Progress in *clasp* series 3

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Outline

1. Motivation
2. Disjunctive solving
3. Optimization
4. Heuristics
5. Configuration
6. Experiments
7. Summary

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Motivation

- DPLL *smodels*, *dlv*
  SAT *assat*, *cmodels*, *lp2sat*
  CDCL *clasp*, *wasp*

- Objective comprehensive description of *clasp*'s series 3
- Features of *clasp* series 3
  - parallel solving of disjunctive logic programs
  - parallel optimization with orthogonal strategies
  - declarative support for specifying domain heuristics
  - a portfolio of prefabricated expert configurations and
  - an application programming interface for library integration
- Empirical study contrasting them for solving optimization problems

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Solving disjunctive logic programs

- Fact Solving DLPs leads to an elevated level of complexity
- Equitable interplay between generating and testing solvers
  - n generating and $k \times n$ testing solvers (given k head cycle components)

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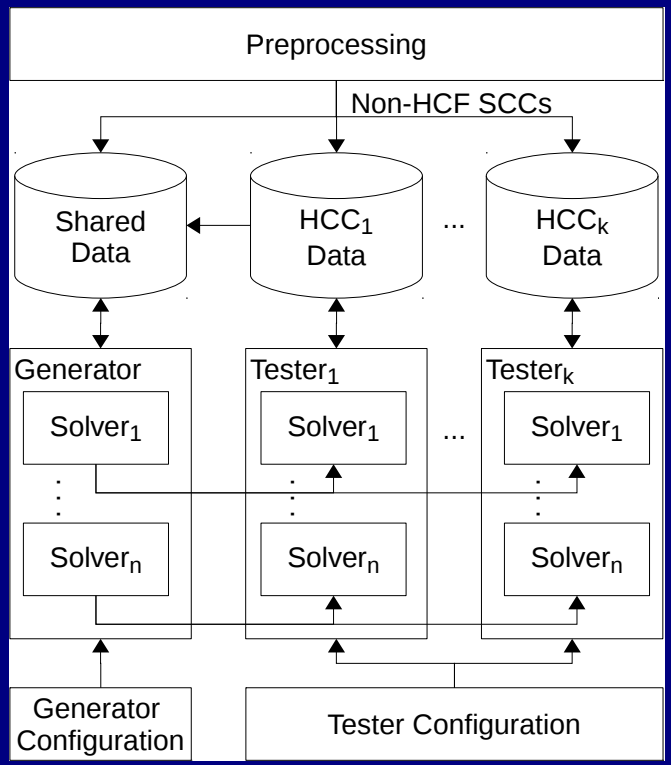

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- Preprocessing
  - `--pre` — Run preprocessing and exit
  - `gringo <file> | clasp --pre | cmodels`

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Optimization strategies

- Model-guided approach `--opt-strategy=bb,`*n*
  - classical branch-and-bound
  - SAT SAT...SAT UNSAT
- Core-guided approach `--opt-strategy=usc,`*n*
  - originated in MaxSAT community
  - UNSAT UNSAT...UNSAT SAT
- Combination via multi-threading
  - exchange of lower and upper bounds (in addition to nogoods)
- Enumeration of optimal models `--opt-mode=optN`
  - combinable with `--enum-mode`,
    eg. to compute intersection and union of optimal models

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Heuristic framework

- Change heuristic scores of atoms and signs `--heuristic=domain`
- Programmed heuristics expressed as a logic program
  - `_heuristic` (must be #shown)
  - `init`, `factor`, `level`, `sign`

```
_heuristic(occurs(A,T),factor,T) :- action(A), time(T).
```

- Structural heuristics invoked via command line options
  - `--dom-mod=`*m*`,`*p*
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- Structural heuristics invoked via command line options
  - Option `--dom-mod=`*m*`,`*p*
  - Modifiers `level`, `sign`
  - Example `--dom-mod=4,8`
    - 4 negative `sign`
    - 8 atoms in #minimize statements

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    ➥ often boosts convergence to minimum

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- Structural heuristics invoked via command line options
  - Option `--dom-mod=`*m*`,`*p*
  - Modifiers `level`, `sign`
  - Example `--dom-mod=5,16`

    5 `level` and negative `sign`

    16 atoms in #show statements

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    ➥ compute $\subseteq$-minimal models wrt shown atoms

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Prefabricated configurations and portfolios

- Option `--configuration`

`frumpy`	Use conservative defaults as used in earlier *clasp* versions
`jumpy`	Use more aggressive defaults (than `frumpy`)
`tweety`	Use defaults geared towards typical ASP problems
`trendy`	Use defaults geared towards industrial problems
`crafty`	Use defaults geared towards crafted problems
`handy`	Use defaults geared towards large problems
`<file>`	Use configuration file to configure solver(s)

- Option `--print-portfolio`

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Experimental setup

- Objective Study the interplay of the various techniques
- Subjects Optimization problems
  - Great practical relevance
  - Algorithmic challenge due to multiple SAT and UNSAT problems
- Experimental series I Sum-based optimization
  - core- and model-guided strategies
  - domain heuristics
  - multi-threading
  - computation
- Experimental series II Inclusion-based optimization
  - saturation-based, disjunctive encodings
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Experimental setup, series I

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations
  - tweety
  - trendy
  - crafty

```
--opt-strategy=bb  --config=tweety
--opt-strategy=usc --config=tweety
--dom-mod=5,8   --opt-strategy=bb  --config=tweety
--opt-strategy=bb,2  --config=trendy
--opt-strategy=usc,3 --config=crafty
--dom-mod=4,8 --opt-strategy=bb,1  --config=trendy
--config=myPortfolio4
```

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  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
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  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
    - model-guided optimization strategy
    - heuristics preferring minimized atoms and assigning them to false
  - *model** `--opt-strategy=bb,2 --config=trendy`
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    - * = best configuration for respective optimization strategy
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark		*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
15-puzzle	(16)	260/ 5/ 90	45/ 0/ 100	425/ 9/ 62	266/ 5/ 83	21/ 0/ 100	249/ 5/ 88	9/ 0
Fastfood ^{w}	(29)	9/ 0/ 100	290/ 13/ 55	30/ 0/ 100	22/ 0/ 100	290/ 14/ 67	10/ 0/ 100	7/ 0
Labyrinth	(29)	445/ 18/ 75	299/ 11/ 62	365/ 14/ 84	395/ 15/ 79	250/ 10/ 66	442/ 19/ 58	229/ 9
Sokoban	(28)	1/ 0/ 100	1/ 0/ 100	1/ 0/ 100	1/ 0/ 100	1/ 0/ 100	1/ 0/ 100	0/ 0
Tsp ^{w}	(29)	600/ 29/ 57	600/ 29/ 0	600/ 29/ 100	600/ 29/ 70	600/ 29/ 32	600/ 29/ 73	600/ 29
Wbds	(29)	600/ 29/ 70	421/ 19/ 34	600/ 29/ 82	600/ 29/ 31	394/ 17/ 67	600/ 29/ 72	397/ 17
Abstract ^{m2}	(30)	19/ 0/ 100	99/ 0/ 100	311/ 13/ 57	20/ 0/ 100	73/ 2/ 94	21/ 0/ 100	6/ 0
Connected	(26)	513/ 22/ 75	476/ 20/ 23	513/ 22/ 89	531/ 23/ 52	474/ 20/ 51	514/ 22/ 93	479/ 20
Crossing	(30)	372/ 16/ 78	177/ 5/ 83	451/ 20/ 66	381/ 17/ 61	174/ 6/ 88	367/ 16/ 86	162/ 5
MaxClique	(30)	593/ 29/ 20	50/ 0/ 100	528/ 23/ 61	370/ 13/ 75	23/ 0/ 100	313/ 8/ 91	21/ 0
Valves ^{w}	(30)	508/ 24/ 79	543/ 27/ 10	561/ 28/ 7	515/ 25/ 87	561/ 28/ 55	513/ 25/ 92	518/ 25
Aspeed ^{m2,w}	(30)	57/ 0/ 100	540/ 27/ 38	490/ 21/ 42	89/ 1/ 99	470/ 23/ 54	64/ 0/ 100	65/ 0
Expansion	(30)	103/ 3/ 92	1/ 0/ 100	40/ 0/ 100	63/ 2/ 96	1/ 0/ 100	30/ 0/ 100	0/ 0
Repair	(30)	113/ 1/ 97	0/ 0/ 100	10/ 0/ 100	32/ 0/ 100	1/ 0/ 100	44/ 0/ 100	1/ 0
Iscas85	(30)	129/ 4/ 96	0/ 0/ 100	158/ 7/ 88	134/ 4/ 92	0/ 0/ 100	306/ 13/ 71	0/ 0
Paranoid ^{m2}	(30)	377/ 8/ 79	1/ 0/ 100	103/ 4/ 92	80/ 3/ 94	1/ 0/ 100	59/ 2/ 98	1/ 0
Trendy ^{m4,w}	(30)	485/ 19/ 47	4/ 0/ 100	241/ 11/ 80	254/ 11/ 82	6/ 0/ 100	219/ 10/ 87	6/ 0
Metro ^{w}	(30)	42/ 0/ 100	237/ 7/ 77	325/ 14/ 59	45/ 0/ 100	162/ 4/ 93	29/ 0/ 100	21/ 0
PartnerUnits	(30)	234/ 5/ 94	111/ 2/ 93	150/ 4/ 87	225/ 8/ 82	103/ 1/ 97	251/ 9/ 83	97/ 0
Ricochet	(30)	86/ 0/ 100	85/ 0/ 100	97/ 0/ 100	167/ 2/ 95	88/ 0/ 100	136/ 1/ 97	21/ 0
ShiftDesign ^{m3}	(30)	600/ 30/ 19	23/ 0/ 100	105/ 5/ 86	436/ 16/ 67	44/ 1/ 99	351/ 13/ 80	29/ 0
Timetabling ^{w}	(30)	407/ 17/ 63	8/ 0/ 100	205/ 10/ 84	208/ 10/ 84	31/ 1/ 97	280/ 11/ 73	4/ 0
SUM	(636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/**156**/1859	5397/212/**1942**	*2674/105*
AVG		298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

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Results for sum-based optimization

Benchmark		*model*			*core*			*heuristic*			*model**			*core**			*heuristic**			*multi*	
15-puzzle	(16)	260/	5/	90	45/	0/	100	425/	9/	62	266/	5/	83	21/	0/	100	249/	5/	88	9/	0
Fastfood ^{w}	(29)	9/	0/	100	290/	13/	55	30/	0/	100	22/	0/	100	290/	14/	67	10/	0/	100	7/	0
Labyrinth	(29)	445/	18/	75	299/	11/	62	365/	14/	84	395/	15/	79	250/	10/	66	442/	19/	58	229/	9
Sokoban	(28)	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	0/	0
Tsp ^{w}	(29)	600/	29/	57	600/	29/	0	600/	29/	100	600/	29/	70	600/	29/	32	600/	29/	73	600/	29
Wbds	(29)	600/	29/	70	421/	19/	34	600/	29/	82	600/	29/	31	394/	17/	67	600/	29/	72	397/	17
Abstract ^{m2}	(30)	19/	0/	100	99/	0/	100	311/	13/	57	20/	0/	100	73/	2/	94	21/	0/	100	6/	0
Connected	(26)	513/	22/	75	476/	20/	23	513/	22/	89	531/	23/	52	474/	20/	51	514/	22/	93	479/	20
Crossing	(30)	372/	16/	78	177/	5/	83	451/	20/	66	381/	17/	61	174/	6/	88	367/	16/	86	162/	5
MaxClique	(30)	593/	29/	20	50/	0/	100	528/	23/	61	370/	13/	75	23/	0/	100	313/	8/	91	21/	0
Valves ^{w}	(30)	508/	24/	79	543/	27/	10	561/	28/	7	515/	25/	87	561/	28/	55	513/	25/	92	518/	25
Aspeed ^{m2,w}	(30)	57/	0/	100	540/	27/	38	490/	21/	42	89/	1/	99	470/	23/	54	64/	0/	100	65/	0
Expansion	(30)	103/	3/	92	1/	0/	100	40/	0/	100	63/	2/	96	1/	0/	100	30/	0/	100	0/	0
Repair	(30)	113/	1/	97	0/	0/	100	10/	0/	100	32/	0/	100	1/	0/	100	44/	0/	100	1/	0
Iscas85	(30)	129/	4/	96	0/	0/	100	158/	7/	88	134/	4/	92	0/	0/	100	306/	13/	71	0/	0
Paranoid ^{m2}	(30)	377/	8/	79	1/	0/	100	103/	4/	92	80/	3/	94	1/	0/	100	59/	2/	98	1/	0
Trendy ^{m4,w}	(30)	485/	19/	47	4/	0/	100	241/	11/	80	254/	11/	82	6/	0/	100	219/	10/	87	6/	0
Metro ^{w}	(30)	42/	0/	100	237/	7/	77	325/	14/	59	45/	0/	100	162/	4/	93	29/	0/	100	21/	0
PartnerUnits	(30)	234/	5/	94	111/	2/	93	150/	4/	87	225/	8/	82	103/	1/	97	251/	9/	83	97/	0
Ricochet	(30)	86/	0/	100	85/	0/	100	97/	0/	100	167/	2/	95	88/	0/	100	136/	1/	97	21/	0
ShiftDesign ^{m3}	(30)	600/	30/	19	23/	0/	100	105/	5/	86	436/	16/	67	44/	1/	99	351/	13/	80	29/	0
Timetabling ^{w}	(30)	407/	17/	63	8/	0/	100	205/	10/	84	208/	10/	84	31/	1/	97	280/	11/	73	4/	0
SUM	(636)	6553/	259/	1731	4011/	160/	1676	6307/	263/	1724	5435/	213/	1829	3768/	**156**/	1859	5397/	212/	**1942**	*2674*/	*105*
AVG		298/	12/	79	182/	7/	76	287/	12/	78	247/	10/	83	171/	7/	85	245/	10/	88	122/	5

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Results for sum-based optimization

Benchmark		*model*			*core*			*heuristic*			*model**			*core**			*heuristic**			*multi*	
15-puzzle	(16)	260/	5/	90	45/	0/	100	425/	9/	62	266/	5/	83	21/	0/	100	249/	5/	88	9/	0
Fastfood ^{w}	(29)	9/	0/	100	290/	13/	55	30/	0/	100	22/	0/	100	290/	14/	67	10/	0/	100	7/	0
Labyrinth	(29)	445/	18/	75	299/	11/	62	365/	14/	84	395/	15/	79	250/	10/	66	442/	19/	58	229/	9
Sokoban	(28)	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	0/	0
Tsp ^{w}	(29)	600/	29/	57	600/	29/	0	600/	29/	100	600/	29/	70	600/	29/	32	600/	29/	73	600/	29
Wbds	(29)	600/	29/	70	421/	19/	34	600/	29/	82	600/	29/	31	394/	17/	67	600/	29/	72	397/	17
Abstract ^{m2}	(30)	19/	0/	100	99/	0/	100	311/	13/	57	20/	0/	100	73/	2/	94	21/	0/	100	6/	0
Connected	(26)	513/	22/	75	476/	20/	23	513/	22/	89	531/	23/	52	474/	20/	51	514/	22/	93	479/	20
Crossing	(30)	372/	16/	78	177/	5/	83	451/	20/	66	381/	17/	61	174/	6/	88	367/	16/	86	162/	5
MaxClique	(30)	593/	29/	20	50/	0/	100	528/	23/	61	370/	13/	75	23/	0/	100	313/	8/	91	21/	0
Valves ^{w}	(30)	508/	24/	79	543/	27/	10	561/	28/	7	515/	25/	87	561/	28/	55	513/	25/	92	518/	25
Aspeed ^{m2,w}	(30)	57/	0/	100	540/	27/	38	490/	21/	42	89/	1/	99	470/	23/	54	64/	0/	100	65/	0
Expansion	(30)	103/	3/	92	1/	0/	100	40/	0/	100	63/	2/	96	1/	0/	100	30/	0/	100	0/	0
Repair	(30)	113/	1/	97	0/	0/	100	10/	0/	100	32/	0/	100	1/	0/	100	44/	0/	100	1/	0
Iscas85	(30)	129/	4/	96	0/	0/	100	158/	7/	88	134/	4/	92	0/	0/	100	306/	13/	71	0/	0
Paranoid ^{m2}	(30)	377/	8/	79	1/	0/	100	103/	4/	92	80/	3/	94	1/	0/	100	59/	2/	98	1/	0
Trendy ^{m4,w}	(30)	485/	19/	47	4/	0/	100	241/	11/	80	254/	11/	82	6/	0/	100	219/	10/	87	6/	0
Metro ^{w}	(30)	42/	0/	100	237/	7/	77	325/	14/	59	45/	0/	100	162/	4/	93	29/	0/	100	21/	0
PartnerUnits	(30)	234/	5/	94	111/	2/	93	150/	4/	87	225/	8/	82	103/	1/	97	251/	9/	83	97/	0
Ricochet	(30)	86/	0/	100	85/	0/	100	97/	0/	100	167/	2/	95	88/	0/	100	136/	1/	97	21/	0
ShiftDesign ^{m3}	(30)	600/	30/	19	23/	0/	100	105/	5/	86	436/	16/	67	44/	1/	99	351/	13/	80	29/	0
Timetabling ^{w}	(30)	407/	17/	63	8/	0/	100	205/	10/	84	208/	10/	84	31/	1/	97	280/	11/	73	4/	0
SUM	(636)	6553/	259/	1731	4011/	160/	1676	6307/	263/	1724	5435/	213/	1829	3768/	**156**/	1859	5397/	212/	**1942**	*2674*/	*105*
AVG		298/	12/	79	182/	7/	76	287/	12/	78	247/	10/	83	171/	7/	85	245/	10/	88	122/	5

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Results for sum-based optimization

Benchmark		*model*			*core*			*heuristic*			*model**			*core**			*heuristic**			*multi*		
15-puzzle	(16)	260/	5/	90	45/	0/	100	425/	9/	62	266/	5/	83	21/	0/	100	249/	5/	88	9/	0	
Fastfood ^{w}	(29)	9/	0/	100	290/	13/	55	30/	0/	100	22/	0/	100	290/	14/	67	10/	0/	100	7/	0	
Labyrinth	(29)	445/	18/	75	299/	11/	62	365/	14/	84	395/	15/	79	250/	10/	66	442/	19/	58	229/	9	
Sokoban	(28)	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	1/	0/	100	0/	0	
Tsp ^{w}	(29)	600/	29/	57	600/	29/	0	600/	29/	100	600/	29/	70	600/	29/	32	600/	29/	73	600/	29	
Wbus	(29)	600/	29/	76	421/	19/	34	600/	29/	82	600/	29/	31	394/	17/	67	600/	29/	72	397/	17	
Abstract ^{m2}	(30)	19/	0/	100	99/	0/	100	311/	13/	57	20/	0/	100	73/	2/	94	21/	0/	100	6/	0	
Connected	(26)	513/	22/	75	476/	20/	23	513/	22/	89	531/	23/	52	474/	20/	51	514/	22/	93	479/	20	
Crossing	(30)	372/	16/	78	177/	5/	83	451/	20/	66	381/	17/	61	174/	6/	88	367/	16/	86	162/	5	
MaxClique	(30)	593/	29/	20	50/	0/	100	528/	23/	61	370/	13/	75	23/	0/	100	313/	8/	91	21/	0	
Valves ^{w}	(30)	508/	24/	79	543/	27/	10	561/	28/	7	515/	25/	87	561/	28/	55	513/	25/	92	518/	25	
Aspeed ^{m2,w}	(30)	57/	0/	100	540/	27/	38	490/	21/	42	89/	1/	99	470/	23/	54	64/	0/	100	65/	0	
Expansion	(30)	103/	3/	92	1/	0/	100	40/	0/	100	63/	2/	96	1/	0/	100	30/	0/	100	0/	0	
Repair	(30)	113/	1/	97	0/	0/	100	10/	0/	100	32/	0/	100	1/	0/	100	44/	0/	100	1/	0	
Iscas85	(30)	129/	4/	96	0/	0/	100	158/	7/	88	134/	4/	92	0/	0/	100	306/	13/	71	0/	0	
Paranoid ^{m2}	(30)	377/	8/	79	1/	0/	100	103/	4/	92	80/	3/	94	1/	0/	100	59/	2/	98	1/	0	
Trendy ^{m4,w}	(30)	485/	19/	47	4/	0/	100	241/	11/	80	254/	11/	82	6/	0/	100	219/	10/	87	6/	0	
Metro ^{w}	(30)	42/	0/	100	237/	7/	77	325/	14/	59	45/	0/	100	162/	4/	93	29/	0/	100	21/	0	
PartnerUnits	(30)	234/	5/	94	111/	2/	93	150/	4/	87	225/	8/	82	103/	1/	97	251/	9/	83	97/	0	
Ricochet	(30)	86/	0/	100	85/	0/	100	97/	0/	100	167/	2/	95	88/	0/	100	136/	1/	97	21/	0	
ShiftDesign ^{m3}	(30)	600/	30/	19	23/	0/	100	105/	5/	86	436/	16/	67	44/	1/	99	351/	13/	80	29/	0	
Timetabling ^{w}	(30)	407/	17/	63	8/	0/	100	205/	10/	84	208/	10/	84	31/	1/	97	280/	11/	73	4/	0	
SUM	(636)	6553/	259/	1731	4011/	160/	1676	6307/	263/	1724	5435/	213/	1829	3768/	**156**/	1859	5397/	212/	**1942**	*2674*/	*105*	
AVG		298/	12/	79	182/	7/	76	287/	12/	78	247/	10/	83	171/	7/	85	245/	10/	88	122/	5	

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	2674/105
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	2674/105
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
    - model-guided optimization with exponentially increasing steps
    - configuration `trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	2674/105
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
    - model-guided optimization with exponentially increasing steps
    - configuration `trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
    - core-guided optimization with algorithm *oll*
    - configuration `crafty`
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	2674/105
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
    - model-guided optimization with exponentially increasing steps
    - configuration `trendy` — *frequent restarts*
  - *core** `--opt-strategy=usc,3 --config=crafty`
    - core-guided optimization with algorithm *oll*
    - configuration `crafty` — *infrequent restarts*
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	2674/105
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
    - hierarchic model-guided optimization
    - heuristics preferring to assign false to minimized atoms
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/**156**/1859	5397/212/**1942**	2674/105
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
    - *most problems solved* (among single-threaded strategies)
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
    - *best anytime behaviour* (among single-threaded strategies)
  - *multi* `--config=myPortfolio4`

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	**2674**/**105**
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
    - *most problems solved* (among single-threaded strategies)
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
    - *best anytime behaviour* (among single-threaded strategies)
  - *multi* `--config=myPortfolio4`
    - *faster and more problems solved*

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	**2674**/**105**
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
  - *multi* `--config=myPortfolio4`
    - *faster and more problems solved*
    - improves over the virtually best single-threaded configuration

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Results for sum-based optimization

Benchmark	*model*	*core*	*heuristic*	*model**	*core**	*heuristic**	*multi*
SUM (636)	6553/259/1731	4011/160/1676	6307/263/1724	5435/213/1829	3768/156/1859	5397/212/1942	**2674**/**105**
AVG	298/ 12/ 79	182/ 7/ 76	287/ 12/ 78	247/ 10/ 83	171/ 7/ 85	245/ 10/ 88	122/ 5

- Configurations
  - *model* `--opt-strategy=bb --config=tweety`
  - *core* `--opt-strategy=usc --config=tweety`
  - *heuristic* `--dom-mod=5,8 --opt-strategy=bb --config=tweety`
  - *model** `--opt-strategy=bb,2 --config=trendy`
  - *core** `--opt-strategy=usc,3 --config=crafty`
  - *heuristic** `--dom-mod=4,8 --opt-strategy=bb,1 --config=trendy`
  - *multi* `--config=myPortfolio4`
    - *faster and more problems solved*
    - improves over the virtually best single-threaded configuration

    ☞ *¡SYNERGY AT WORK!*

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Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations `--configuration=tweety`
  - tweety
  - frumpy
  - crafty
  - jumpy
  - handy
  - trendy
  - many

(enumeration only)

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Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations `--configuration=tweety`
  - *meta*
  - *heuristic*
  - *meta-heuristic*
  - *meta-heuristic-recording* (enumeration only)

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Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations (Computation) `--configuration=tweety`
  - *meta*
  - *heuristic*
  - *meta-heuristic*
  - *meta-heuristic-recording* (enumeration only)

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Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations (Computation) `--configuration=tweety`
  - *meta*
    - saturation-based, disjunctive encodings generated via *metasp*
  - *heuristic*
  - *meta-heuristic*
  - *meta-heuristic-recording* (enumeration only)

Potassco

Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations (Computation) `--configuration=tweety`
  - *meta*
    - saturation-based, disjunctive encodings generated via *metasp*
  - *heuristic* `--dom-mod=5,16`
    - heuristics preferring shown atoms and assigning them to false
  - *meta-heuristic*
  - *meta-heuristic-recording* (enumeration only)

Potassco

Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations (Computation) `--configuration=tweety`
  - *meta*
    - saturation-based, disjunctive encodings generated via *metasp*
  - *heuristic* `--dom-mod=5,16`
    - heuristics preferring shown atoms and assigning them to false
  - *meta-heuristic*
    - use heuristics to reduce number of invalid solution candidates
  - *meta-heuristic-recording* (enumeration only)

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Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations (Enumeration) `--configuration=tweety`
  - *meta*
    - saturation-based, disjunctive encodings generated via *metasp*
  - *heuristic*
    - heuristics preferring shown atoms and assigning them to false
  - *meta-heuristic*
  - *meta-heuristic-recording* (enumeration only)

Potassco

Experimental setup, series II

- Limits 600 seconds wall-clock time and 6 GB of memory per run
- Measurements
  - Average time (timeout accounts for 600 seconds)
  - Number of timeouts
  - Relative quality (score similar to that of ASP'14)
- Configurations (Enumeration) `--configuration=tweety`
  - *meta*
    - saturation-based, disjunctive encodings generated via *metasp*
    - enumeration in polynomial space
  - *heuristic*
    - heuristics preferring shown atoms and assigning them to false
    - enumeration in exponential space
  - *meta-heuristic*
  - *meta-heuristic-recording* (enumeration only)

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Results for inclusion-based optimization

Benchmark		*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
15-puzzle	(16)	25/ 0	14/ 0	23/ 0	321/ 7/ 91	408/ 9/ 75	354/ 7/ 69	444/ 9/ 38
Fastfood	(29)	1/ 0	0/ 0	0/ 0	356/ 14/ 59	210/ 9/ 100	348/ 14/ 65	268/ 10/ 71
Labyrinth	(29)	356/ 16	84/ 3	347/ 15	600/ 29/ 72	600/ 29/ 91	600/ 29/ 73	600/ 29/ 61
Sokoban	(28)	22/ 0	1/ 0	12/ 0	22/ 0/ 95	1/ 0/ 100	23/ 0/ 96	12/ 0/ 98
Tsp	(29)	7/ 0	0/ 0	7/ 0	600/ 29/ 48	600/ 29/ 100	600/ 29/ 58	600/ 29/ 44
Wbds	(29)	219/ 7	23/ 1	38/ 1	600/ 29/ 53	600/ 29/ 82	600/ 29/ 72	600/ 29/ 49
Connected	(26)	109/ 3	0/ 0	61/ 2	532/ 23/ 35	532/ 23/ 100	532/ 23/ 60	532/ 23/ 70
Crossing	(30)	98/ 1	14/ 0	14/ 0	600/ 30/ 32	600/ 30/ 99	600/ 30/ 42	600/ 30/ 76
MaxClique	(30)	189/ 3	0/ 0	3/ 0	600/ 30/ 25	600/ 30/ 100	600/ 30/ 50	600/ 30/ 75
Valves	(30)	600/ 30	560/ 28	600/ 30	600/ 30/ 98	560/ 28/ 100	600/ 30/ 98	600/ 30/ 98
Aspeed	(30)	600/ 30	4/ 0	581/ 29	600/ 30/ 73	600/ 30/ 100	600/ 30/ 74	600/ 30/ 75
Expansion	(30)	600/ 30	0/ 0	600/ 30	600/ 30/ 75	298/ 14/ 100	600/ 30/ 75	600/ 30/ 75
Repair	(30)	552/ 26	0/ 0	5/ 0	595/ 29/ 25	438/ 20/ 100	589/ 29/ 50	481/ 21/ 77
Iscas85	(30)	60/ 3	0/ 0	0/ 0	600/ 30/ 25	600/ 30/ 100	600/ 30/ 50	600/ 30/ 75
Paranoid	(30)	191/ 6	1/ 0	16/ 0	600/ 30/ 25	600/ 30/ 100	600/ 30/ 50	600/ 30/ 75
Trendy	(30)	411/ 18	3/ 0	133/ 0	581/ 29/ 27	580/ 29/ 100	581/ 29/ 51	581/ 29/ 75
Metro	(30)	126/ 5	54/ 1	33/ 1	571/ 27/ 42	576/ 28/ 70	581/ 28/ 65	573/ 27/ 78
PartnerUnits	(30)	600/ 30	168/ 4	507/ 9	600/ 30/ 42	168/ 4/ 98	596/ 29/ 61	501/ 9/ 78
Ricochet	(30)	405/ 16	57/ 0	266/ 10	388/ 14/ 46	56/ 0/ 100	285/ 11/ 77	264/ 10/ 83
Timetabling	(30)	600/ 30	16/ 0	85/ 1	600/ 30/ 27	283/ 14/ 98	600/ 30/ 51	336/ 15/ 82
SUM	(576)	5773/254	999/ **37**	3332/ 128	10568/500/1013	8908/**415**/**1913**	10490/497/1285	9991/450/1453
AVG		289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

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Results for inclusion-based optimization

Benchmark	*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
SUM (576)	5773/254	999/ 37	3332/ 128	10568/500/1013	8908/415/1913	10490/497/1285	9991/450/1453
AVG	289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

- Configurations (Computation)
  - *meta*
  - *heuristic*
  - *meta-heuristic*
  - *meta-heuristic-recording*

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Results for inclusion-based optimization

Benchmark	*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
SUM (576)	5773/254	**999**/ **37**	3332/ 128	10568/500/1013	8908/415/1913	10490/497/1285	9991/450/1453
AVG	289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

- Configurations (Computation)
  - *meta*
  - *heuristic*
    - *faster and more problems solved*
  - *meta-heuristic*
  - *meta-heuristic-recording*

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Results for inclusion-based optimization

Benchmark	*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
SUM (576)	5773/254	999/ 37	3332/ 128	10568/500/1013	**8908**/**415**/**1913**	10490/497/1285	9991/450/1453
AVG	289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

- Configurations (Enumeration)
  - *meta*
  - *heuristic*
    - *faster and more problems solved*
    - *more models enumerated*
  - *meta-heuristic*
  - *meta-heuristic-recording*

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Results for inclusion-based optimization

Benchmark	*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
SUM (576)	5773/254	999/ 37	3332/ 128	10568/500/1013	8908/415/1913	10490/497/1285	9991/450/1453
AVG	289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

- Configurations (Enumeration)
  - *meta*
    - worst performance
  - *heuristic*
  - *meta-heuristic*
  - *meta-heuristic-recording*

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Results for inclusion-based optimization

Benchmark	*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
SUM (576)	5773/254	999/ 37	3332/ 128	10568/500/1013	8908/415/1913	10490/497/1285	9991/450/1453
AVG	289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

- Configurations (Enumeration)
  - *meta*
    - worst performance
  - *heuristic*
  - *meta-heuristic*
    - better performance
  - *meta-heuristic-recording*

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Results for inclusion-based optimization

Benchmark	*meta*	*heuristic*	*meta-heur.*	*meta*	*heuristic*	*meta-heuristic*	*meta-heur.-rec*
SUM (576)	5773/254	999/ 37	3332/ 128	10568/500/1013	8908/415/1913	10490/497/1285	9991/450/1453
AVG	289/ 13	50/ 2	167/ 6	528/ 25/ 51	445/ 21/ 96	525/ 25/ 64	500/ 22/ 73

- Configurations (Enumeration)
  - *meta*
    - worst performance
  - *heuristic*
  - *meta-heuristic*
    - better performance
  - *meta-heuristic-recording*
    - even better performance

(enumeration only)

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Outline

1 Motivation

2 Disjunctive solving

3 Optimization

4 Heuristics

5 Configuration

6 Experiments

7 Summary

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Summary

- Various ASP solving techniques
  - Disjunctive solving
  - Optimization
  - Heuristics
  - Configuration
- Empirical study of their impact on optimization problems
- Paper
  - Multi-threading
  - C++ library
- `http://potassco.sourceforge.net`

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Summary

- Various ASP solving techniques
  - Disjunctive solving
  - Optimization
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Summary

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