Puzzles with SMV

Bug Catching in 2006 Fall

Nov. 09, 2006

Gi-Hwon Kwon

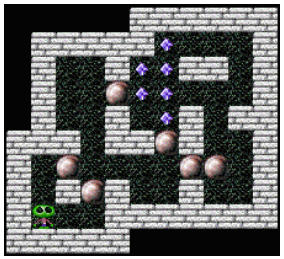
Agenda

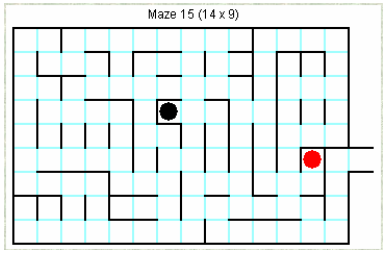
- Puzzles as Model Checking Problem
  - Missionary cannibal problem
  - Bridge crossing problem
  - Maze game
  - Push-Push game
  - Sokomind-PLUS game
  - Sokomind Game
- Challenge works
  - Puzzle as Bounded Model Checking Problem
  - Puzzle as Directed Model Checking Problem

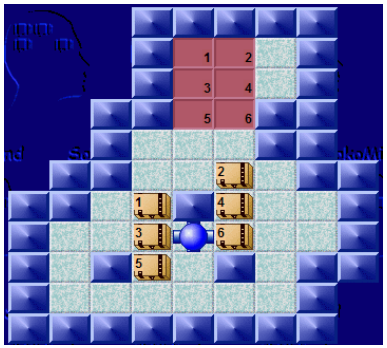
Puzzle Worlds

		6	1		2	5		
	3	9				1	4	
				4				
9		2		3		4		1
	8						7	
1		3		6		8		9
				1				
	5	4				9	1	
		7	5		3	2		

6	1	8
7	5	3
2	9	4







solvable in one time

no temporal properties

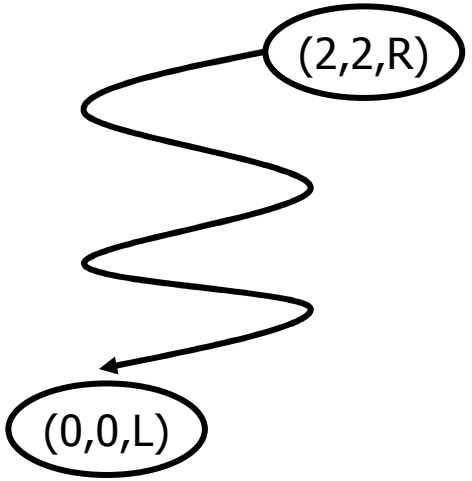
solvable in several times

temporal properties

Missionary Cannibal Problem

Missionary Cannibal Problem

- State is 3-tuple (M,C,B)
  - M = {0,1,2} on the right side
  - C = {0,1,2} on the right side
  - B = {L,R}
  - initial state: (2,2,R)
  - final state: (0,0,L)
  - unsafe state: (m,c,?), where m < c



- Transitions
  - (0,1) : 1 cannibal on board
  - (0,2) : 2 cannibals on board
  - (1,0) : 1 missionary on board
  - (1,1) : 1 missionary and 1 cannibal on board
  - (2,0) : 2 missionaries

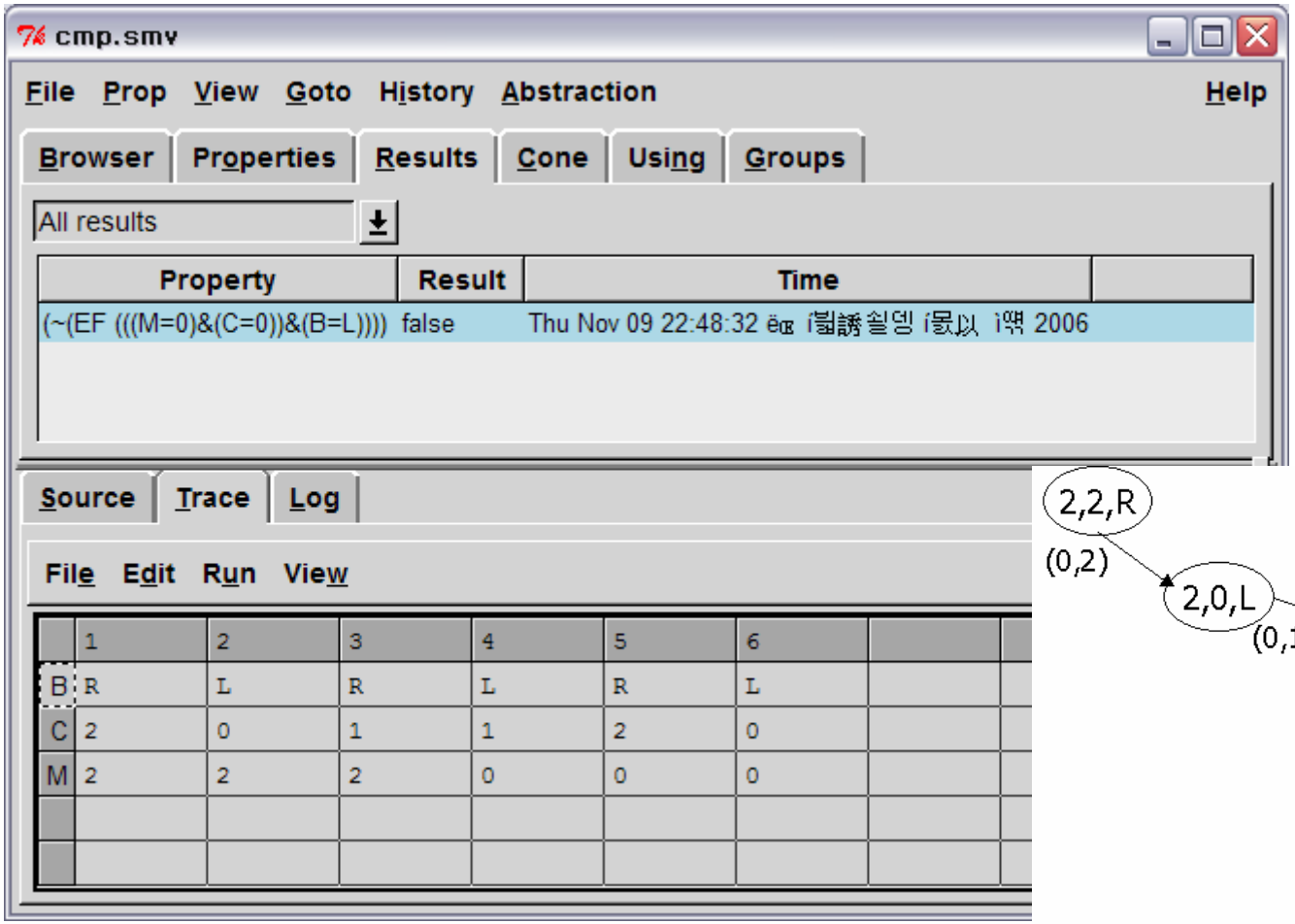
Missionary Cannibal Problem

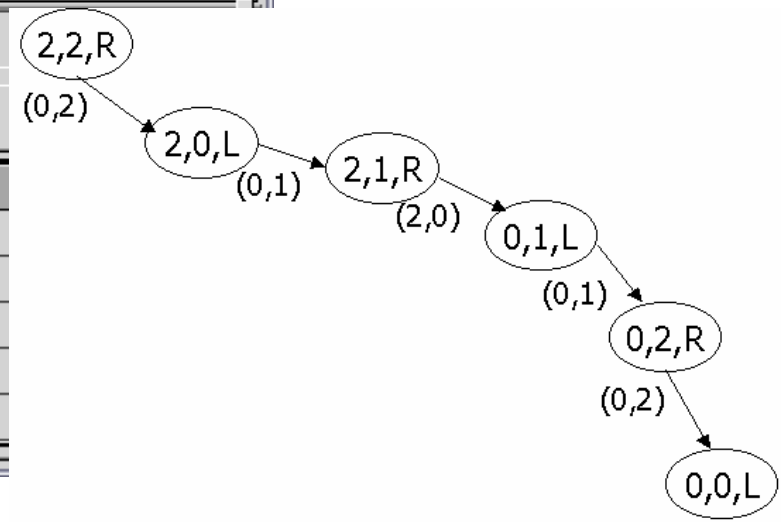
	Transition				
State	(0,1)	(0,2)	(1,0)	(1,1)	(2,0)
(2,2,R)	(2,1,L)	(2,0,L)	(unsafe)	(1,1,L)	(0,2,L)
(2,1,R)	(2,0,L)	(unsafe)	(1,1,L)	(1,0,L)	(0,1,L)
(2,0,R)	(unsafe)	(unsafe)	(1,0,L)	(unsafe)	(0,0,L)
(1,1,R)	(1,0,L)	(unsafe)	(0,1,L)	(0,0,L)	(unsafe)
(0,2,R)	(0,1,L)	(0,0,L)	(unsafe)	(unsafe)	(unsafe)
(0,1,R)	(0,0,L)	(unsafe)	(unsafe)	(unsafe)	(unsafe)
(2,1,L)	(2,2,R)	(unsafe)	(unsafe)	(unsafe)	(unsafe)
(2,0,L)	(2,1,R)	(2,2,R)	(unsafe)	(unsafe)	(unsafe)
(1,1,L)	(unsafe)	(unsafe)	(2,1,R)	(2,2,R)	(unsafe)
(0,2,L)	(unsafe)	(2,2,R)	(unsafe)	(unsafe)	(2,2,R)
(0,1,L)	(0,2,R)	(unsafe)	(1,1,R)	(unsafe)	(2,1,R)
(0,0,L)	(0,1,R)	(0,2,R)	(1,0,R)	(1,1,R)	(2,0,R)
(unsafe)	(unsafe)	(unsafe)	(unsafe)	(unsafe)	(unsafe)

EF (0,0,L)

¬EF (0,0,L)

Missionary Cannibal Problem

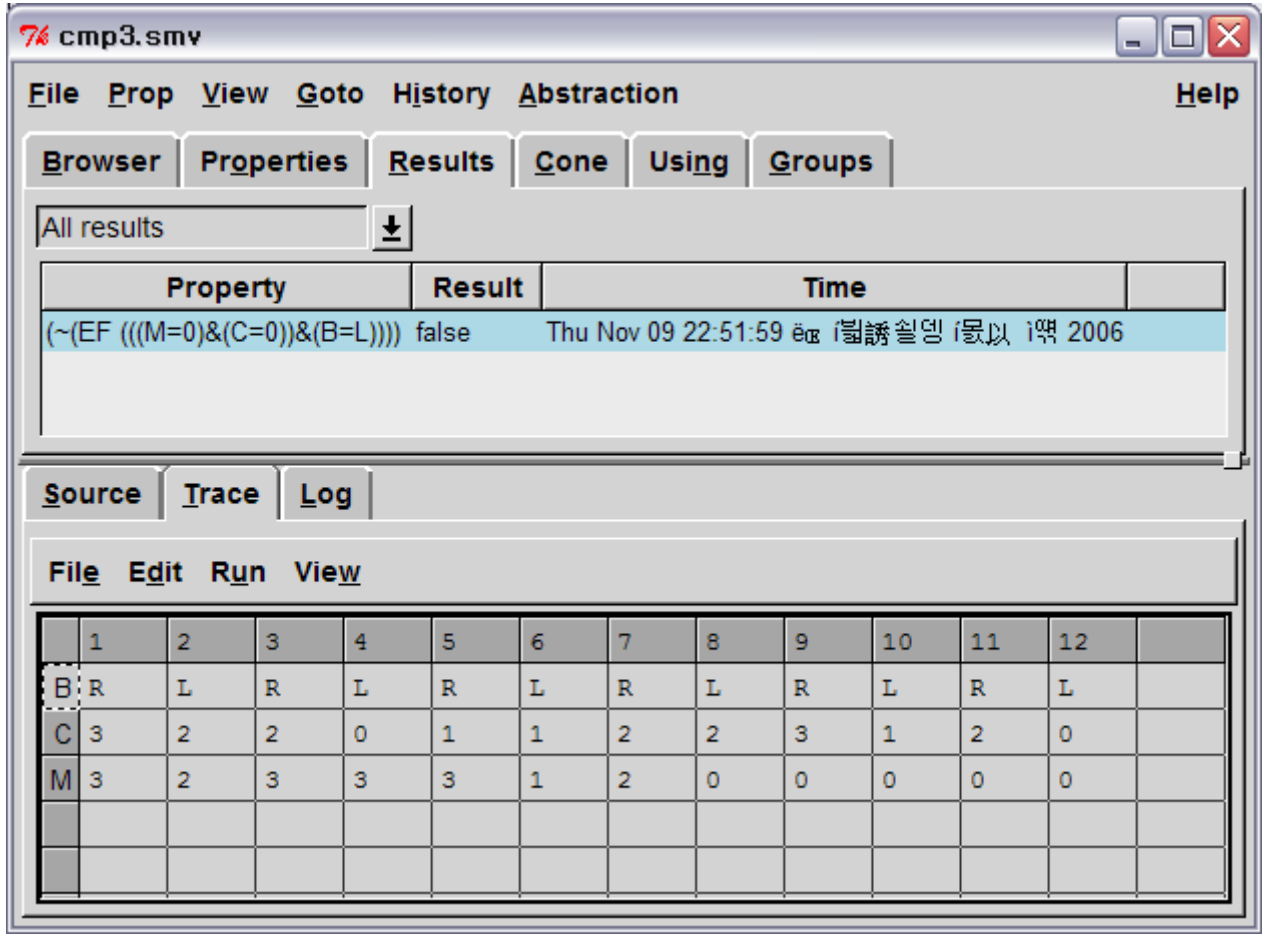




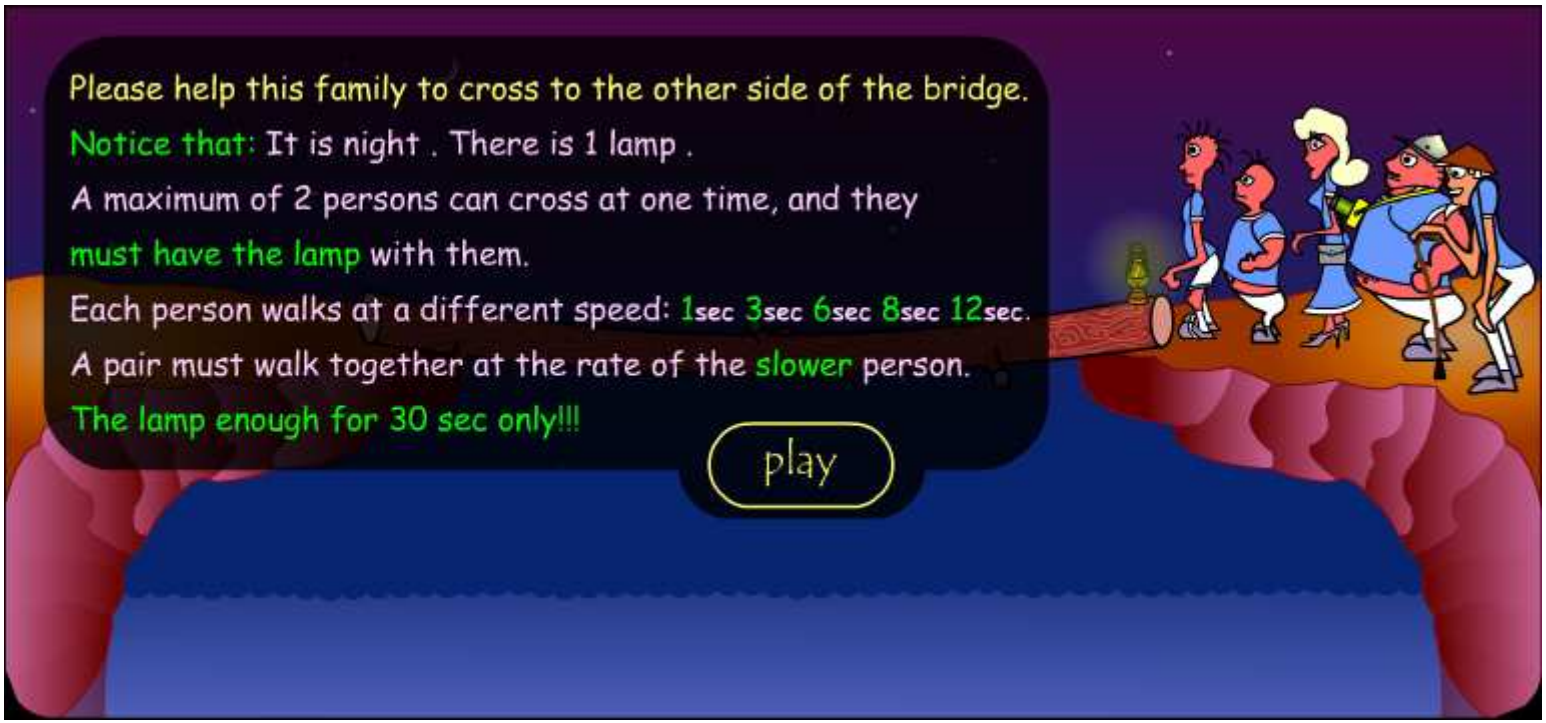
Quiz #1


Please help the 3 cannibals
and the 3 missionaries to move
to the other side of the lake.
notice that: when there is on one side
more cannibals than
missionaries , they eat them.
play

Solution


cmp3.smv
File Prop View Goto History Abstraction Help
Browser Properties Results Cone Using Groups
All results
Property Result Time
(~(EF (((M=0)&(C=0))&(B=L)))) false Thu Nov 09 22:51:59
Source Trace Log
File Edit Run View
1 2 3 4 5 6 7 8 9 10 11 12
B R L R L R L R L R L R L
C 3 2 2 0 1 1 2 2 3 1 2 0
M 3 2 3 3 3 1 2 0 0 0 0 0

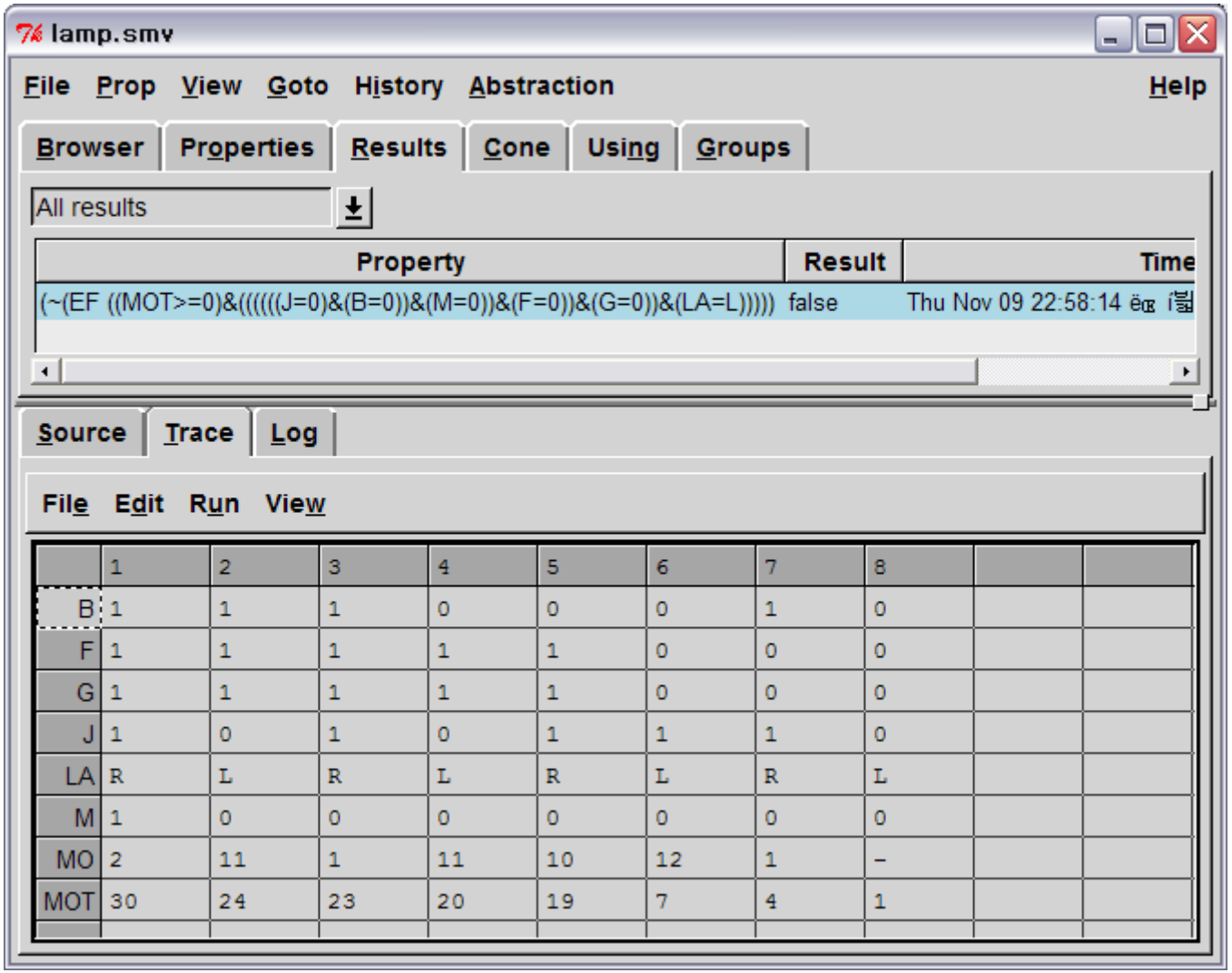
Crossing Bridge Problem



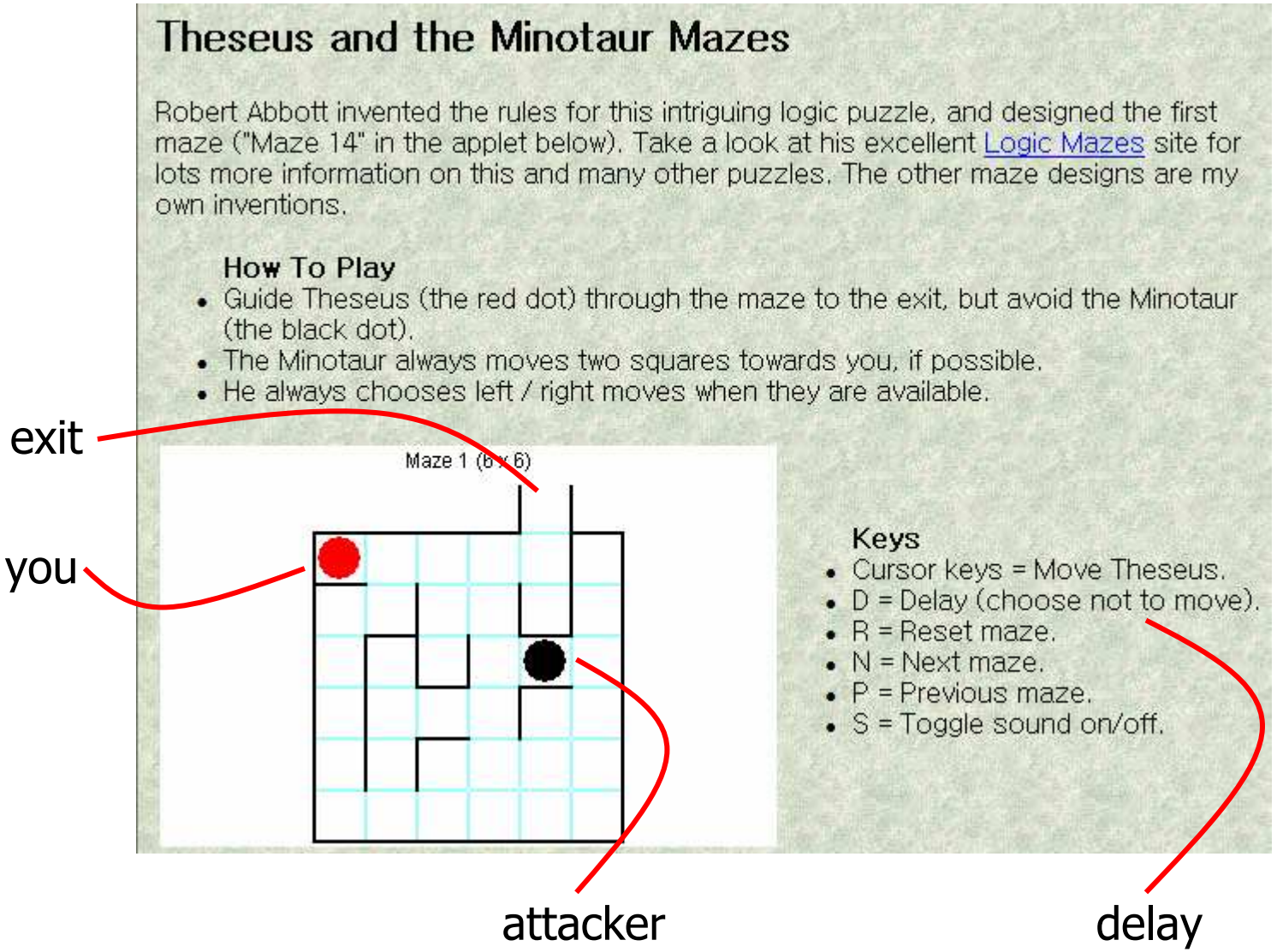
Quiz #2

¬EF (time<=30 & all family on the left side
& lamp also on the left side)

Solution

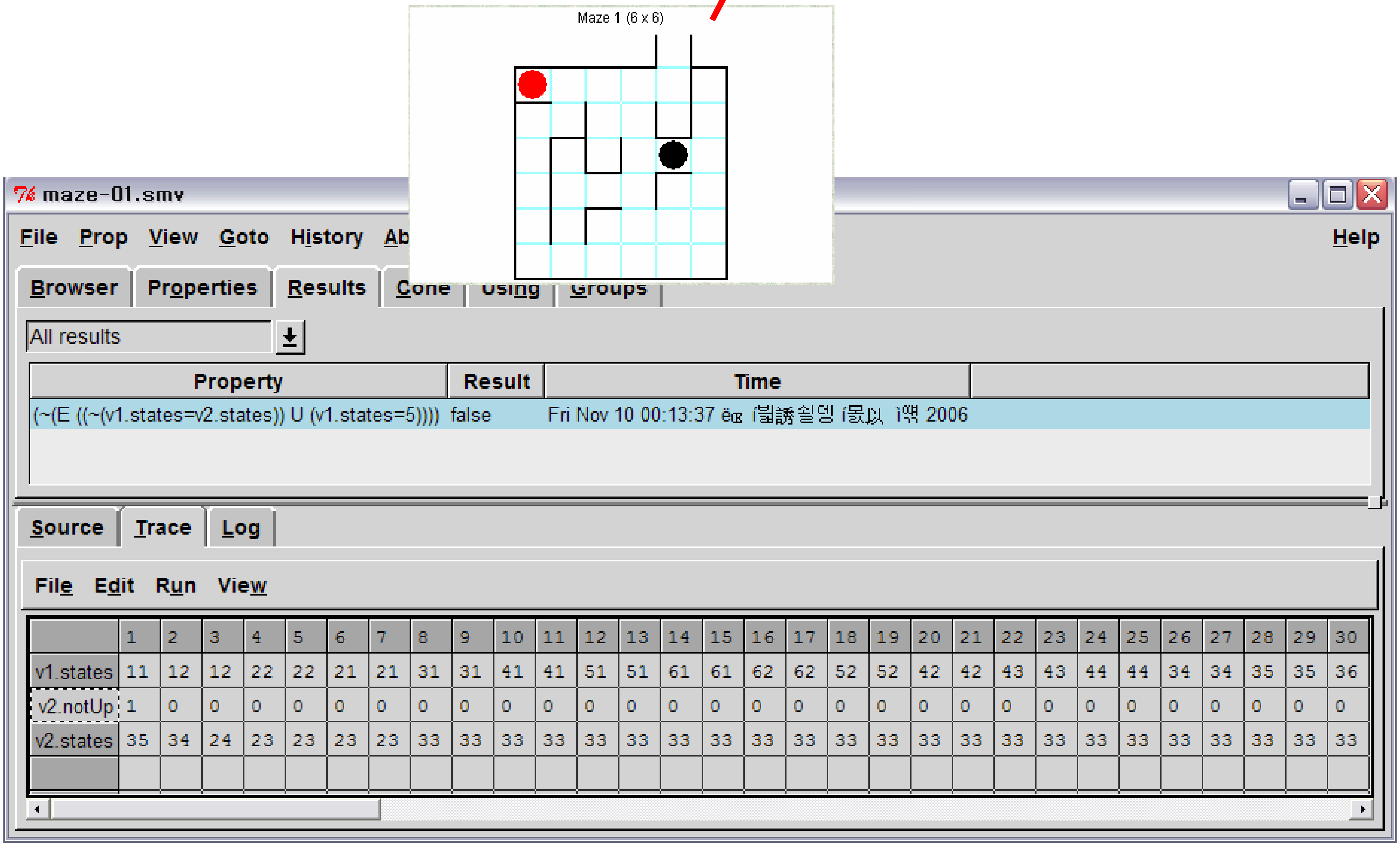

lamp.smv
File Prop View Goto History Abstraction Help
Browser Properties Results Cone Using Groups
All results
Property Result Time
(~(EF ((MOT>=0)&((((((J=0)&(B=0))&(M=0))&(F=0))&(G=0))&(LA=L))))) false Thu Nov 09 22:58:14
Source Trace Log
File Edit Run View
1 2 3 4 5 6 7 8
B 1 1 1 0 0 0 1 0
F 1 1 1 1 1 0 0 0
G 1 1 1 1 1 0 0 0
J 1 0 1 0 1 1 1 0
LA R L R L R L R L
M 1 0 0 0 0 0 0 0
MO 2 11 1 11 10 12 1 -
MOT 30 24 23 20 19 7 4 1

Maze Games


Theseus and the Minotaur Mazes
Robert Abbott invented the rules for this intriguing logic puzzle, and designed the first maze ("Maze 14" in the applet below). Take a look at his excellent Logic Mazes site for lots more information on this and many other puzzles. The other maze designs are my own inventions.
How To Play
Guide Theseus (the red dot) through the maze to the exit, but avoid the Minotaur (the black dot).
The Minotaur always moves two squares towards you, if possible.
He always chooses left / right moves when they are available.
Maze 1 (6 x 6)
Keys
Cursor keys = Move Theseus.
D = Delay (choose not to move).
R = Reset maze.
N = Next maze.
P = Previous maze.
S = Toggle sound on/off.
exit
you
attacker
delay

Maze Games

¬E[¬unsafe U exit]



Browser | Properties | Results | Cone | Using | Groups

All results

Property	Result	Time
(~(E ((~(v1.states=v2.states)) U (v1.states=5))))	false	Fri Nov 10 00:13:37 ëœ í뇌誘쉴뎁 í뮻以 í괙 2006

Source | Trace | Log

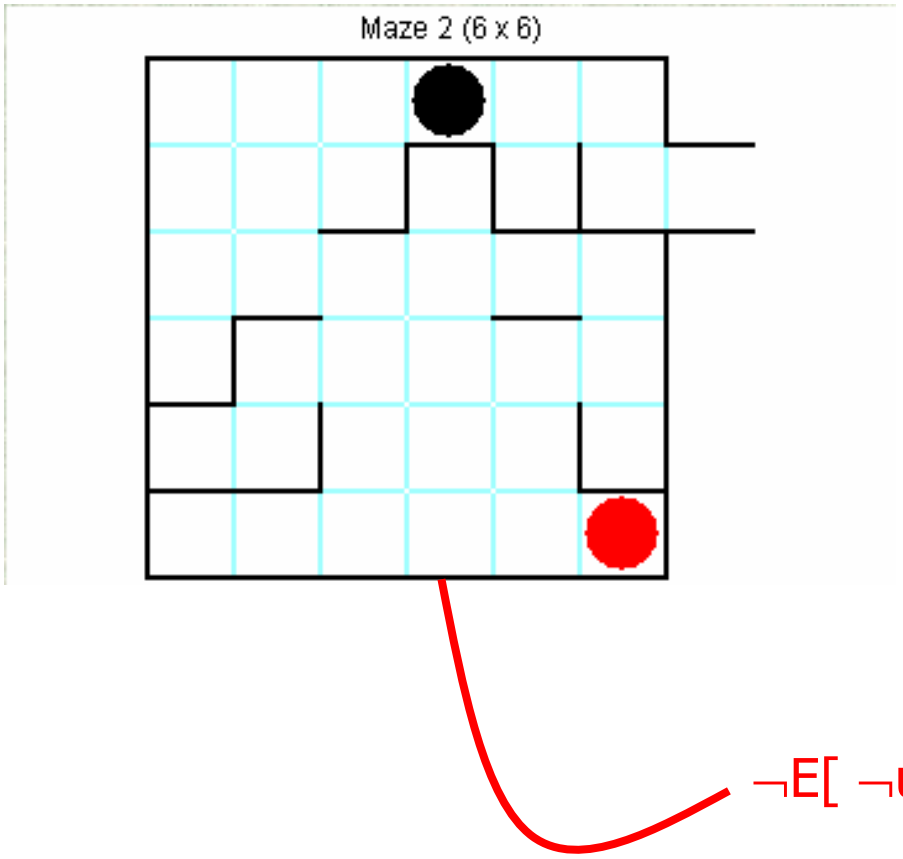
File Edit Run View

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
v1.states	36	26	26	16	16	26	26	36	36	46	46	56	56	66	66	65	65	64	64	63	63	62	62	61	61	51	51	41	41	31
v2.notUp	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
v2.states	33	23	24	14	15	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25

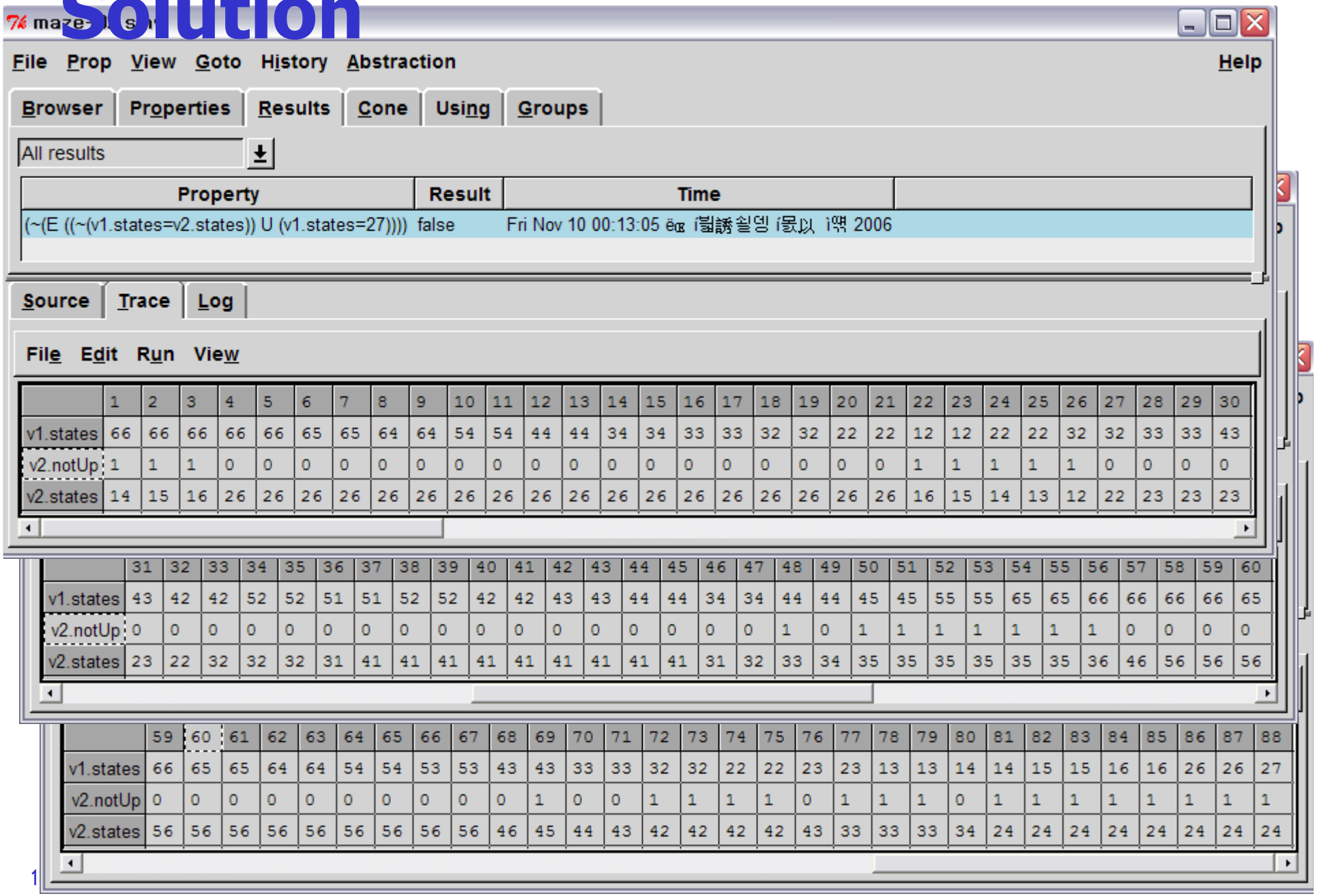
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
v1.states	31	21	21	22	22	12	12	22	22	21	21	31	31	41	41	51	51	61	61	62	62	61	61	62	62	52	52	42	42	43
v2.notUp	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
v2.states	25	25	25	25	25	15	14	13	12	11	11	11	11	11	11	11	11	11	11	12	22	21	31	41	51	51	51	41	41	41

	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
v1.states	42	43	43	44	44	54	54	55	55	56	56	66	66	56	56	46	46	36	36	35	35	34	34	24	24	14	14	15	15	5
v2.notUp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
v2.states	41	41	41	41	41	51	51	51	51	51	51	61	62	63	64	65	66	56	46	45	45	45	45	45	45	45	45	45	45	45

Quiz #3

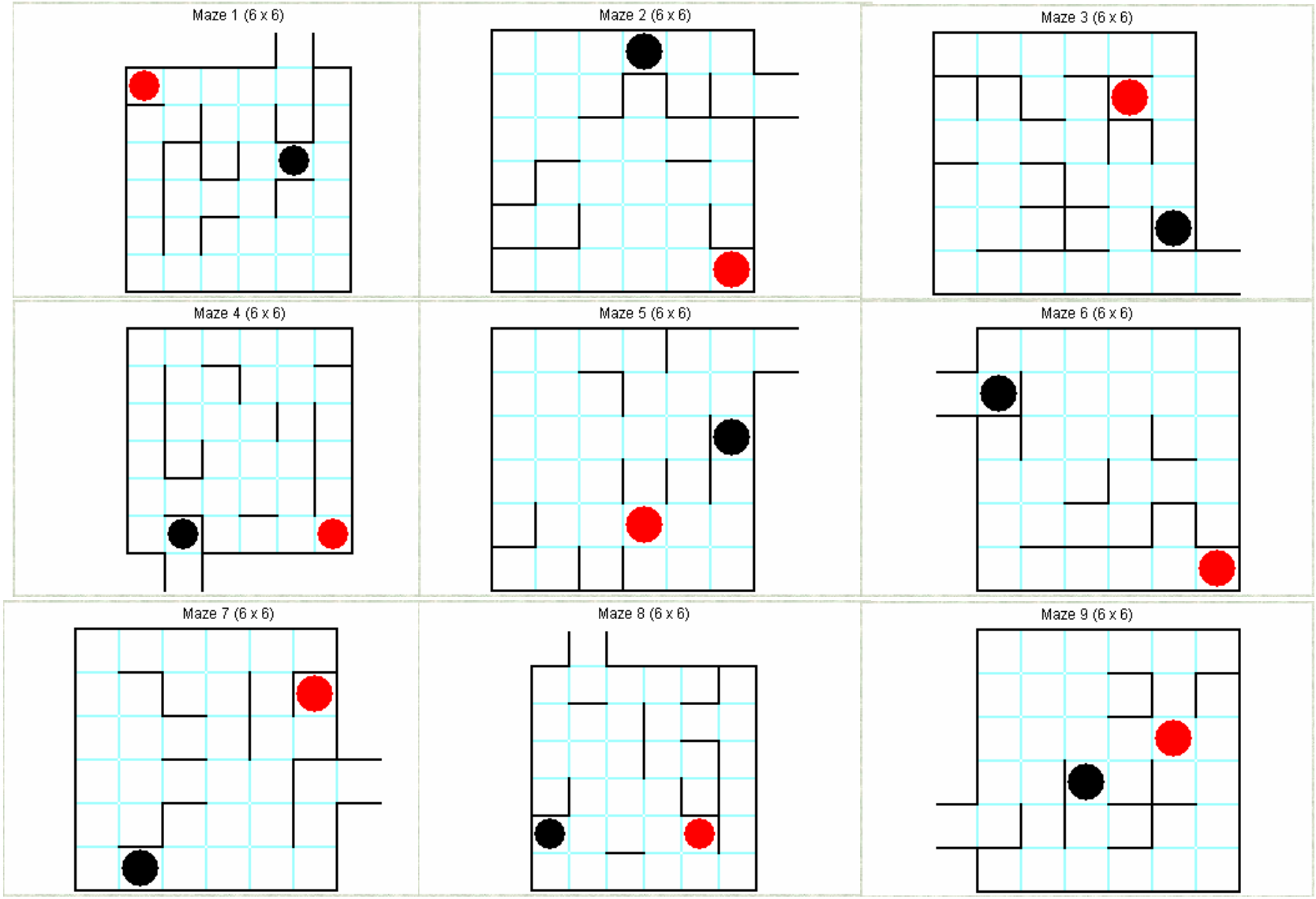


Solution

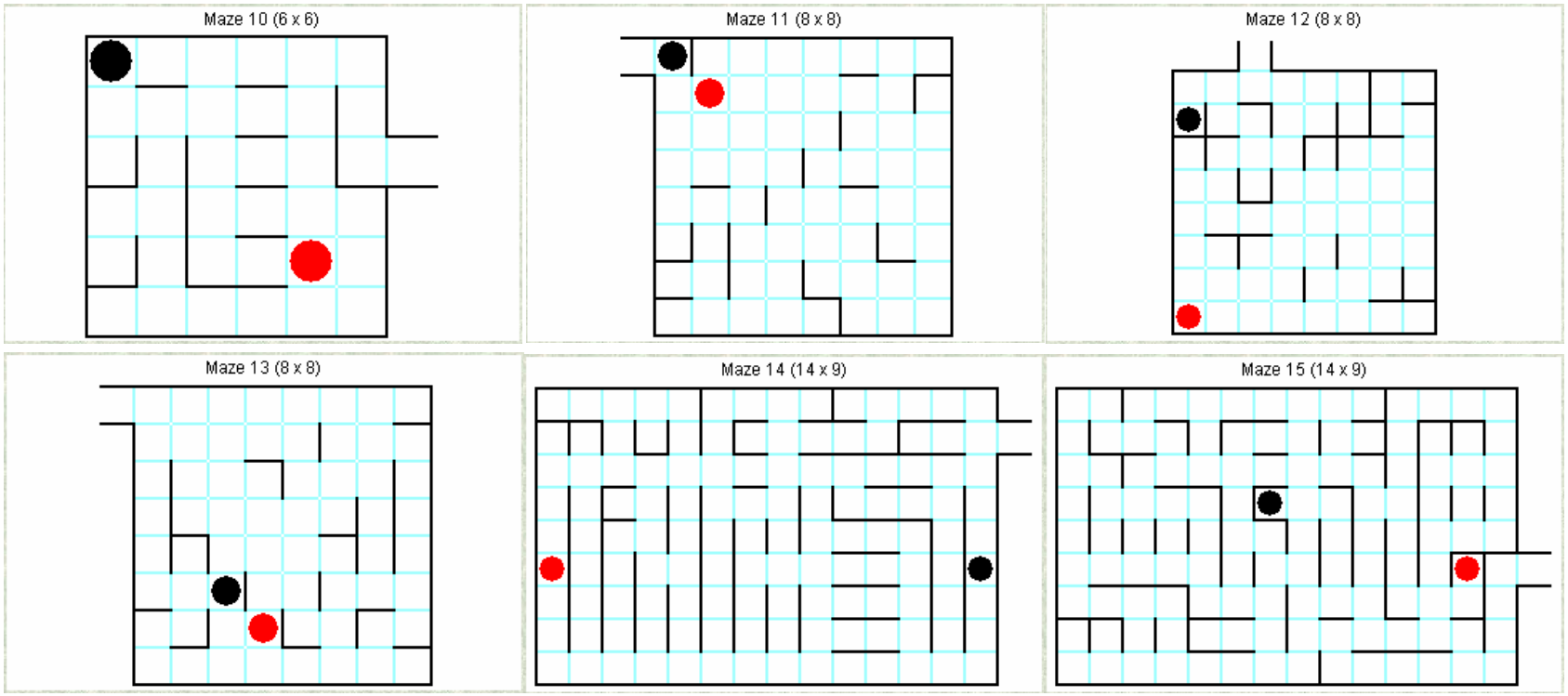

File Prop View Goto History Abstraction Help
Browser Properties Results Cone Using Groups
All results
Property Result Time
(~(E ((~(v1.states=v2.states)) U (v1.states=27)))) false Fri Nov 10 00:13:05 2006
Source Trace Log
File Edit Run View
v1.states 66 66 66 66 66 65 65 64 64 54 54 44 44 34 34 33 33 32 32 22 22 12 12 22 22 32 32 33 33 43
v2.notUp 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 0
v2.states 14 15 16 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 26 16 15 14 13 12 22 23 23 23
v1.states 43 42 42 52 52 51 51 52 52 42 42 43 43 44 44 34 34 44 44 45 45 55 55 65 65 66 66 66 66 65
v2.notUp 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1 1 1 0 0 0 0
v2.states 23 22 32 32 32 31 41 41 41 41 41 41 41 41 41 31 32 33 34 35 35 35 35 35 35 36 46 56 56 56
v1.states 66 65 65 64 64 54 54 53 53 43 43 33 33 32 32 22 22 23 23 13 13 14 14 15 15 16 16 26 26 27
v2.notUp 0 0 0 0 0 0 0 0 0 0 1 0 0 1 1 1 1 0 1 1 1 0 1 1 1 1 1 1 1 1
v2.states 56 56 56 56 56 56 56 56 56 46 45 44 43 42 42 42 42 43 33 33 33 34 24 24 24 24 24 24 24 24

Maze Games

15 levels



Maze Games

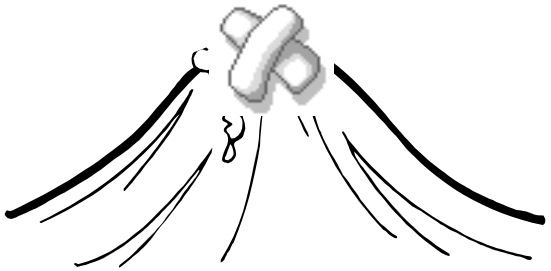

Maze 10 (6 x 6)
Maze 11 (8 x 8)
Maze 12 (8 x 8)
Maze 13 (8 x 8)
Maze 14 (14 x 9)
Maze 15 (14 x 9)

Model Checking Results

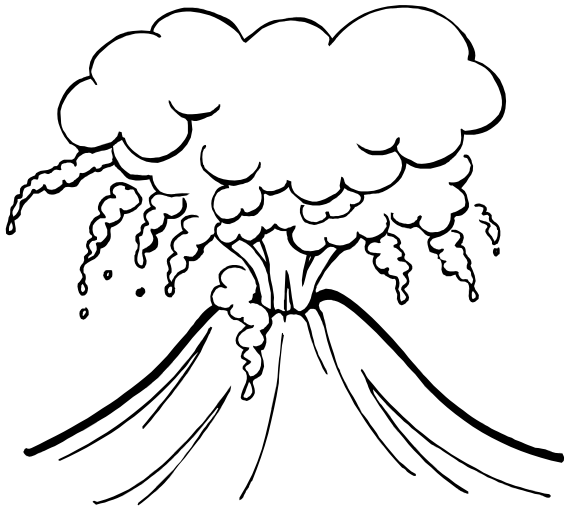
Level	Size	Time(sec)	Memory(KB)	BDD	Steps
1	6x6	0.16	2440	35922	59
2	6x6	0.18	2384	33563	44
3	6x6	0.17	2312	28107	48
4	6x6	0.18	2420	33894	37
5	6x6	0.13	2300	28401	25
6	6x6	0.20	2348	31277	49
7	6x6	0.18	2468	37450	43
8	6x6	0.22	2564	42667	63
9	6x6	0.22	2484	38182	52
10	6x6	0.20	2392	33568	27
11	8x8	0.46	3188	76334	66
12	8x8	0.47	3156	74311	79
13	8x8	0.44	3308	83440	72
14	14x9	1.57	5288	39799	94
15	14x9	2.06	6320	237181	184

So Far

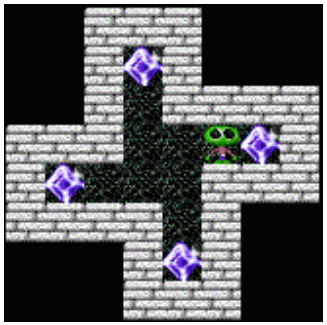
☺ Are you happy ?



☹ When model checking people sad ?



Push Push Games



goal state

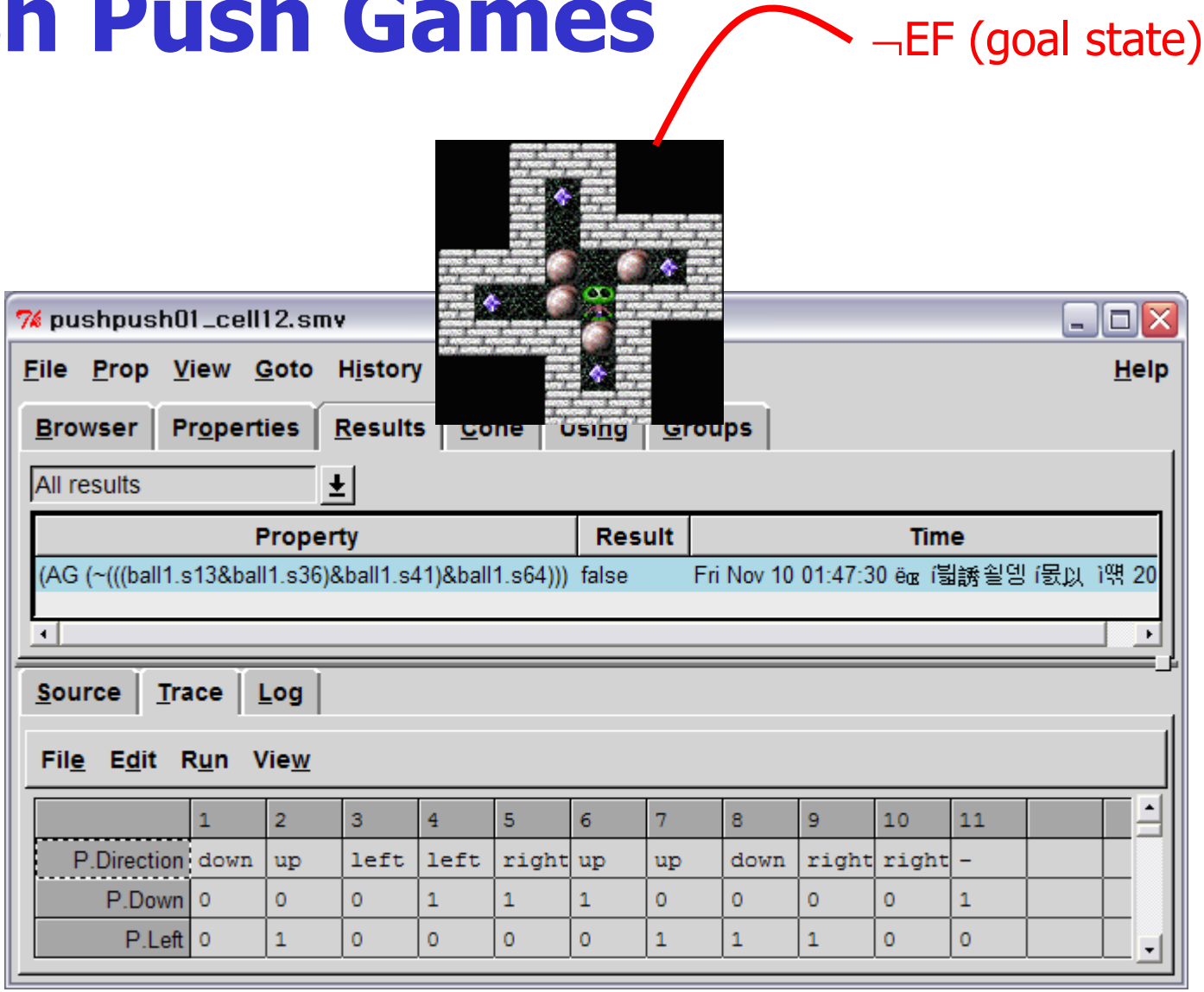
Two questions

Is there a feasible path to a goal state ?

Which one is optimal ?

Push Push Games

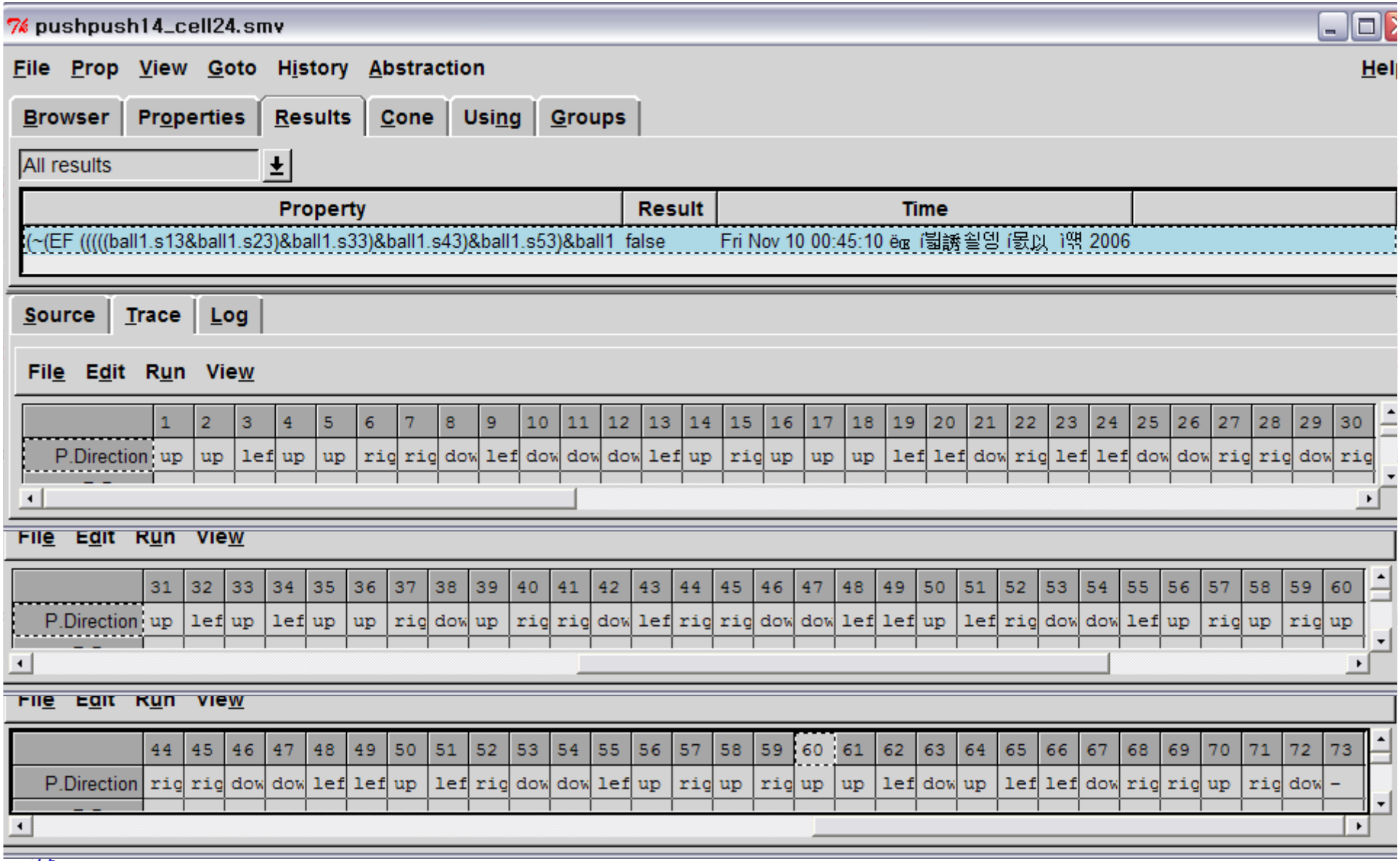
¬EF (goal state)



Quiz #4

¬EF (13 & 23 & 33 & 43 & 53 & 63)

Solution


pushpush14_cell24.smv
File Prop View Goto History Abstraction
Browser Properties Results Cone Using Groups
All results
Property
Result
Time
(~(EF ((((ball1.s13&ball1.s23)&ball1.s33)&ball1.s43)&ball1.s53)&ball1
false
Fri Nov 10 00:45:10
Source Trace Log
File Edit Run View
P.Direction
up up lef up up rig rig dow lef dow dow dow lef up rig up up up lef lef dow rig lef lef dow dow rig rig dow rig
P.Direction
up lef up lef up up rig dow up rig rig dow lef rig rig dow dow lef lef up lef rig dow dow lef up rig up rig up
P.Direction
rig rig dow dow lef lef up lef rig dow dow lef up rig up rig up up lef dow up lef lef dow rig rig up rig dow –

Push Push Games

50 levels

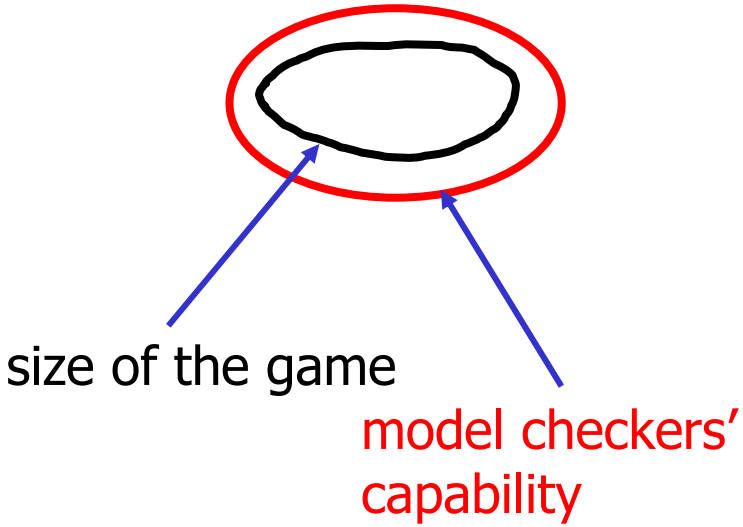
Model Checking Results

Level	Time(sec)	Memory(MB)	BDD
1	0.6	2	10190
2	3.6	6	162264
3	33.8	32	1179417
4	0.7	3	43314
5	1.0	3	45487
6	123.3	93	3293300
7	53.6	37	1493151
8	> 24 hours		
9	11.0	11	352558
10	5.0	8	260339
11	6.2	8	260339
12	10.7	12	409438
13	355.3	240	9794593
14	125.8	80	3490931
15	> 24 hours		
16	16.5	16	514515
17	> 24 hours		
18	1200.0	508	22391859
19	1200.0	613	27678695
20	> 24 hours		
21	2880.0	1109	48330206
22	420.0	219	8571816
23	3000.0	870	34901698
24	600.0	317	14238083
25	10.0	305	13229503

Level	Time(sec)	Memory(MB)	BDD
26	60.0	34	1352886
27	30.0	20	753887
28	420.0	210	8046131
29	16.0	13	493167
30	> 24 hours		
31	1020.0	500	20533835
32	> 24 hours		
33	> 24 hours		
34	> 24 hours		
35	> 24 hours		
36	> 24 hours		
37	2200.0	854	34330495
38	28.0	18	635604
39	960.0	336	15431568
40	> 24 hours		
41	120.0	58	2245640
42	1260.0	532	23060315
43	480.0	299	13302604
44	1860.0	539	23143060
45	300.0	109	4242756
46	780.0	413	15742937
47	35.0	25	1019209
48	1980.0	841	33009636
49	> 24 hours		
50	> 24 hours		

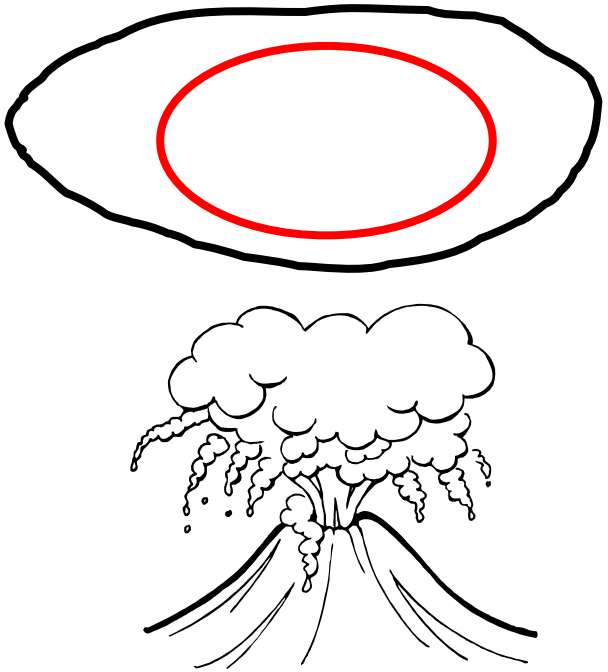
Naïve Model Checking Results

37 levels are solved



no state explosion ☺

13 levels are failed

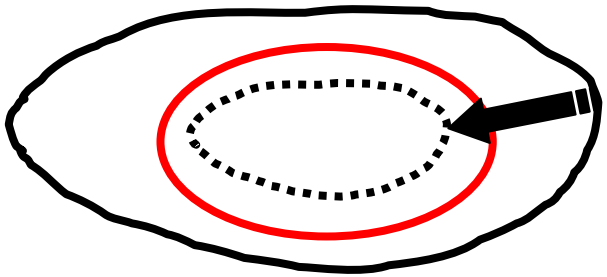


state explosion occurs ☹

How to avoid the state explosion ?

State Explosion Avoidance

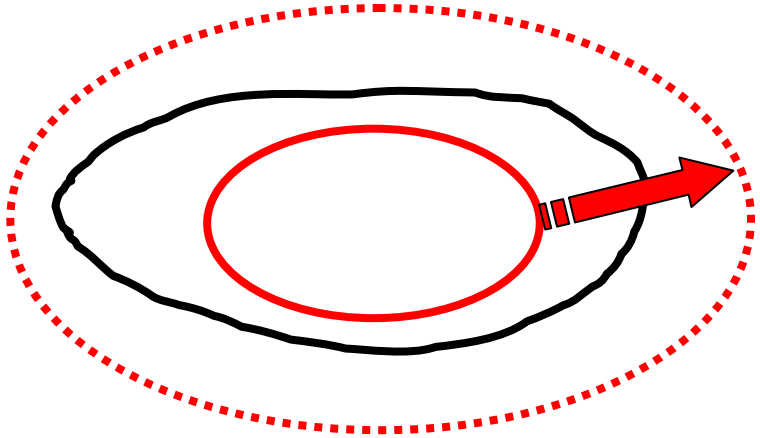
Defensive approach



- Abstraction
- Symmetry reduction
- Partial order reduction

……

Offensive approach

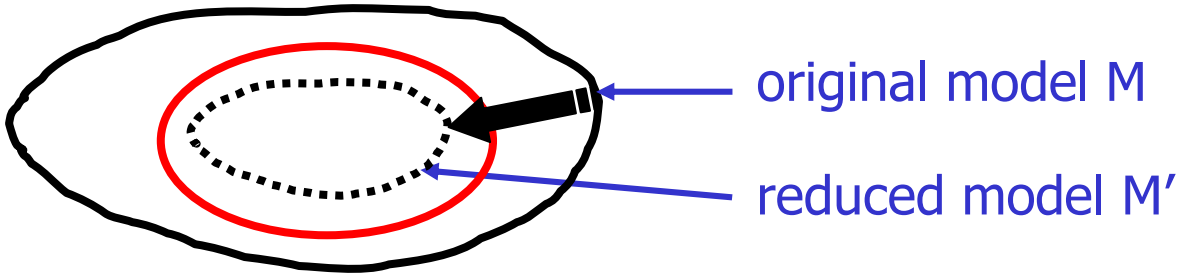


- Efficient data structures
- Distributed and parallelized
- Buy an expensive computer

……

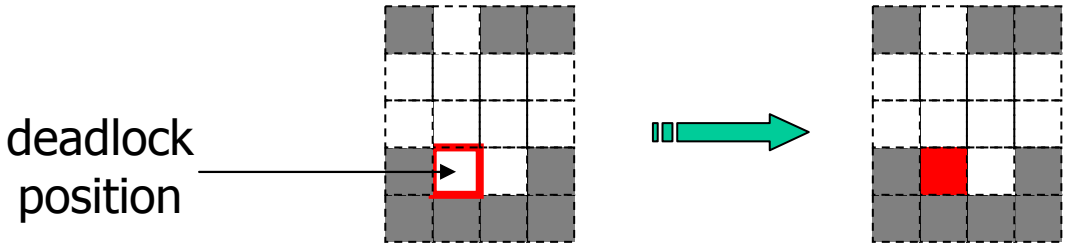
Abstraction

Reduction of the original model into a smaller one

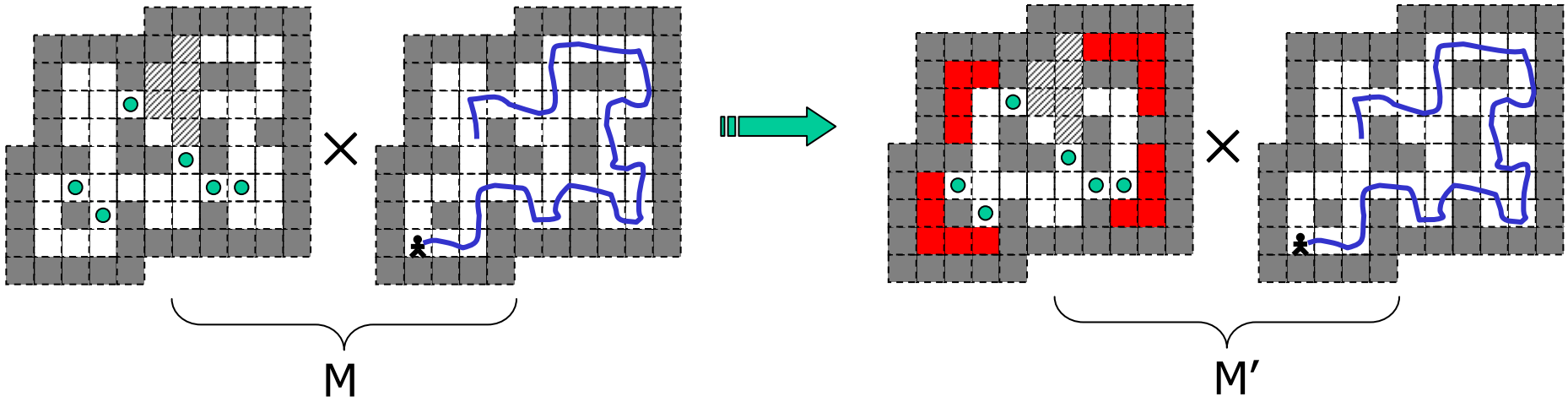


- Removing irrelevant parts w.r.t. properties to be verified
- Reduced model M' still preserves properties of interests

Which parts abstracted away ?



Abstraction



$M \equiv M'$ w.r.t. witness

$M' \models \text{witness} \Rightarrow M \models \text{witness}$

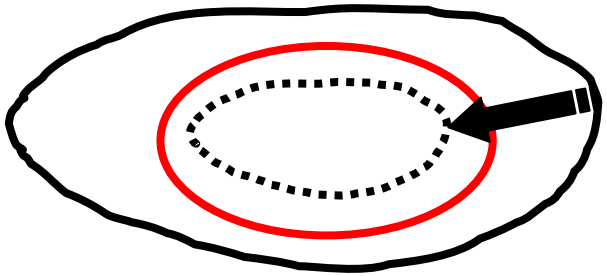
Abstraction Results

Level	Time(sec)	Memory(MB)	BDD
1	0.1	< 1	6523
2	0.5	5	53669
3	2.6	7	181424
4	0.5	< 1	51241
5	0.3	< 1	23324
6	7.5	11	399445
7	8.1	13	361845
8	53.9	105	4037813
9	0.3	< 1	23287
10	0.4	< 1	34465
11	0.3	< 1	32802
12	1.5	6	135401
13	0.4	< 1	29385
14	2.3	7	172012
15	167.8	190	8495225
16	0.5	< 1	45514
17	415.0	470	13184027
18	8.1	21	586773
19	209.0	325	11037872
20	224.0	358	13007571
21	14.8	26	893813
22	52.5	59	2337064
23	79.0	67	4278917
24	7.1	17	611142
25	13.5	25	697371

Level	Time(sec)	Memory(MB)	BDD
26	5.4	8	269886
27	3.0	7	233811
28	4.8	13	376884
29	1.4	5	118553
30	248.1	< 1	28265959
31	8.3	16	655700
32	9.9	20	759229
33	168.2	298	9446378
34	101.8	113	4510854
35	98.6	133	5571438
36	73.6	122	5004938
37	7.7	18	647170
38	3.0	8	237044
39	10.4	11	399459
40	4.3	13	357824
41	3.4	10	310274
42	25.0	40	1195649
43	223.3	272	11769524
44	12.9	18	659379
45	6.5	13	336695
46	10.2	17	595338
47	1.8	5	134084
48	16.6	35	1390943
49	234.2	321	10880846
50	> 24 hours		

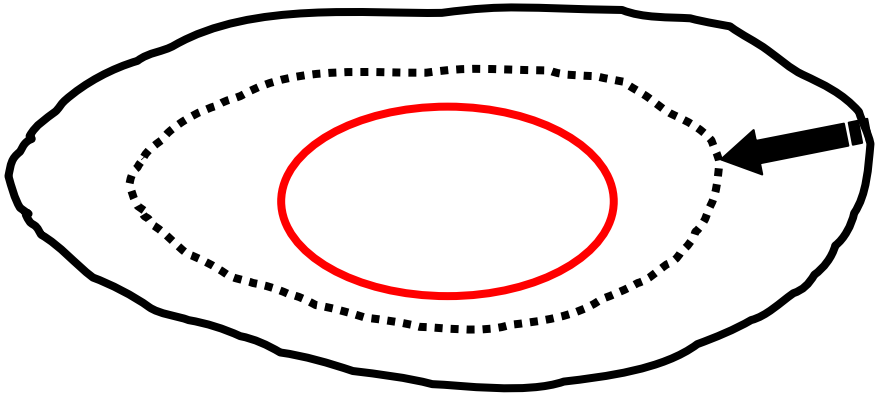
Abstraction Results

49 levels are solved



no state explosion ☺

Last level is failed



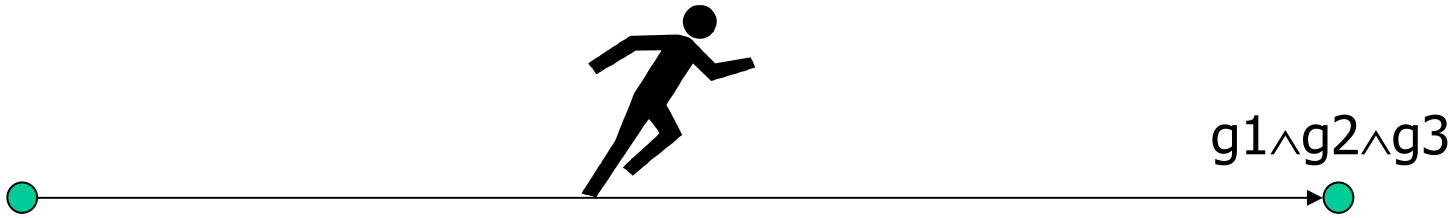
state explosion occurs ☹

A reduced model is still too large

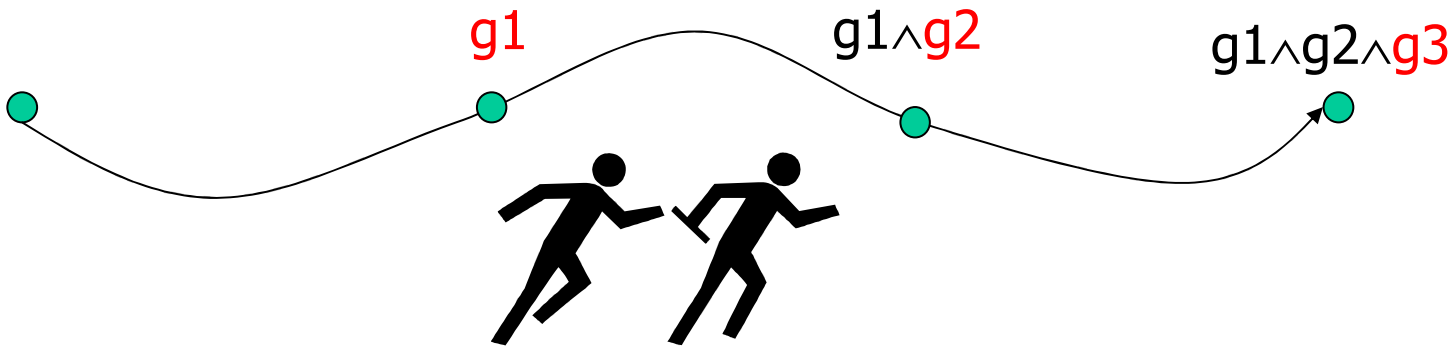
What have to do when abstraction is failed ?

Relay Model Checking

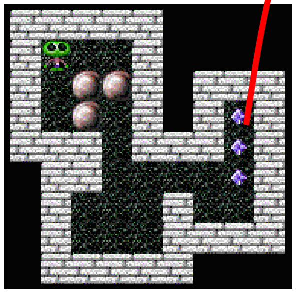
Conventional model checking



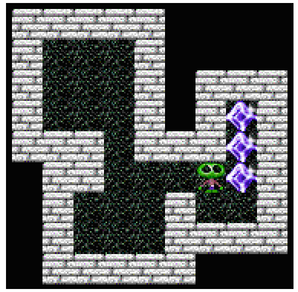
Divide and conquer



Relay Model Checking



¬EF (73 & 74 & 75)



(~(EF ((ball1.s75&ball1.s74)&ball1.s73))) false Fri Dec 01 01:23:32 ëœ í븲誘쐴뎁 í뮳以 í뼢 2006

Source Trace Log

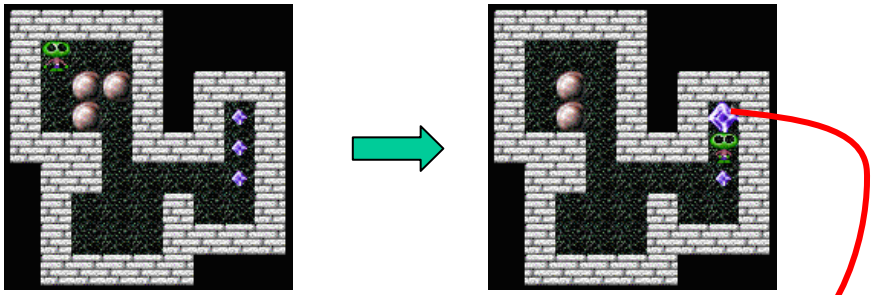
File Edit Run View

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
P.Direction	rig	rig	dow	dow	dow	dow	rig	dow	dow	lef	lef	up	rig	dow	rig	up	lef	up	up	up	up	up	lef	lef	dow	rig	up	rig	dow	dow

31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
dow	dow	rig	rig	rig	dow	rig	up	up	dow	lef	lef	lef	dow	dow	lef	lef	up	rig	dow	rig	up	lef	up	up	up	up	lef	lef	dow

61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
rig	up	rig	dow	dow	dow	rig	rig	rig	dow	rig	up	lef	lef	lef	dow	dow	lef	lef	up	rig	dow	rig	up	lef	up	rig	rig	rig	–

Relay Model Checking



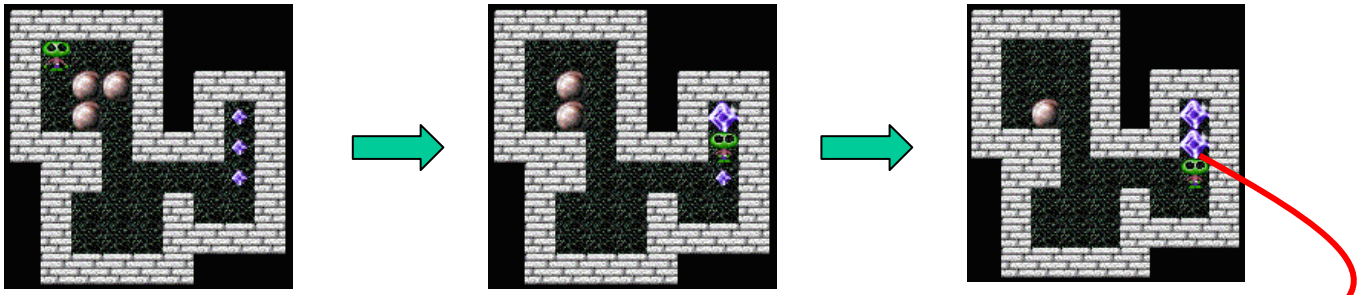
(~(EF ball1.s75)) false Fri Dec 01 01:29:41 ëœ ì¼ìš”ì¼ì´ì—ìš” ì˜¤ì „ 2006

Source | Trace | Log

File Edit Run View

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
P.Direction	rig	rig	dow	dow	dow	dow	rig	dow	dow	lef	lef	up	rig	dow	rig	up	lef	up	rig	rig	rig	dow	rig	up	up	-
P.Down	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0
P.s	17	27	37	36	35	34	33	43	42	41	31	21	22	32	31	41	42	32	33	43	53	63	62	72	73	74

Relay Model Checking



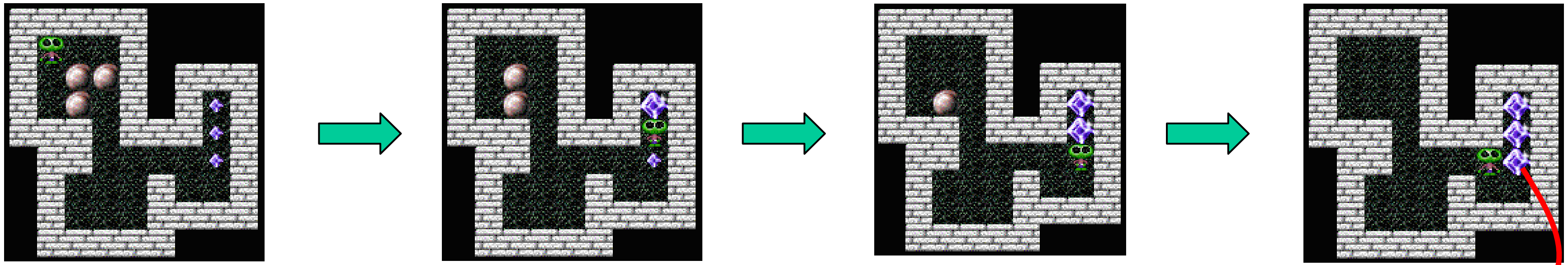
(~(EF ball1.s74)) false Fri Dec 01 01:43:13 ëœ ì§€ë‚œ ì¼ìš”ì¼ ì˜¤ì „ 2006

Source | Trace | Log

File Edit Run View

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
P.Direction	dc	le	le	le	le	up	up	up	up	le	le	dc	ri	up	ri	dc	dc	dc	dc	ri	dc	dc	le	le	up	ri	dc	ri	up	le	up	ri	ri	ri	dc	ri	up	-	
P.canright	1	1	1	1	1	1	0	0	0	0	1	1	1	0	1	0	0	0	0	1	1	0	0	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	
P.s	74	73	63	53	43	33	34	35	36	37	27	17	16	26	27	37	36	35	34	33	43	42	41	31	21	22	32	31	41	42	32	33	43	53	63	62	72	73	

Relay Model Checking



(~(EF ball1.s73)) false Fri Dec 01 01:57:46 2006

Source | Trace | Log

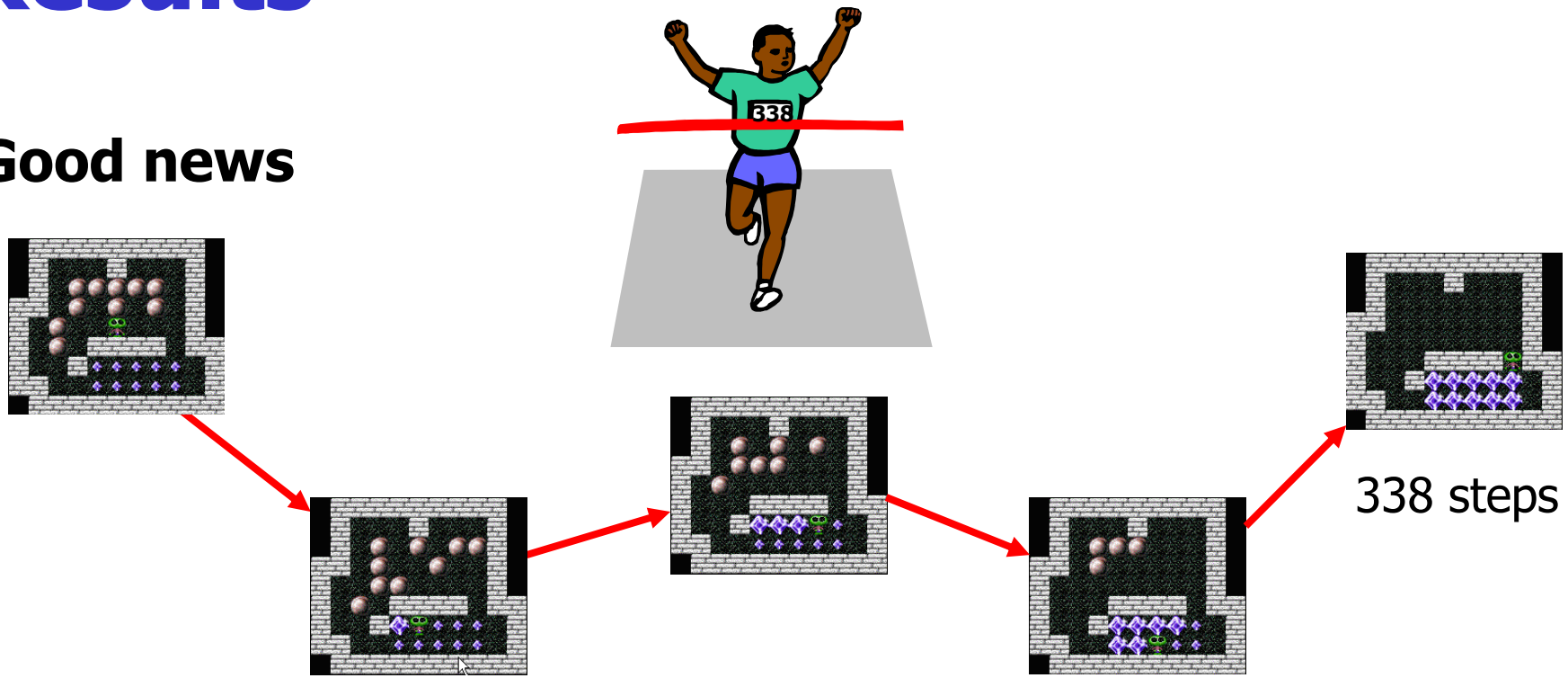
File Edit Run View

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
P.Direction	le	le	le	le	up	up	up	le	le	dc	ri	up	ri	dc	dc	dc
P.canup	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
P.s	73	63	53	43	33	34	35	36	26	16	15	25	26	36	35	34

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
P.Direction	ri	dc	dc	le	le	up	ri	dc	ri	up	le	up	ri	ri	ri	–
P.canup	1	0	1	1	1	1	0	1	1	1	0	1	1	0	0	0
P.s	33	43	42	41	31	21	22	32	31	41	42	32	33	43	53	63

Results

Good news



Bad news

338 steps is not optimal

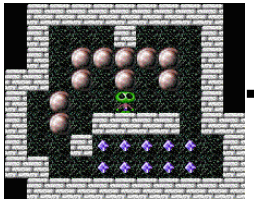
How to get the optimal solution ?

Observations

#1. Conservative, not complete

- Not always working.
- But if it works, then the path is a witness in an original model.

#2. Goal ordering is important



→ Linear ordering of subgoals

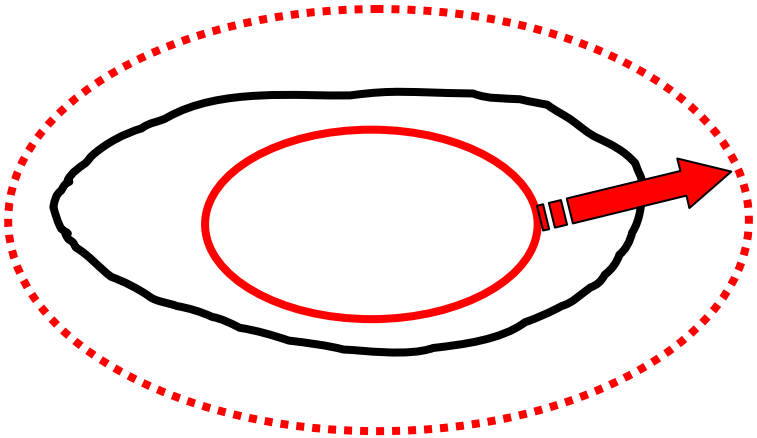
#3. No guarantees an optimal solution

- Optimization is needed

#4. Sometimes, we get lost on the way to a goal

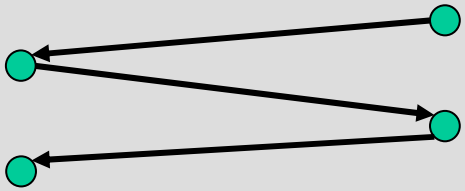
- Guiduance is needed

Modified Model Checker



Current NuSMV

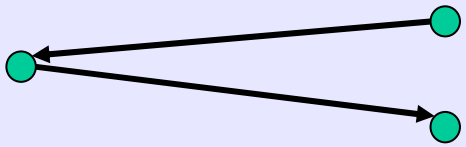
- 3 times traversals



- BDD storage on RAM

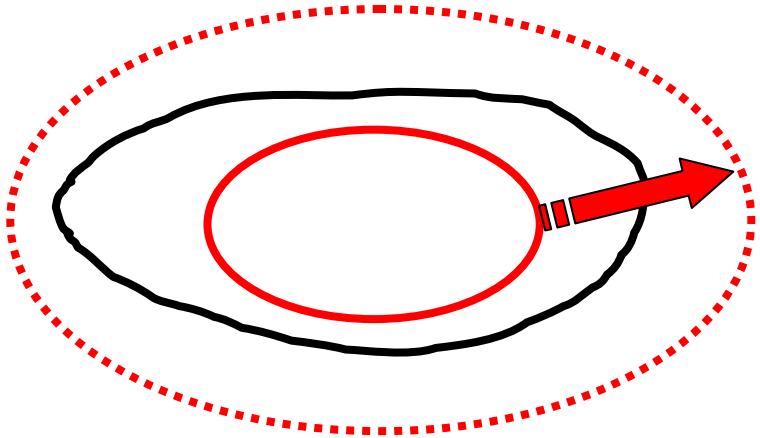
Modified NuSMV

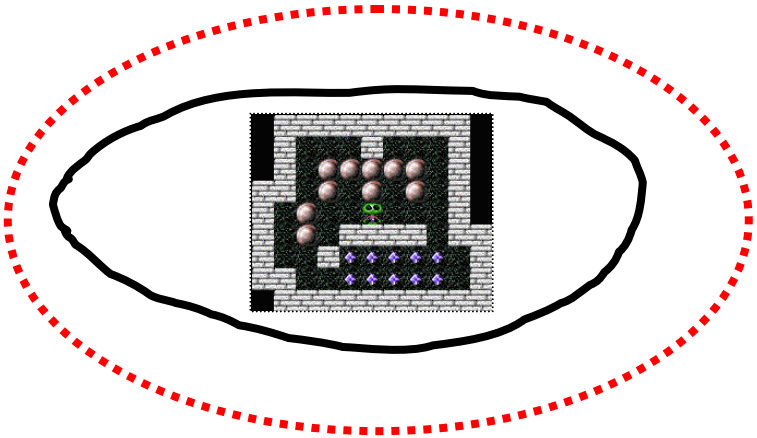
- 2 times traversals



- BDD storage on HD

Modified Model Checker

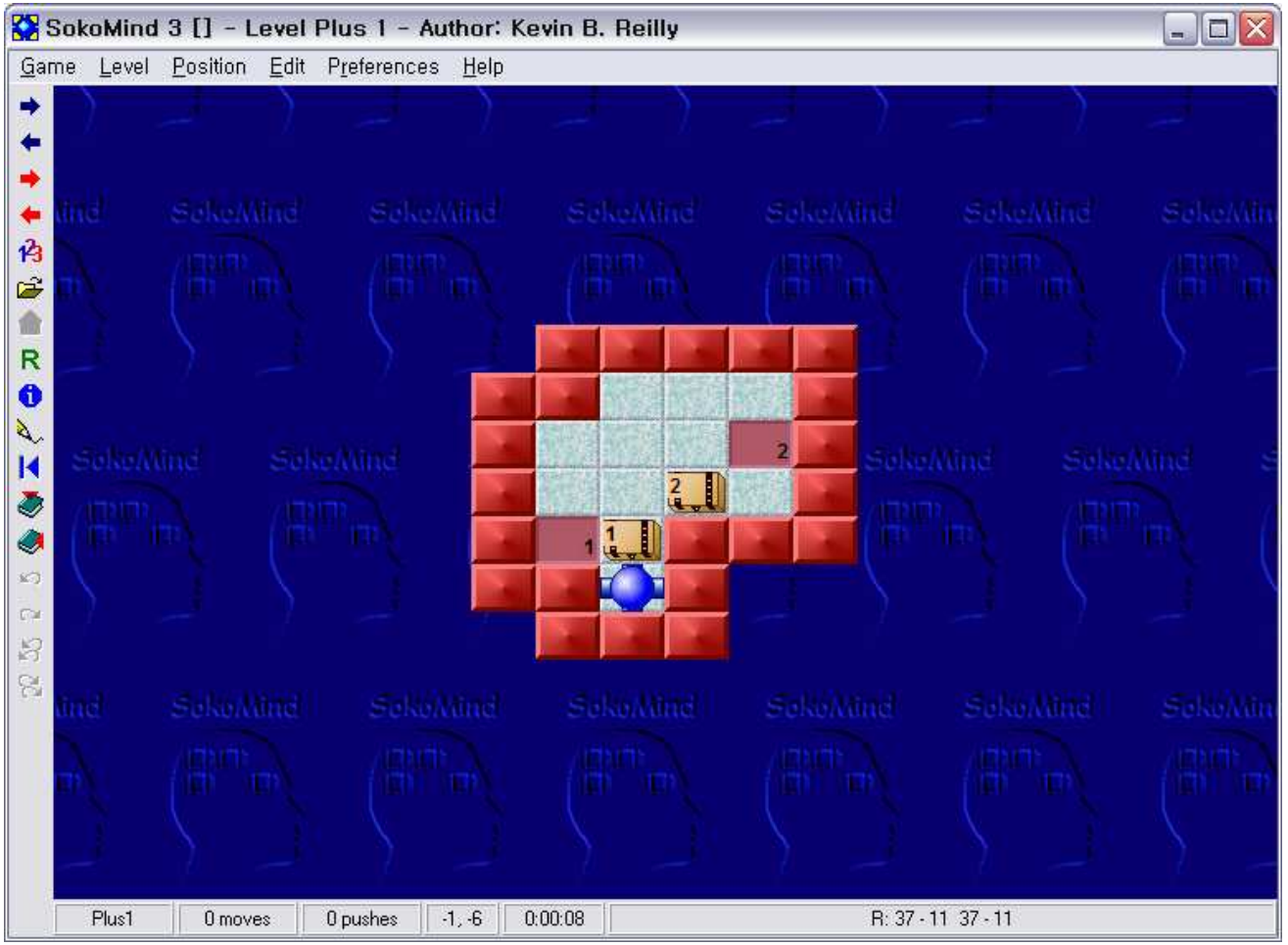




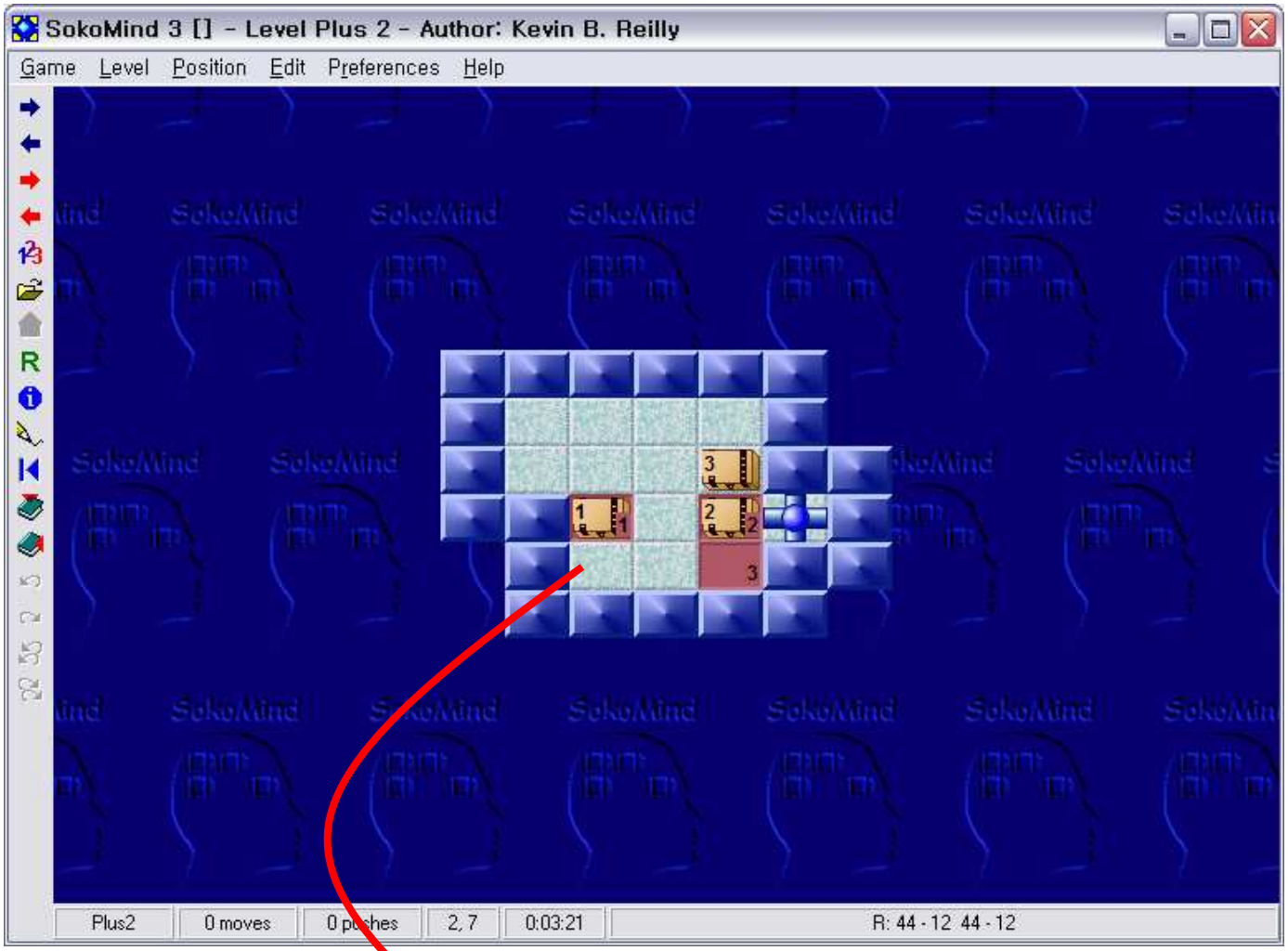
322 steps

Eventually we get an optimal path !!

SokoMind-PLUS Game

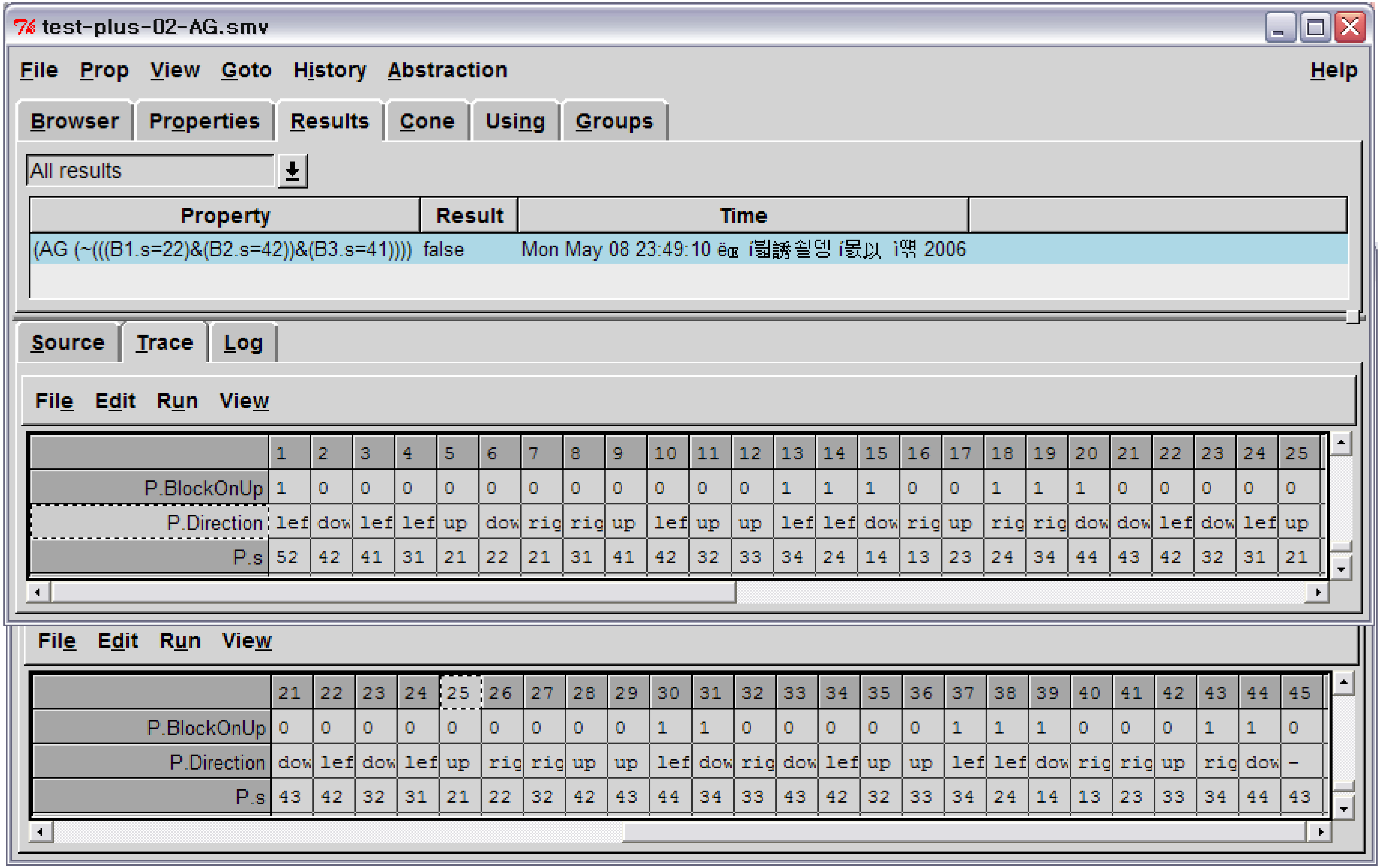


Quiz #4



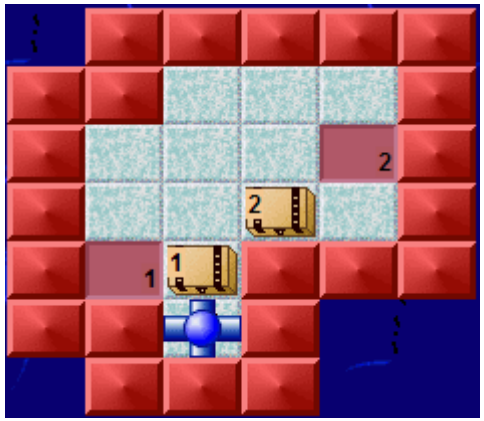
¬EF (ball1=goal1 & ball2=goal2 & ball3=goal3)

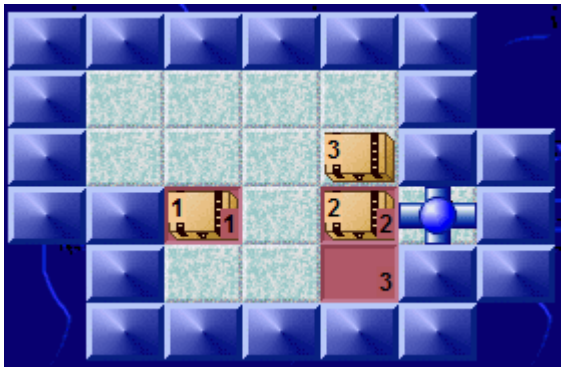
Solution

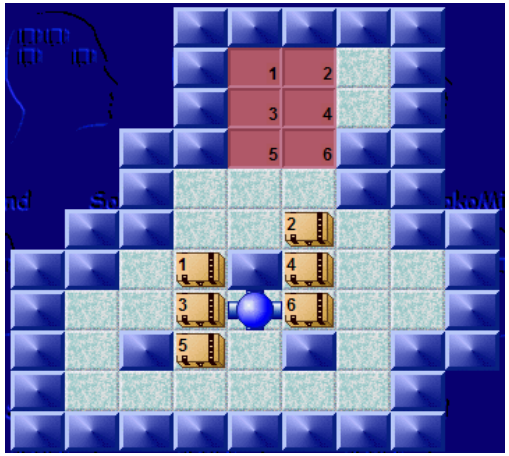

test-plus-02-AG.smv
File Prop View Goto History Abstraction Help
Browser Properties Results Cone Using Groups
All results
Property | Result | Time
(AG (~(((B1.s=22)&(B2.s=42))&(B3.s=41)))) false Mon May 08 23:49:10 2006
Source Trace Log
File Edit Run View
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
P.BlockOnUp 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 1 1 1 0 0 0 0 0
P.Direction lef dow lef lef up dow rig rig up lef up up lef lef dow rig up rig rig dow dow lef dow lef up
P.s 52 42 41 31 21 22 21 31 41 42 32 33 34 24 14 13 23 24 34 44 43 42 32 31 21
File Edit Run View
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
P.BlockOnUp 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 1 1 1 0 0 0 1 1 0
P.Direction dow lef dow lef up rig rig up up lef dow rig dow lef up up lef lef dow rig rig up rig dow -
P.s 43 42 32 31 21 22 32 42 43 44 34 33 43 42 32 33 34 24 14 13 23 33 34 44 43

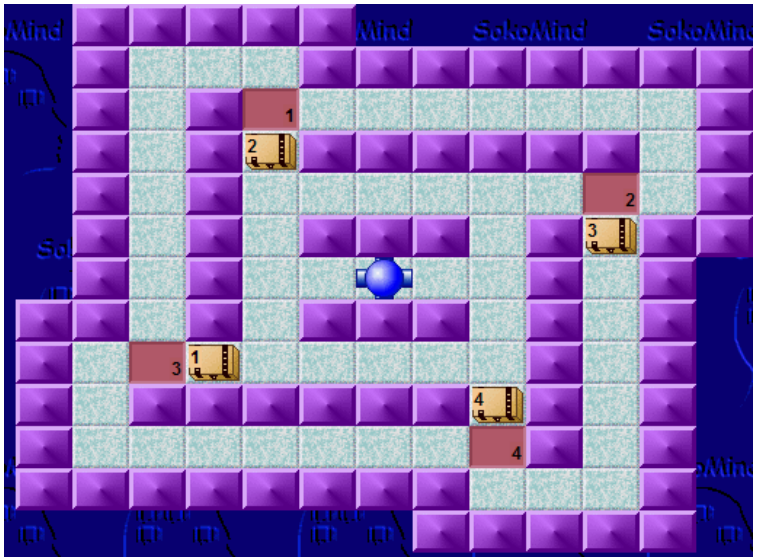
Sokomind-PLUS Game

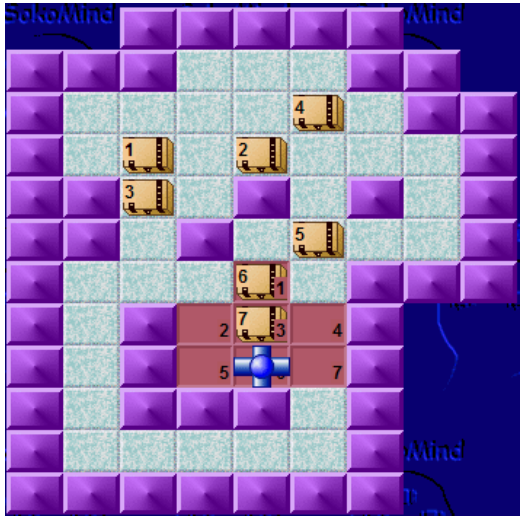
20 levels











Model Checking Results

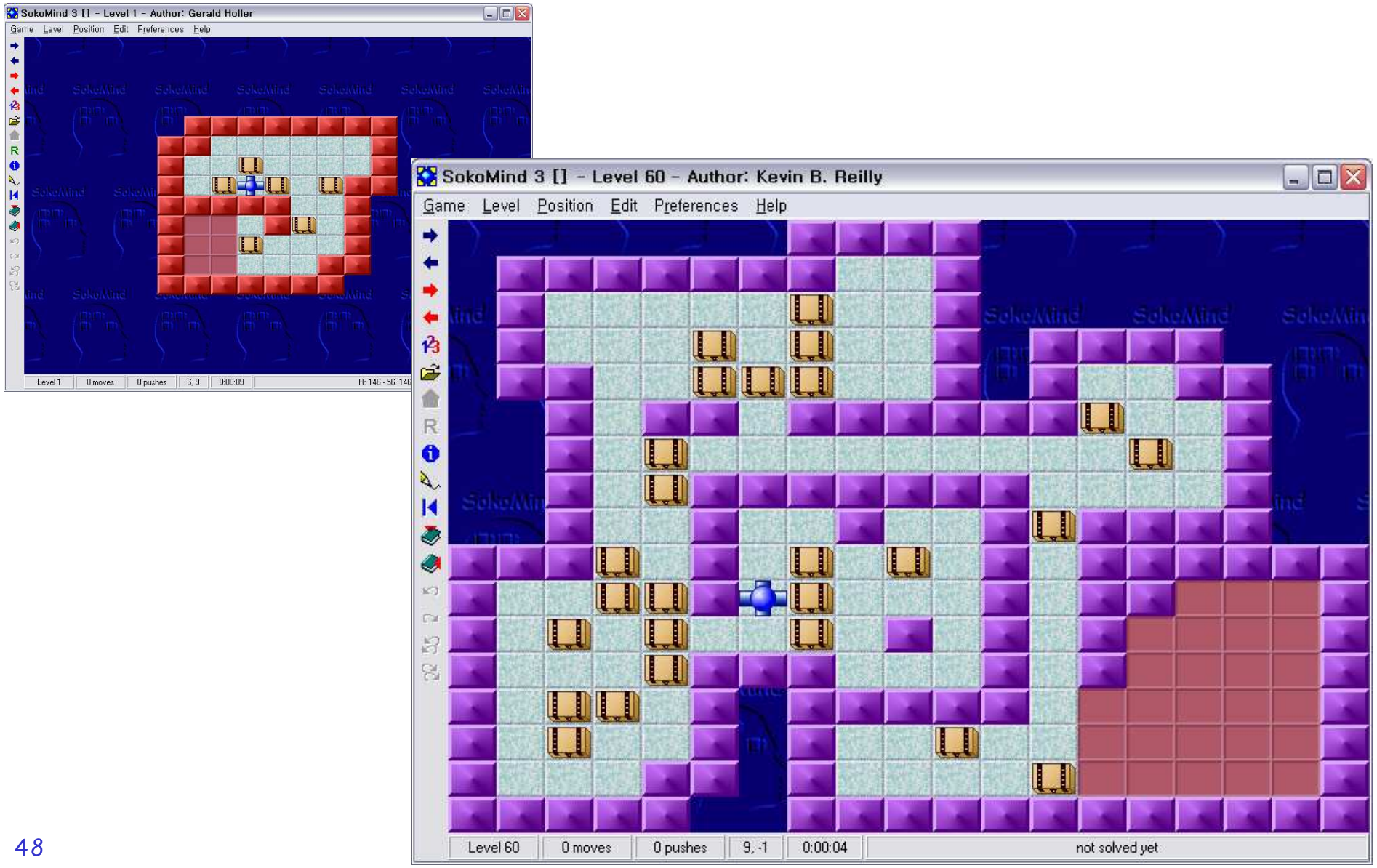
Game	Time (sec)	Space (KB)	Best Moves by human	Best Moves by MC	Remarks
1	0.88	4,245	37	37	–
2	0.08	2,217	44	44	–
3	0.55	3,381	60	60	–
4	0.35	3,055	53	53	–
5	0.15	2,515	77	77	–
6	0.22	2,771	129	129	–
7	6.69	12,009	117	117	–
8	2,739.91	353,037	154	154	–
9	291.80	38,937	97	97	–
10	795.58	93,493	99	99	–
11	1,070.81	215,445	234	234	–
12	**15,659.66**	**916,689**	**336**	**328**	**↓8**
13	**47.18**	**13,181**	**154**	**152**	**↓2**
14	40.68	13,477	199	199	–
15	**681.81**	**66,369**	**339**	**337**	**↓2**

(↓*n* means the game is solved in *n* fewer steps)

But 16th ~ 20th levels are failed !!

SokoMind Games

60 levels

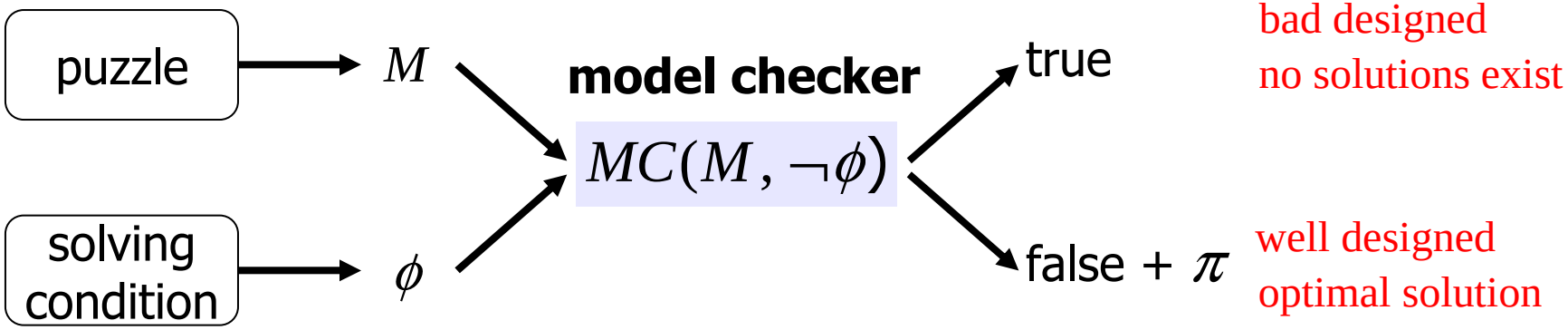


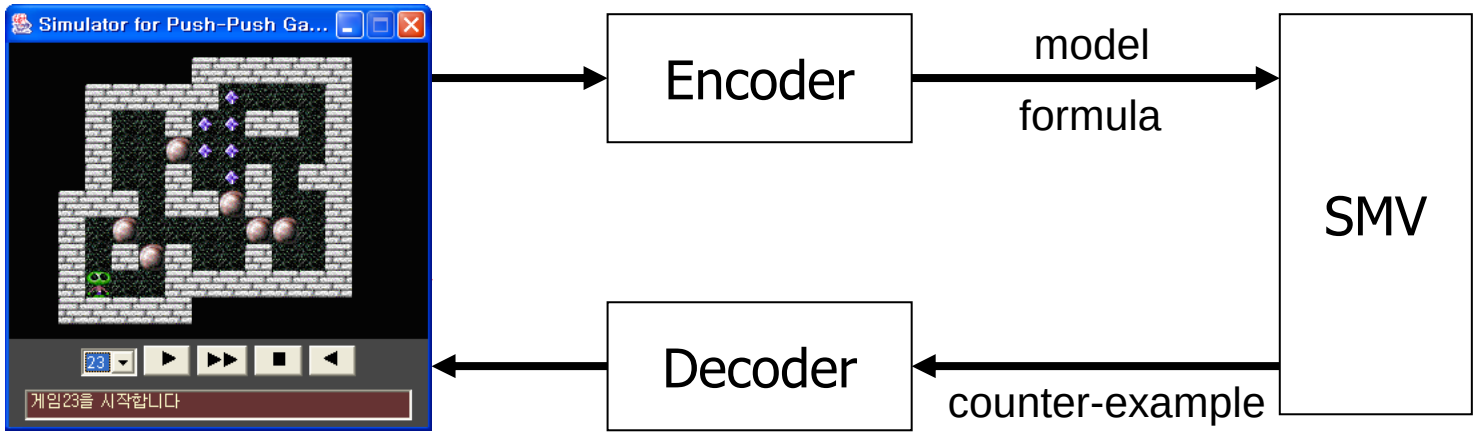
Model Checking Results

Level	Number of positions	Number of steps	World records	Remark
1	37	146	146	solved
2	25	81	81	solved
3	24	70	70	solved
4	47	229	229	solved
5	54		313	failed
6	49	165	165	solved
7	51	229	229	solved
8	39	187	187	solved
9	62		307	failed
10	20	58	58	solved

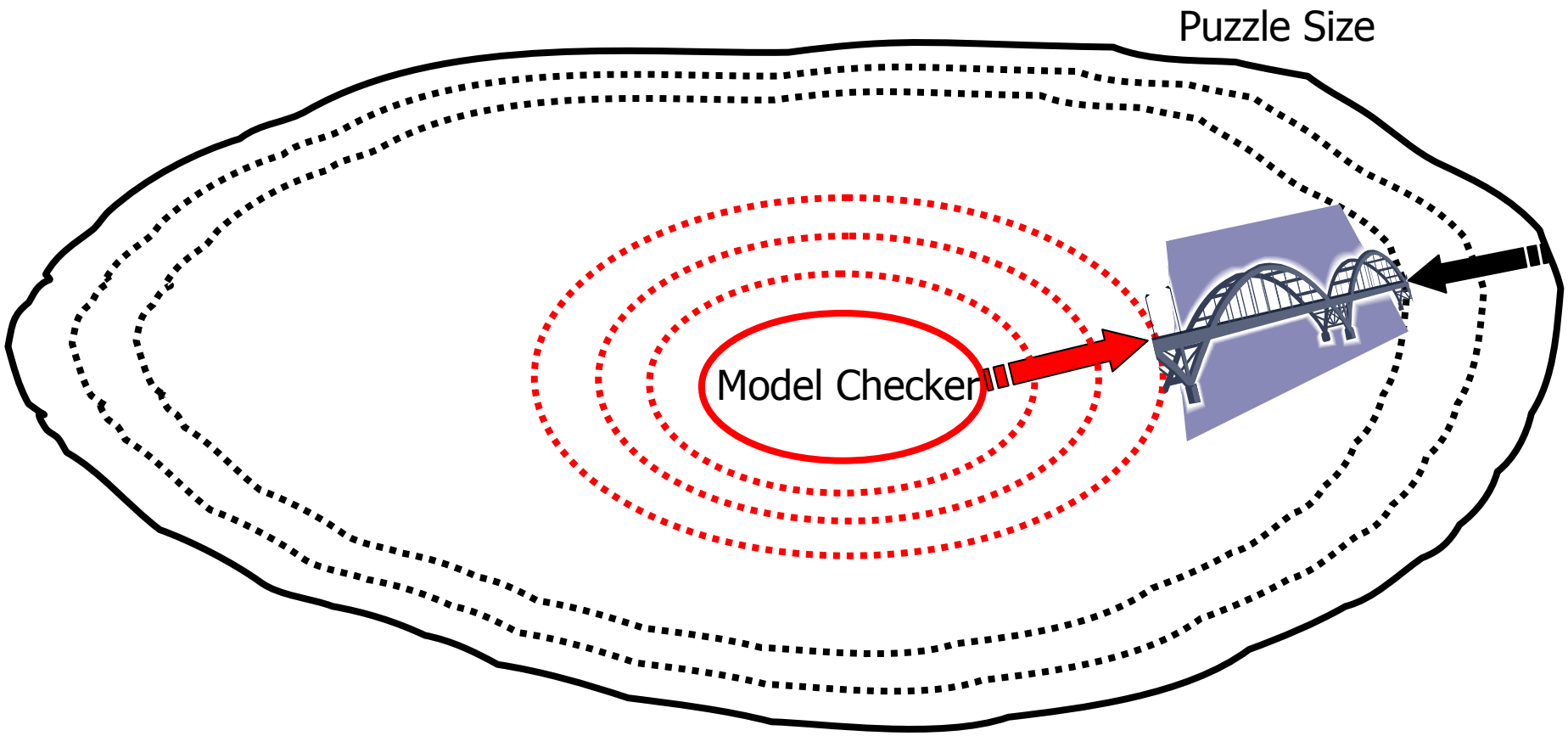
Level	Number of positions	Number of steps	World records	Remark
11	71		456	failed
12	77		365	failed
13	71		433	failed
14	66		369	failed
				failed
				failed
				failed
				failed
59	.....		.....	failed
60	.....		.....	failed

Puzzles as Model Checking Problem





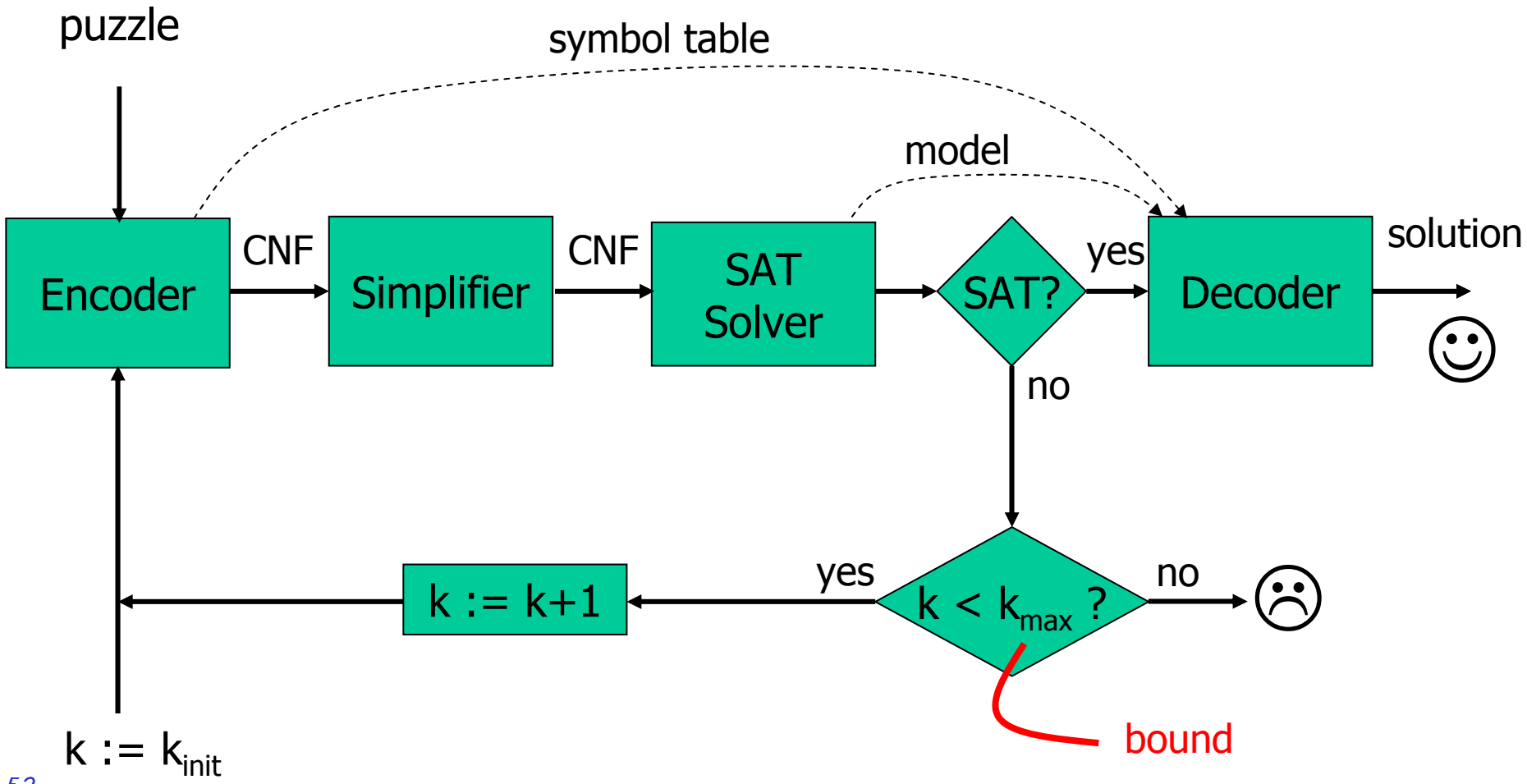
However



How to bridge the gap ?

Challeange Works

Puzzles as Bounded Model Checking Problem

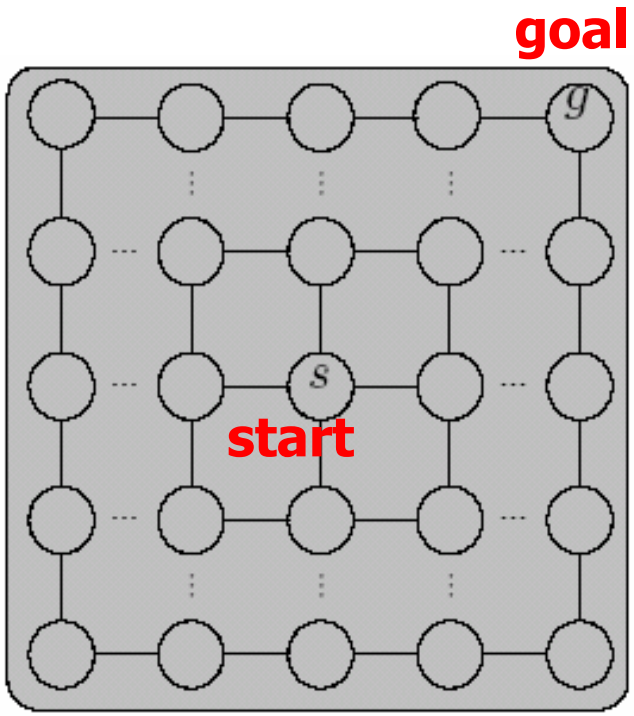


Challeange Works

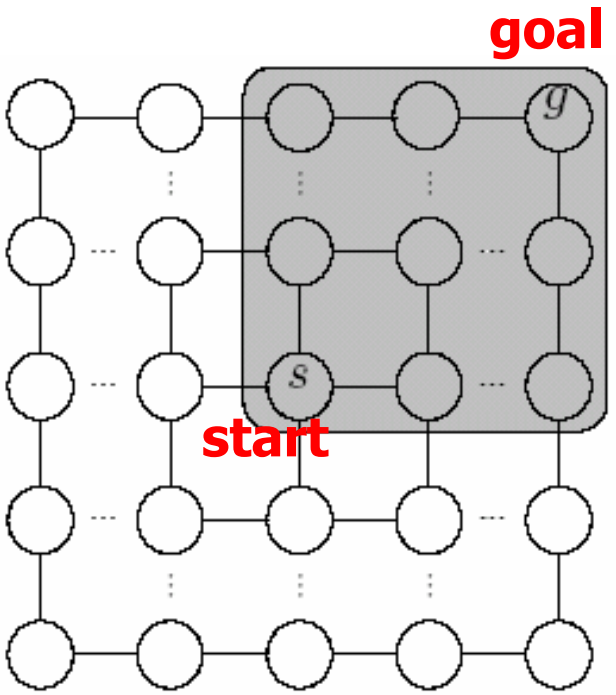
Puzzles as Directed Model Checking Problem

explicit MC
+
guided search

Traditional
Model Checking



Directed
Model Checking



Challeange Works

Puzzles are waiting for Your Breakthrough Technique !!

Thank You!!