clingo board.lp targets.lp ricochet.lp -c horizon=8 \
        <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")

clingo version 4.5.0
Reading from board.lp ...
Solving...
UNSATISFIABLE

Models       : 0
Calls        : 1
Time         : 2.817s (Solving: 2.41s 1st Model: 0.00s Unsat: 2.41s)
CPU Time     : 2.800s
```

Potassco

optimization.lp

```
goon(T) :- target(R,X,Y), T = 0..horizon, not pos(R,X,Y,T).

:- move(R,DX,DY,T-1), time(T), not goon(T-1), not move(R,DX,DY,T).

#minimize{ 1,T : goon(T) }.
```

Potassco

Solving `goal(13)` from cornered robots

```
$ clingo board.lp targets.lp ricochet.lp optimization.lp -c horizon=20 --quiet=1,0 \
        <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")
clingo version 4.5.0
Reading from board.lp ...
Solving...
Optimization: 20
Optimization: 19
Optimization: 18
Optimization: 17
Optimization: 16
Optimization: 15
Optimization: 14
Optimization: 13
Optimization: 12
Optimization: 11
Optimization: 10
Optimization: 9
Answer: 12
move(blue,0,-1,1)   move(blue,1,0,2)    move(yellow,0,-1,3) move(blue,0,1,4)    move(yellow,-1,0,5) \
move(blue,1,0,6)    move(blue,0,-1,7)   move(yellow,1,0,8)  move(yellow,0,1,9)  move(yellow,0,1,10) \
move(yellow,0,1,11) move(yellow,0,1,12) move(yellow,0,1,13) move(yellow,0,1,14) move(yellow,0,1,15) \
move(yellow,0,1,16) move(yellow,0,1,17) move(yellow,0,1,18) move(yellow,0,1,19) move(yellow,0,1,20)
OPTIMUM FOUND

Models       : 12
  Optimum    : yes
Optimization : 9
Calls        : 1
Time         : 16.145s (Solving: 15.01s 1st Model: 3.35s Unsat: 2.02s)
CPU Time     : 16.080s
```

Potassco

Solving `goal(13)` from cornered robots

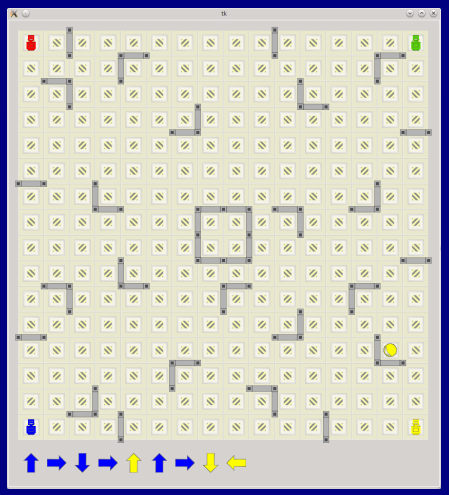
```
$ clingo board.lp targets.lp ricochet.lp optimization.lp -c horizon=20 --quiet=1,0 \
        <(echo "pos(red,1,1). pos(green,16,1). pos(blue,1,16). pos(yellow,16,16).   goal(13).")
clingo version 4.5.0
Reading from board.lp ...
Solving...
Optimization: 20
Optimization: 19
Optimization: 18
Optimization: 17
Optimization: 16
Optimization: 15
Optimization: 14
Optimization: 13
Optimization: 12
Optimization: 11
Optimization: 10
Optimization: 9
Answer: 12
move(blue,0,-1,1)   move(blue,1,0,2)    move(yellow,0,-1,3) move(blue,0,1,4)    move(yellow,-1,0,5) \
move(blue,1,0,6)    move(blue,0,-1,7)   move(yellow,1,0,8)  move(yellow,0,1,9)  move(yellow,0,1,10) \
move(yellow,0,1,11) move(yellow,0,1,12) move(yellow,0,1,13) move(yellow,0,1,14) move(yellow,0,1,15) \
move(yellow,0,1,16) move(yellow,0,1,17) move(yellow,0,1,18) move(yellow,0,1,19) move(yellow,0,1,20)
OPTIMUM FOUND

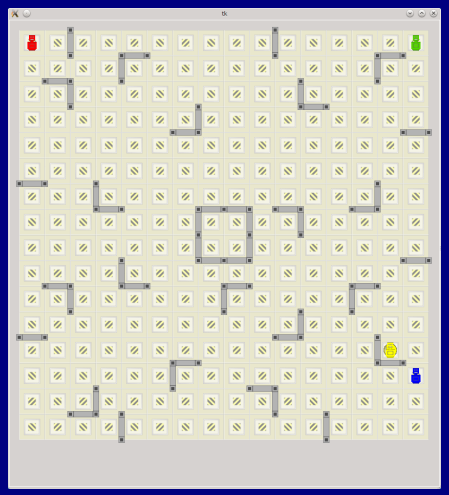
Models       : 12
  Optimum    : yes
Optimization : 9
Calls        : 1
Time         : 16.145s (Solving: 15.01s 1st Model: 3.35s Unsat: 2.02s)
CPU Time     : 16.080s
```

Potassco

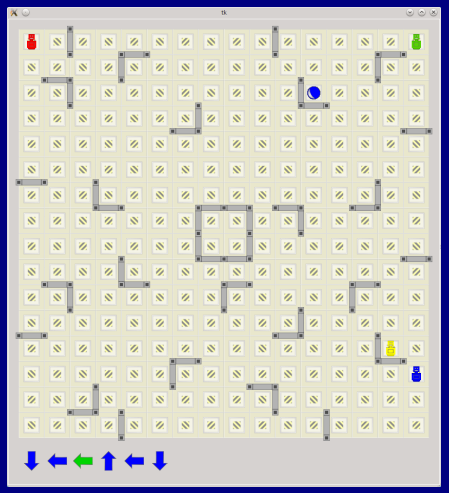
Playing in rounds

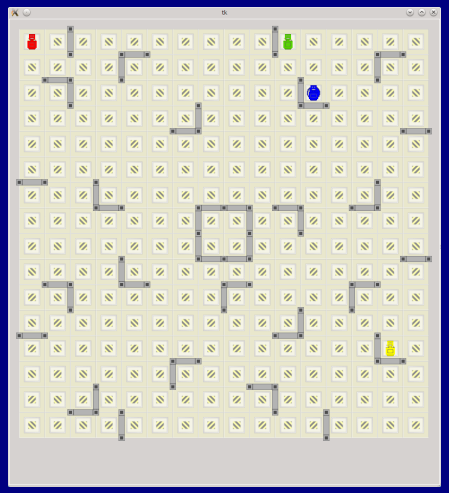
Round 1: `goal(13)`





Round 2: `goal(4)`





Potassco

Control loop

1. Create an operational *clingo* object
2. Load and ground the logic programs encoding Ricochet Robot (relative to some fixed `horizon`) within the control object
3. While there is a goal, do the following
   1. Enforce the initial robot positions
   2. Enforce the current goal
   3. Solve the logic program contained in the control object

Potassco

Ricochet Robot Player

ricochet.py

```
from gringo import Control, Model, Fun

class Player:
    def __init__(self, horizon, positions, files):
        self.last_positions = positions
        self.last_solution = None
        self.undo_external = []
        self.horizon = horizon
        self.ctl = Control(['-c', 'horizon={0}'.format(self.horizon)])
        for x in files:
            self.ctl.load(x)
        self.ctl.ground([("base", [])])

    def solve(self, goal):
        for x in self.undo_external:
            self.ctl.assign_external(x, False)
        self.undo_external = []
        for x in self.last_positions + [goal]:
            self.ctl.assign_external(x, True)
            self.undo_external.append(x)
        self.last_solution = None
        self.ctl.solve(on_model=self.on_model)
        return self.last_solution

    def on_model(self, model):
        self.last_solution = model.atoms()
        self.last_positions = []
        for atom in model.atoms(Model.ATOMS):
            if (atom.name() == "pos" and len(atom.args()) == 4 and atom.args()[3] == self.horizon):
                self.last_positions.append(Fun("pos", atom.args()[:-1]))

horizon   = 15
encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
positions = [Fun("pos", [Fun("red"),     1,  1]), Fun("pos", [Fun("blue"),    1, 16]),
             Fun("pos", [Fun("green"),  16,  1]), Fun("pos", [Fun("yellow"), 16, 16])]
sequence  = [Fun("goal", [13]), Fun("goal", [4]), Fun("goal", [7])]

player = Player(horizon, positions, encodings)
for goal in sequence:
    print player.solve(goal)
```

Potassco

Variables of interest

- `last_positions` holds the starting positions of the robots for each turn
- `last_solution` holds the last solution of a search call
  (Note that callbacks cannot return values directly)
- `undo_external` holds a list containing the current goal and starting positions to be cleared upon the next step
- `horizon` holds the maximum number of moves to find a solution
- `ctl` holds the actual object providing an interface to the grounder and solver; it holds all state information necessary for multi-shot solving

Potassco

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Potassco

Ricochet Robot Player
Setup and control loop

```
from gringo import Control, Model, Fun

class Player:
    def __init__(self, horizon, positions, files):
        self.last_positions = positions
        self.last_solution = None
        self.undo_external = []
        self.horizon = horizon
        self.ctl = Control(['-c', 'horizon={0}'.format(self.horizon)])
        for x in files:
            self.ctl.load(x)
        self.ctl.ground([("base", [])])

    def solve(self, goal):
        for x in self.undo_external:
            self.ctl.assign_external(x, False)
        self.undo_external = []
        for x in self.last_positions + [goal]:
            self.ctl.assign_external(x, True)
            self.undo_external.append(x)
        self.last_solution = None
        self.ctl.solve(on_model=self.on_model)
        return self.last_solution

    def on_model(self, model):
        self.last_solution = model.atoms()
        self.last_positions = []
        for atom in model.atoms(Model.ATOMS):
            if (atom.name() == "pos" and len(atom.args()) == 4 and atom.args()[3] == self.horizon):
                self.last_positions.append(Fun("pos", atom.args()[:-1]))

horizon   = 15
encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
positions = [Fun("pos", [Fun("red"),     1,  1]), Fun("pos", [Fun("blue"),    1, 16]),
             Fun("pos", [Fun("green"),  16,  1]), Fun("pos", [Fun("yellow"), 16, 16])]
sequence  = [Fun("goal", [13]), Fun("goal", [4]), Fun("goal", [7])]

player = Player(horizon, positions, encodings)
for goal in sequence:
    print player.solve(goal)
```

Potassco

Setup and control loop

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sequence  = [Fun("goal", [13]),
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```

1. Initializing variables
2. Creating a player object (wrapping a *clingo* object)
3. Playing in rounds

Potassco

Setup and control loop

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>> encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
>> positions = [Fun("pos", [Fun("red"),     1,  1]),
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>> sequence  = [Fun("goal", [13]),
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```

```
player = Player(horizon, positions, encodings)
for goal in sequence:
    print player.solve(goal)
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sequence  = [Fun("goal", [13]),
             Fun("goal",  [4]),
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>> player = Player(horizon, positions, encodings)
   for goal in sequence:
       print player.solve(goal)
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Potassco

Setup and control loop

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   sequence  = [Fun("goal", [13]),
                Fun("goal",  [4]),
                Fun("goal",  [7])]

   player = Player(horizon, positions, encodings)
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```

1. Initializing variables
2. Creating a player object (wrapping a *clingo* object)
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Potassco

Setup and control loop

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             Fun("pos", [Fun("blue"),    1, 16]),
             Fun("pos", [Fun("green"),  16,  1]),
             Fun("pos", [Fun("yellow"), 16, 16])]
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    print player.solve(goal)
```

1. Initializing variables
2. Creating a player object (wrapping a *clingo* object)
3. Playing in rounds

Potassco

Ricochet Robot Player

__init__

```
from gringo import Control, Model, Fun

class Player:
    def __init__(self, horizon, positions, files):
        self.last_positions = positions
        self.last_solution = None
        self.undo_external = []
        self.horizon = horizon
        self.ctl = Control(['-c', 'horizon={0}'.format(self.horizon)])
        for x in files:
            self.ctl.load(x)
        self.ctl.ground([("base", [])])

    def solve(self, goal):
        for x in self.undo_external:
            self.ctl.assign_external(x, False)
        self.undo_external = []
        for x in self.last_positions + [goal]:
            self.ctl.assign_external(x, True)
            self.undo_external.append(x)
        self.last_solution = None
        self.ctl.solve(on_model=self.on_model)
        return self.last_solution

    def on_model(self, model):
        self.last_solution = model.atoms()
        self.last_positions = []
        for atom in model.atoms(Model.ATOMS):
            if (atom.name() == "pos" and len(atom.args()) == 4 and atom.args()[3] == self.horizon):
                self.last_positions.append(Fun("pos", atom.args()[:-1]))

horizon   = 15
encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
positions = [Fun("pos", [Fun("red"),     1,  1]), Fun("pos", [Fun("blue"),    1, 16]),
             Fun("pos", [Fun("green"),  16,  1]), Fun("pos", [Fun("yellow"), 16, 16])]
sequence  = [Fun("goal", [13]), Fun("goal", [4]), Fun("goal", [7])]

player = Player(horizon, positions, encodings)
for goal in sequence:
    print player.solve(goal)
```

Potassco

__init__

```
def __init__(self, horizon, positions, files):
    self.last_positions = positions
    self.last_solution = None
    self.undo_external = []
    self.horizon = horizon
    self.ctl = Control(['-c', 'horizon={0}'.format(self.horizon)])
    for x in files:
        self.ctl.load(x)
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1. Initializing variables
2. Creating *clingo* object
3. Loading encoding and instance
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Potassco

Ricochet Robot Player
solve

```
from gringo import Control, Model, Fun

class Player:
    def __init__(self, horizon, positions, files):
        self.last_positions = positions
        self.last_solution = None
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    def solve(self, goal):
        for x in self.undo_external:
            self.ctl.assign_external(x, False)
        self.undo_external = []
        for x in self.last_positions + [goal]:
            self.ctl.assign_external(x, True)
            self.undo_external.append(x)
        self.last_solution = None
        self.ctl.solve(on_model=self.on_model)
        return self.last_solution

    def on_model(self, model):
        self.last_solution = model.atoms()
        self.last_positions = []
        for atom in model.atoms(Model.ATOMS):
            if (atom.name() == "pos" and len(atom.args()) == 4 and atom.args()[3] == self.horizon):
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horizon   = 15
encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
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Potassco

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1. Unsetting previous external atoms (viz. previous goal and positions)
2. Setting next external atoms (viz. next goal and positions)
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Potassco

Ricochet Robot Player
on_model

```
from gringo import Control, Model, Fun

class Player:
    def __init__(self, horizon, positions, files):
        self.last_positions = positions
        self.last_solution = None
        self.undo_external = []
        self.horizon = horizon
        self.ctl = Control(['-c', 'horizon={0}'.format(self.horizon)])
        for x in files:
            self.ctl.load(x)
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horizon   = 15
encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
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Potassco

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2. Extracting atoms (viz. last robot positions)
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   by adding `pos(R,X,Y)` for each `pos(R,X,Y,horizon)`

Potassco

ricochet.py

```
from gringo import Control, Model, Fun

class Player:
    def __init__(self, horizon, positions, files):
        self.last_positions = positions
        self.last_solution = None
        self.undo_external = []
        self.horizon = horizon
        self.ctl = Control(['-c', 'horizon={0}'.format(self.horizon)])
        for x in files:
            self.ctl.load(x)
        self.ctl.ground([("base", [])])

    def solve(self, goal):
        for x in self.undo_external:
            self.ctl.assign_external(x, False)
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        for x in self.last_positions + [goal]:
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horizon   = 15
encodings = ["board.lp", "targets.lp", "ricochet.lp", "optimization.lp"]
positions = [Fun("pos", [Fun("red"),     1,  1]), Fun("pos", [Fun("blue"),    1, 16]),
             Fun("pos", [Fun("green"),  16,  1]), Fun("pos", [Fun("yellow"), 16, 16])]
sequence  = [Fun("goal", [13]), Fun("goal", [4]), Fun("goal", [7])]

player = Player(horizon, positions, encodings)
for goal in sequence:
    print player.solve(goal)
```

Potassco

Let's play!

```
$ python ricochet.py
[move(red,0,1,1), move(yellow,-1,0,14), move(yellow,-1,0,12), move(yellow,-1,0,11),
 move(yellow,-1,0,9), move(red,1,0,7), move(red,1,0,2), move(yellow,-1,0,10),
 move(yellow,-1,0,13), move(yellow,-1,0,15), move(red,-1,0,4), move(yellow,0,-1,6),
 move(red,0,1,3), move(red,0,1,5), move(yellow,0,1,8)]
[move(blue,0,1,15), move(blue,0,1,11), move(blue,0,1,8), move(blue,0,1,3),
 move(blue,1,0,2), move(blue,0,1,9), move(blue,-1,0,7), move(blue,0,1,10),
 move(blue,0,1,13), move(blue,-1,0,4), move(blue,0,-1,1), move(blue,0,-1,6),
 move(green,-1,0,5), move(blue,0,1,12), move(blue,0,1,14)]
[move(green,1,0,15), move(green,1,0,8), move(green,1,0,5), move(green,1,0,4),
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 move(green,1,0,6), move(green,1,0,14), move(green,0,1,1)]

$ ./visualize.py
```

http://potassco.sourceforge.net

☞ gringo/clingo distribution ./examples/clingo/robots/

Potassco

Let's play!

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[move(red,0,1,1), move(yellow,-1,0,14), move(yellow,-1,0,12), move(yellow,-1,0,11),
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Potassco

Outline

1 Introduction
2 Foundations
3 Modeling
4 Modeling and Controlling
5 Case-study: Ricochet Robots
6 Case-sketch: Preferences and optimization
7 Potassco
8 Summary

Potassco

Motivation

- Preferences are pervasive
- The identification of preferred, or optimal, solutions is often indispensable in real-world applications

  In many cases, this also involves the combination of various qualitative and quantitative preferences

- Only optimization statements representing objective functions using sum or count aggregates are established components of ASP systems
- Example $\#minimize\{40 : sauna, 70 : dive\}$

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The asprin framework

- asprin is a framework for handling preferences among the stable models of logic programs
  - general because it captures numerous existing approaches to preference from the literature
  - flexible because it allows for an easy implementation of new or extended existing approaches
- asprin builds upon advanced control capacities for incremental and meta solving, allowing for

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  significantly reducing redundancies

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Potassco

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  - search for specific preferred solutions without any modifications to the ASP solver
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  - continuous integrated solving process significantly reducing redundancies
  - high customizability via an implementation through ordinary ASP encodings

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The asprin framework

- asprin is a framework for handling preferences among the stable models of logic programs
  - general because it captures numerous existing approaches to preference from the literature
  - flexible because it allows for an easy implementation of new or extended existing approaches
- asprin builds upon advanced control capacities for incremental and meta solving, allowing for
  - search for specific preferred solutions without any modifications to the ASP solver
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Example

$$\#preference(costs, less(weight))\{40 : sauna, 70 : dive\}$$
$$\#preference(fun, superset)\{sauna, dive, hike, \sim bunji\}$$
$$\#preference(temps, aso)\{dive > sauna \,\|\, hot, sauna > dive \,\|\, \neg hot\}$$
$$\#preference(all, pareto)\{name(costs), name(fun), name(temps)\}$$

$$\#optimize(all)$$

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asprin's library

- Basic preference types
  - `subset` and `superset`
  - `less(cardinality)` and `more(cardinality)`
  - `less(weight)` and `more(weight)`
  - `aso` (Answer Set Optimization)
  - `poset` (Qualitative Preferences)
- Composite preference types
  - `neg`
  - `and`
  - `pareto`
  - `lexico`
- See *Potassco Guide* on how to define further types

  and `http://potassco.sourceforge.net/labs.html#asprin`

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1 Introduction
2 Foundations
3 Modeling
4 Modeling and Controlling
5 Case-study: Ricochet Robots
6 Case-sketch: Preferences and optimization
7 Potassco
8 Summary

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Potassco, the Potsdam Answer Set Solving Collection,
bundles tools for ASP developed at the University of Potsdam:

- Grounder gringo, lingo
- Solver clasp, claspfolio, claspar, aspeed
- Grounder+Solver Clingo, Clingcon, ROSoClingo
- Further Tools aspartame, aspcud, asprin, chasp, claspre, clavis, coala, fimo, insight, metasp, plasp, piclasp, etc

- Benchmarks, Repository asparagus.cs.uni-potsdam.de

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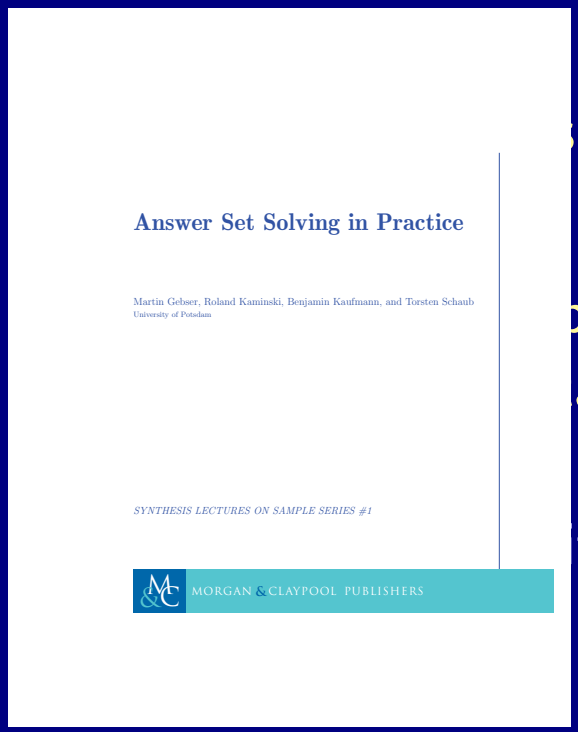

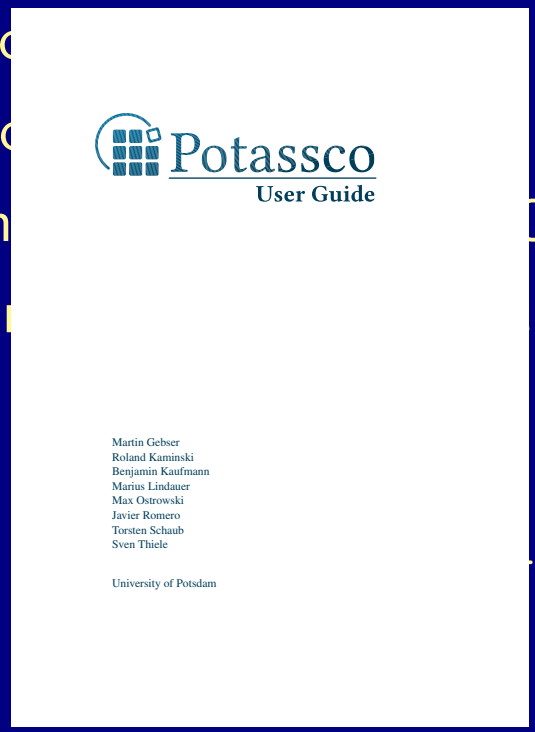

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Summary

- ASP is a viable tool for Knowledge Representation and Reasoning
- ASP offers efficient and versatile off-the-shelf solving technology
- ASP offers an expanding functionality and ease of use
  - rapid application development tool
- ASP has a growing range of applications

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Summary

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ASP = DB+LP+KR+SAT

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