CS 171 Intro to AI

Mini Project Report

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Backtrace Count and Time Report

** Due to the extreme complexity of some test cases, some of the cases below were not solved within reasonable time, and their results are marked "N/A".*

File / Test No.	Consistency Check	Value Heuristic	Variable Heuristic	Backtrace Count	Total Time (s)	Note
PE1, 1	FC			6	0.1535	
PE1, 2	FC			6	0.144	
PE1, 3	FC			6	0.1515	
PE1, 4	ACP			3	0.056	
PE1, 5	ACP			3	0.0494	
PE1, 6	ACP			3	0.0512	
PE2, 1	FC	NKP		7	0.155	
PE2, 2	FC	NKT		8	0.0192	
PE2, 3	FC	NKP NKT		6	0.142	
PE2, 4	ACP	NKP		3	0.102	
PE2, 5	ACP	NKT		3	0.0995	
PE2, 6	ACP	NKP NKT		3	0.106	
PE3, 1	FC		MRV	42	0.864	
PE3, 2	FC		DH	3083	36.5	
PE3, 3	FC		LCV	73	0.875	
PE3, 4	ACP		MRV	13	0.203	
PE3, 5	ACP		DH	1024	5.28	
PE3, 6	ACP		LCV	25	0.255	
PE4, 1	FC	NKP	MRV	3	0.174	
PE4, 2	FC	NKP	DH	22	0.319	
PE4, 3	FC	NKP	LCV	2	0.16	
PE4, 4	ACP	NKP	MRV	0	0.0511	
PE4, 5	ACP	NKP	DH	9	0.188	
PE4, 6	ACP	NKP	LCV	0	0.0522	
PE5, 1	FC	NKT	MRV	5	0.0939	
PE5, 2	FC	NKT	DH	10	0.114	
PE5, 3	FC	NKT	LCV	5	0.0933	
PE5, 4	ACP	NKT	MRV	4	0.0477	
PE5, 5	ACP	NKT	DH	7	0.0839	
PE5, 6	ACP	NKT	LCV	4	0.0495	

Table 1. Easy level Sudoku

File / Test No.	Consistency Check	Value Heuristic	Variable Heuristic	Backtrace Count	Total Time (s)
PM1, 1	FC			2947	109.3
PM1, 2	FC			2947	106.7
PM1, 3	FC			2947	108.5
PM1, 4	ACP			1719	24.1
PM1, 5	ACP			1719	23.4
PM1, 6	ACP			1719	23.6
PM2, 1	FC	NKP		N/A	N/A: t > 600s
PM2, 2	FC	NKT		1713	66.3
PM2, 3	FC	NKP NKT		N/A	N/A: t > 600s
PM2, 4	ACP	NKP		15293	220.3
PM2, 5	ACP	NKT		14263	201.2
PM2, 6	ACP	NKP NKT		8419	129.6
PM3, 1	FC		MRV	64	4.79
PM3, 2	FC		DH	N/A	N/A: t > 600s
PM3, 3	FC		LCV	859	32.4
PM3, 4	ACP		MRV	27	1.06
PM3, 5	ACP		DH	N/A	N/A: t > 600s
PM3, 6	ACP		LCV	611	8.16
PM4, 1	FC	NKP	MRV	2	2.15
PM4, 2	FC	NKP	DH	N/A	N/A: t > 600s
PM4, 3	FC	NKP	LCV	N/A	N/A: t > 600s
PM4, 4	ACP	NKP	MRV	3	0.988
PM4, 5	ACP	NKP	DH	N/A	N/A: t > 600s
PM4, 6	ACP	NKP	LCV	N/A	N/A: t > 600s
PM5, 1	FC	NKT	MRV	354	17.3
PM5, 2	FC	NKT	DH	N/A	N/A: t > 600s
PM5, 3	FC	NKT	LCV	270	10.7
PM5, 4	ACP	NKT	MRV	184	4.02
PM5, 5	ACP	NKT	DH	N/A	N/A: t > 600s
PM5, 6	ACP	NKT	LCV	178	3.18

Table 2. Moderate level Sudoku.

File / Test No.	Consistency Check	Value Heuristic	Variable Heuristic	Backtrace Count	Total Time (s)
PH1, 1	FC			8597	504.4
PH1, 2	FC			8597	503.2
PH1, 3	FC			8597	505.1
PH1, 4	ACP			8520	533
PH1, 5	ACP			8520	500.8
PH1, 6	ACP			8520	516
PH2, 1	FC	NKP		183	13.46
PH2, 2	FC	NKT		24	3.16
PH2, 3	FC	NKP NKT		16	2.43
PH2, 4	ACP	NKP		107	6.34
PH2, 5	ACP	NKT		16	3.27
PH2, 6	ACP	NKP NKT		11	2.95
PH3, 1	FC		MRV	N/A	N/A: t > 1200s / 20 min
PH3, 2	FC		DH	N/A	N/A: t > 1200s / 20 min
PH3, 3	FC		LCV	N/A	N/A: t > 1200s / 20 min
PH3, 4	ACP		MRV	N/A	N/A: t > 1800s / 30 min
PH3, 5	ACP		DH	N/A	N/A: t > 1800s / 30 min
PH3, 6	ACP		LCV	N/A	N/A: t > 1800s / 30 min
PH4, 1	FC	NKP	MRV	3670	353.1
PH4, 2	FC	NKP	DH	N/A	N/A: t > 1800s / 30 min
PH4, 3	FC	NKP	LCV	10230	880.2
PH4, 4	ACP	NKP	MRV	2245	103.7
PH4, 5	ACP	NKP	DH	N/A	N/A: t > 1800s / 30 min
PH4, 6	ACP	NKP	LCV	4262	177.7
PH5, 1	FC	NKT	MRV		
PH5, 2	FC	NKT	DH	N/A	N/A: t > 1800s / 30 min
PH5, 3	FC	NKT	LCV	N/A	N/A: t > 1800s / 30 min
PH5, 4	ACP	NKT	MRV	28431	1224.88
PH5, 5	ACP	NKT	DH	N/A	N/A: t > 1800s / 30 min
PH5, 6	ACP	NKT	LCV	39986	1829

Table 3. Hard level Sudoku

I. Method

File Selections:

1. For consistency checks including Forward Checking (FC) and Arc Propagation (ACP) tests, test files ending with number 1 (PE1, PM1, PH1) were used.

2. For consistency checks followed by value heuristics, for example Naked Pairs (NKP) and Naked Triples (NKT), test files ending with number 2 (PE2, PM2, PH2) were used.

3. For consistency checks followed by variable heuristics, for example Minimum Remaining Value heuristic (MRV), Degree Heuristic (DH), Least Constraining Variable heuristic (LCV), test files ending with number 3 were used.

4. For use of consistency checks and variable heuristics in combined with NKP, test files ending with 4 were used.

5. For use of consistency checks and variable heuristics in combined with NKT, test files ending with 5 were used.

Maximum Time Settings:

1. For easy Sudoku games: no extreme case was expected so maximum time limit was set to 600 second (default).

2. For moderate Sudoku games: 600 second (10 minutes) was set as a reasonable maximum time. Games last longer than 10 minutes will be stopped at 10-minute time mark.

3. For hard Sudoku games: 1200 second (20 minutes) was originally set as the max time allowed. However, due to the low pass rate, 3600 second (60 minutes) and 1800 second (30 minutes) were set respectively for variable only heuristics and NKP / NKT combined tests.

II. Analysis

- For easy Sudoku games, consistency check only and value heuristic only tests showed minimum differences in backtrace counts and time consumption. As showed in Table 1, time consumption of the above tests was around 0.05 – 0.15 second. However, tests utilizing consistency checks in combined variable heuristics showed high time consumption and backtrace counts. Yet, no significant backtrace counts and time consumption was observed for tests utilizing all methods.

- For moderate Sudoku games, consistency check's complexity increased by a great extent from which it was in easy level. Value heuristics showed more increase in complexity, with occasional tests with prolonged durations. Rather, for variable heuristic, the

complexity experienced little changes compared to that in easy level. In addition, solver utilizing NKP and two other methods was the mostly successful as it achieved minimum increase in complexity from easy to moderate level.

- For hard Sudoku games, consistency check's complexity was increased furthermore. Yet, value heuristic showed a significant drop in complexity. Nevertheless, several tests that were not recorded on the table above showed that, test case PH2 was remarkably easy to solve when comparing to other hard level Sudoku problems. Besides, tests with variable heuristic MRV showed great performances in hard level games, as showed in Table 3. However, other variable heuristics did not outperform other heuristic or consistency checks.

- Solver with variable heuristic DH experienced the most significant increase in complexity compared to other heuristics. As showed in Table 1, 2, and 3, the initial backtrace count and total time was much higher than other methods. Whereas in moderate and hard levels, DH's time consumption exceeded the maximum / reasonable time limit and hence we conclude that DH could not succeed in Sudoku problem.

Conclusion

From what we have from the test data, we noticed that the best method with minimum complexities was Arc Consistency Propagation (ACP) combined with Naked Pairs (NKP) and Minimum Remaining Value heuristic (MRV). In easy level, ACP-NKP-MRV succeeds with 0 backtrace count and 0.0511 second of total time. In moderate level, ACP-NKP-MRV succeeds with 3 backtraces and 0.988 second. While in hard level, ACP-NKP-MRV succeeds with 2245 backtraces and 103.7 second total time. Therefore, we conclude that ACP-NKP-MRV is the best and optimal way of solving Sudoku games.

Advantages of ACP-NKP-MRV:

- ACP's asymptotic complexity: O(ed^3)
- NKP and MRV are the two methods closest to human's method while solve Sudoku.