asprin: Answer Set Programming with Preferences

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Potassco

Outline

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Motivation

- Answer Set Programming (ASP) is an approach to declarative problem solving, combining
  - a rich yet simple modeling language
  - with high-performance solving capacities

  tailored to Knowledge Representation and Reasoning
- ASP allows for solving all search problems in NP (and NP^{NP}) in a uniform way
- ASP is versatile as reflected by the ASP solver *clingo*, winning first places at ASP, CASC, MISC, PB, and SAT competitions
- ASP embraces many emerging application areas, and users

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- For real-world applications, the identification of preferred, or optimal, solutions is often indispensable

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

- Only optimization statements representing objective functions using summation are established components of today's ASP systems

- Example $\#minimize\{40 : coast; 70 : mountain\}$

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Approach

- asprin is a framework for handling preferences among the (stable) models of logic programs
  - general because it captures many existing approaches to preference
  - flexible because it allows combining different types of preferences
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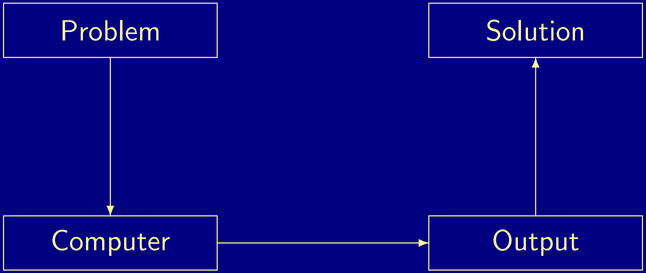
Informatics

"What is the problem?" versus *"How to solve the problem?"*



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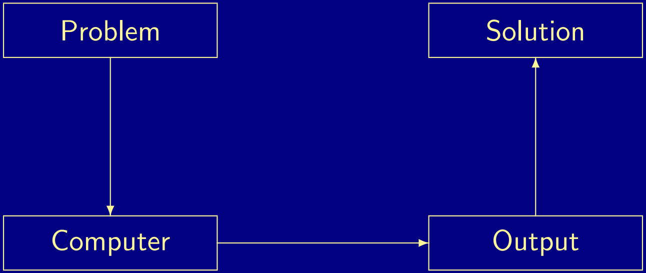

Traditional programming

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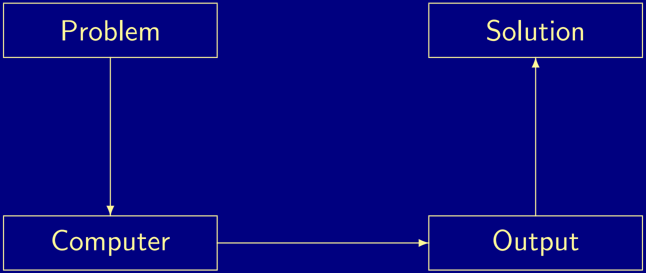

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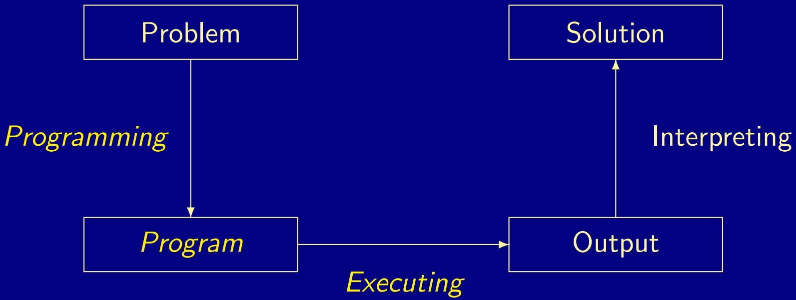

Declarative problem solving

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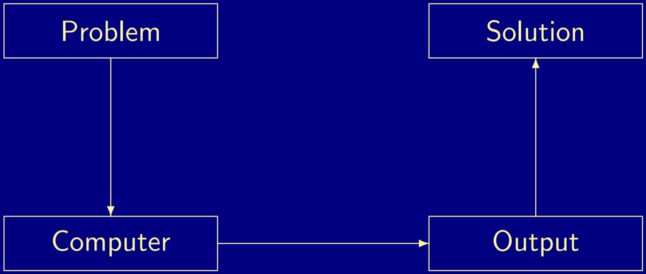

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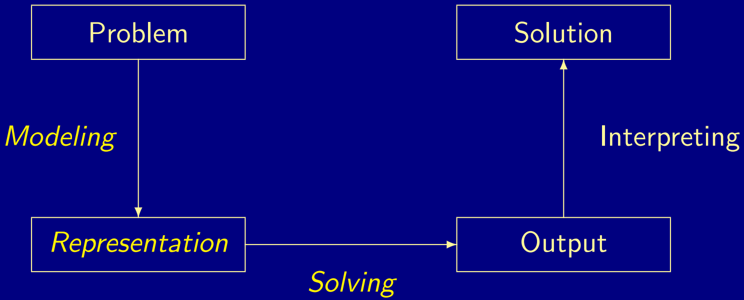

ASP for Declarative problem solving

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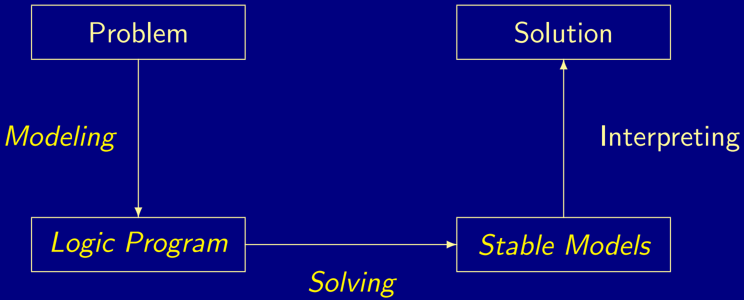
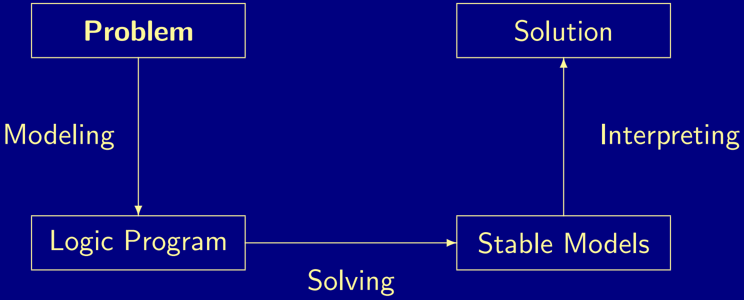


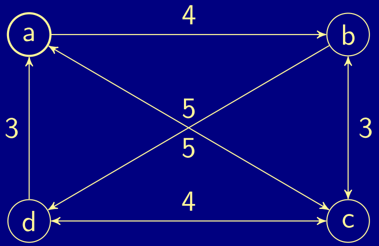
Outline

An Example: Travelling Salesperson



Travelling Salesperson

- Problem instance A map with cities, directed roads with distances, and one starting city
- Problem class Find a route visiting every city once, and returning to the starting city



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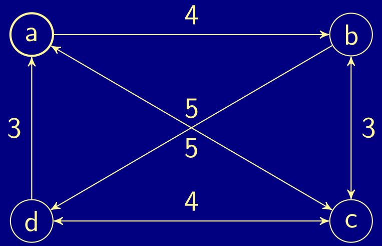

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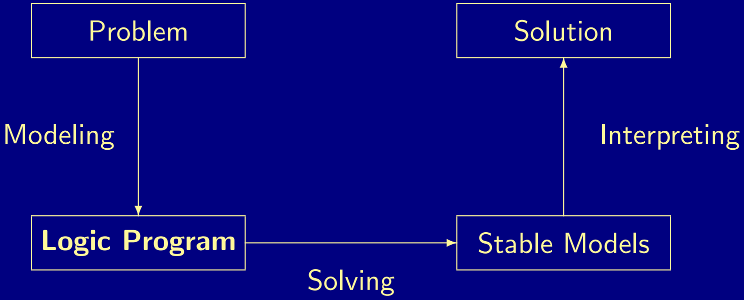

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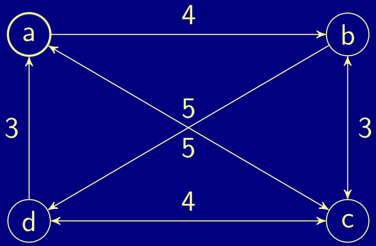


```
city(a). city(b). city(c). city(d). start(a).
road(a,b,4). road(a,c,5). road(b,c,3). road(b,d,5).
road(c,a,5). road(c,b,3). road(c,d,4).
road(d,a,3). road(d,c,4).
```

Travelling Salesperson

- Problem class Find a route visiting every city once, and returning to the starting city

```
{ travel(X,Y) } :- road(X,Y,D).

visited(Y) :-   start(X), travel(X,Y).
visited(Y) :- visited(X), travel(X,Y).

:- city(X), not visited(X).
:- city(X), 2 {  travel(X,Y) }.
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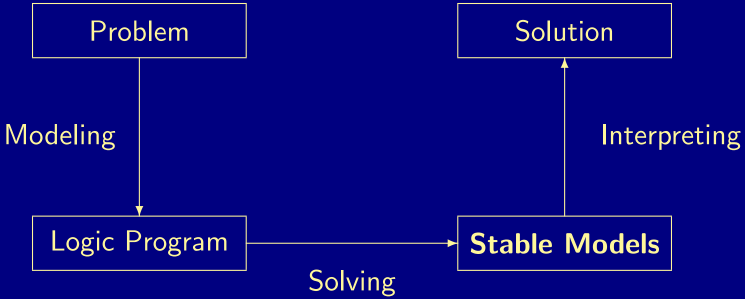

Travelling Salesperson

```
$ clingo tsp.lp 0

clingo version 5.1.0
Reading from tsp.lp
Solving...
Answer: 1
travel(a,b) travel(b,c) travel(c,d) travel(d,a) ...
Answer: 2
travel(a,b) travel(b,d) travel(d,c) travel(c,a) ...
Answer: 3
travel(a,c) travel(c,b) travel(b,d) travel(d,a) ...
SATISFIABLE

Models       : 3
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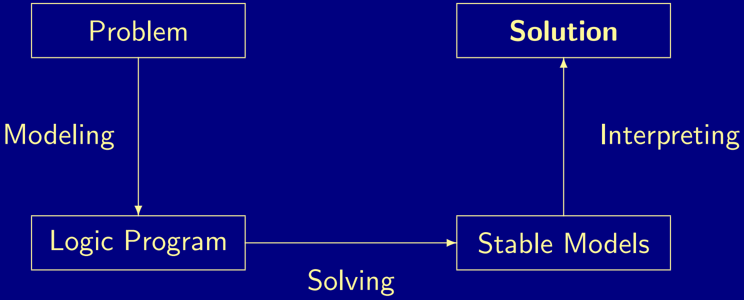

A route

```
Answer: 1
travel(a,b) travel(b,c) travel(c,d) travel(d,a) ...
```

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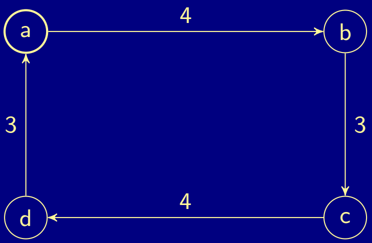
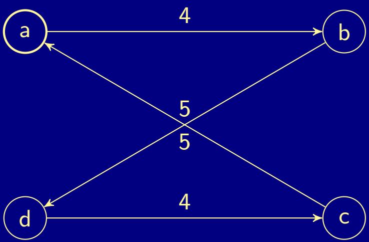


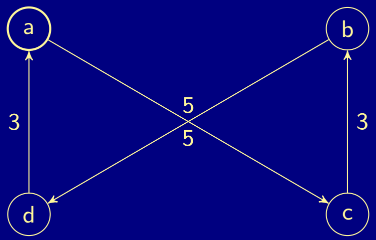
A route

```
Answer: 2
travel(a,b) travel(b,d) travel(d,c) travel(c,a) ...
```

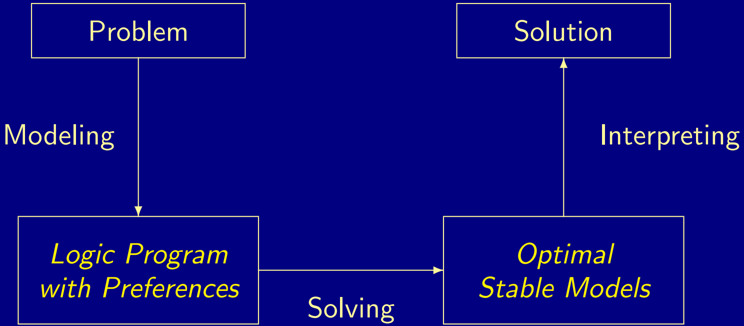


A route

```
Answer: 3
travel(a,c) travel(c,b) travel(b,d) travel(d,a) ...
```



asprin for Declarative Problem Solving



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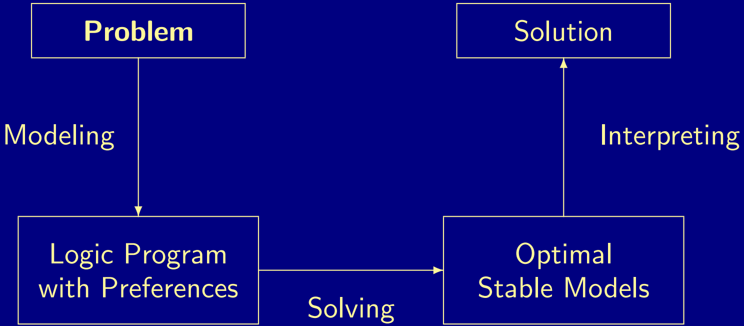
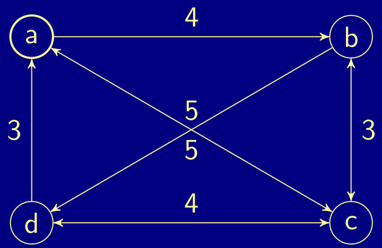


Travelling Salesperson

- Problem class Find a route visiting every city once, and returning to the starting city. *Prefer routes of minimum distance.*



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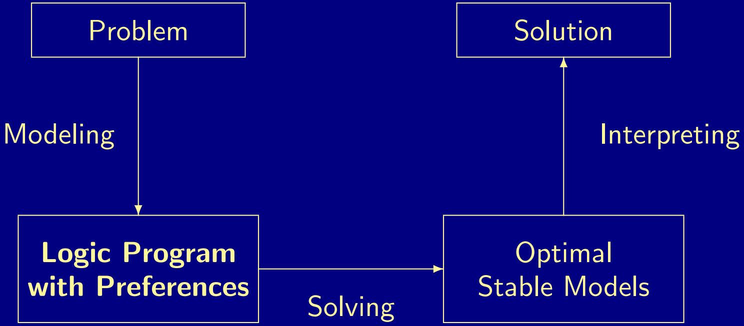

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#preference(distance,less(weight)){
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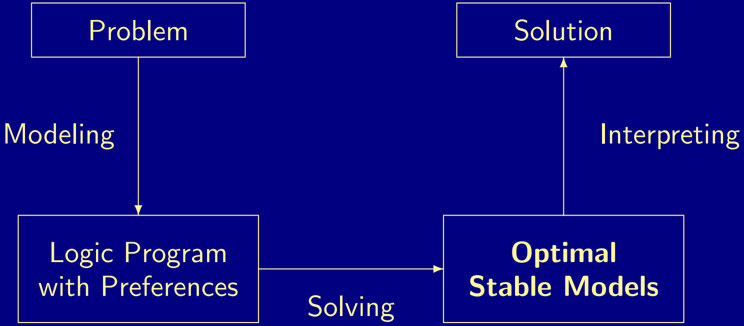

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Reading from tsp.lp ...
Solving...
Answer: 1
travel(a,c) travel(c,b) travel(b,d) travel(d,a) ...
Answer: 2
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OPTIMUM FOUND

Models : 2
  Optimum : yes
  Optimal : 1
```

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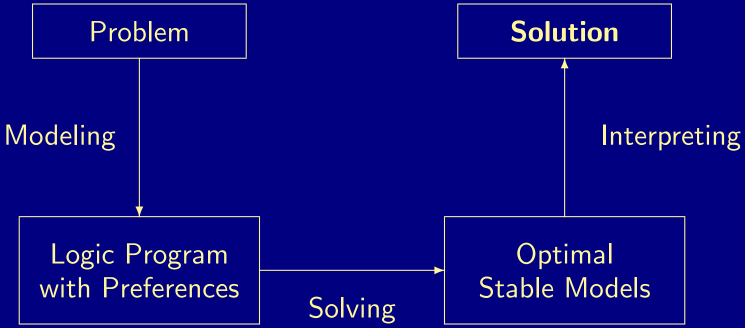

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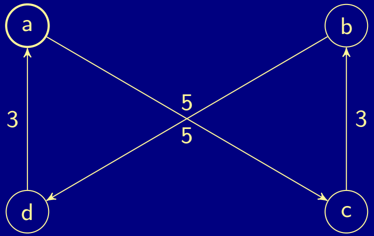

An optimal route

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Answer: 1
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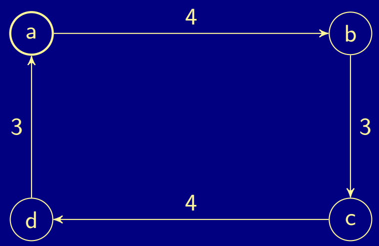

Extending Travelling Salesperson

- Problem class Find a route visiting every city once, and returning to the starting city. *Prefer going along the outside coast if it is cloudy, else prefer going through the inside mountains.*

```
type(X,Y,mountain) :- road(X,Y,D), D == 5.
type(X,Y,coast)    :- road(X,Y,D), D != 5.

#preference(weather,aso){
  travel(X,Y), type(X,Y,coast) >>
              travel(X',Y), type(X',Y,mountain) || cloudy;
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}.

#optimize(weather).
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Answer: 3
travel(a,b) travel(b,d) travel(c,a) travel(d,c)
OPTIMUM FOUND

Models : 3
  Optimum : yes
  Optimal : 2
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Models : 3
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Extending Travelling Salesperson

- Problem class Find a route visiting every city once, and returning to the starting city. Prefer routes of minimum distance. Prefer going through the outside coast if it is cloudy, else prefer going through the inside mountains. *Combine both preferences with Pareto.*

```
#preference(all,pareto){
  **distance;
  **weather
}.
#optimize(all).
```

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- A strict partial order $\succ$ on the stable models of a logic program
  That is, $X \succ Y$ means that X is preferred to Y
- A stable model X is $\succ$-preferred, if there is no other stable model Y such that $Y \succ X$

- A preference type is a (parametric) class of preference relations
- Example *subset*, *pareto*, etc.

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Language

- naming atom $**s$

  where s is the name of a preference
- weighted formula $w_1, \dots, w_l : \phi$

  where each w_i is a term and ϕ is a Boolean formula
- preference element $\Phi_1 \gg \cdots \gg \Phi_m \parallel \Phi_{m+1}$

  where each Φ_r is a set of weighted formulas
- preference statement $\#preference(s, t)\{e_1, \dots, e_n\}$

  where s and t represent the preference statement and its type and each e_j is a preference element
- optimization directive $\#optimize(s)$

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- preference specification is a set S of preference statements and a directive $\#optimize(s)$ such that S is acyclic, closed, and $s \in S$

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- preference element $\Phi_1 \gg \cdots \gg \Phi_m \parallel \Phi_{m+1}$

  where each Φ_r is a set of weighted formulas
- preference statement $\#preference(s, t)\{e_1, \dots, e_n\}$

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- optimization directive $\#optimize(s)$

  where s is the name of a preference

- preference specification is a set S of preference statements and a directive $\#optimize(s)$ such that S is acyclic, closed, and $s \in S$

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Preference type

- A preference type t is a function mapping a set of preference elements E to a preference relation

$$t(E) \subseteq \mathcal{A} \times \mathcal{A}$$

- Examples

$$(X, Y) \in \mathit{subset}(E) \text{ iff } \{\ell \in E \mid X \models \ell\} \subset \{\ell \in E \mid Y \models \ell\}$$

$$(X, Y) \in \mathit{pareto}(E) \text{ iff } \bigwedge_{**s \in E}(X \succeq_s Y) \wedge \bigvee_{**s \in E}(X \succ_s Y)$$

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Outline

Preference program

- Reification $H_X = \{holds(a) \mid a \in X\}$ and $H'_X = \{holds'(a) \mid a \in X\}$
- Preference program Let s be a preference statement declaring $\succ_s$.

  We define Q_s as a preference program for s, if for all sets $X, Y \subseteq \mathcal{A}$, we have

  $$X \succ_s Y \text{ iff } Q_s \cup H_X \cup H'_Y \text{ is satisfiable}$$

- Note Q_s is implemented as $F_s \cup E_{t_s} \cup C$
- Note *asprin*'s expressiveness is delineated by the decision problem

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$$\#\mathit{preference}(1, \mathit{subset})\{a, b, c\}$$
$$\#\mathit{optimize}(1)$$

$H_{\{a\}} = \{$
```
holds(a).
```
$\}$

$H'_{\{a,b\}} = \{$
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holds'(a).  holds'(b).
```
$\}$

$F_1 = \{$
```
preference(1,subset).       preference(1,1,1,for(a),()).
                            preference(1,2,1,for(b),()).
optimize(1).                preference(1,3,1,for(c),()).
```
$\}$

$E_{subset} = \{$
```
better(P) :- preference(P,subset),
  not holds(X),      holds'(X), preference(P,_,_,for(X),_),
  not holds(Y) : not holds'(Y), preference(P,_,_,for(Y),_).
```
$\}$

$C = \{$
```
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```
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There is a stable model, indicating that $\{a\} \succ_1 \{a, b\}$

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```
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```
$\}$

There is no stable model, indicating that $\{a, b\} \not\succ_1 \{a\}$

Basic algorithm $solveOpt(P, s)$

Input : A program P over $\mathcal{A}$ and preference statement s
Output : A $\succ_s$-preferred stable model of P, if P is satisfiable, and $\bot$ otherwise

$Y \leftarrow solve(P)$
if $Y = \bot$ **then return** $\bot$
repeat
    $X \leftarrow Y$
    $Y \leftarrow solve\big(P \cup Q_s \cup R \cup H'_X\big)$
until $Y = \bot$
return X

where $R = \{holds(a) \leftarrow a \mid a \in \mathcal{A}\}$

asprin's library

- Basic preference types
  - `subset` and `superset`
  - `less(cardinality)` and `more(cardinality)`
  - `less(weight)` and `more(weight)`
  - `maxmin` and `minmax`
  - `aso` (Answer Set Optimization)
  - `poset` (Qualitative Preferences)
- Composite preference types
  - `neg`
  - `and`
  - `pareto`
  - `lexico`
- And more to come. . .
  - `cp` (restricted CP nets)

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Outline

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Heuristic framework

- *clingo* allows for incorporating domain-specific heuristics into ASP solving
  - input language for expressing domain-specific heuristics
  - solving capacities for integrating domain-specific heuristics
- Heuristic directive `#heuristic`
- Heuristic modifiers (atom, *a*, and integer, *v*)
  - `init` for initializing the heuristic value of *a* with *v*
  - `factor` for amplifying the heuristic value of *a* by factor *v*
  - `level` for ranking all atoms; the rank of *a* is *v*
  - `sign` for attributing the sign of *v* as truth value to *a*
- Heuristic statements

```
#heuristic occurs(A,T) : action(A), time(T). [T,factor]
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- Heuristic statements

```
#heuristic occurs(mv,5) : action(mv), time(5). [5,factor]
```

asprin with different heuristic settings

Benchmark \ System			$asprin_w$	$asprin_w$+s	$asprin_w$+l	$asprin_w$+f	$asprin_s$	$asprin_s$+s	$asprin_s$+l	$asprin_s$+f
Ricochet	(30)	20.00	432 (8, 4)	407 (7, 4)	68 (1, 0)	71 (1, 0)	365 (8, 3)	461 (7, 10)	69 (1, 0)	71 (1, 0)
Timetabling	(12)	23687.75	345 (285, 3)	255 (202, 2)	900 (4, 12)	6 (1, 0)	217 (144, 2)	21 (18, 0)	900 (2, 12)	5 (1, 0)
Puzzle	(7)	580.57	82 (2, 0)	112 (2, 0)	136 (2, 0)	416 (2, 1)	31 (1, 0)	32 (1, 0)	21 (1, 0)	51 (1, 0)
Crossing	(24)	211.92	104 (42, 1)	98 (35, 0)	805 (19, 20)	387 (6, 6)	0 (6, 0)	1 (6, 0)	7 (9, 0)	3 (1, 0)
Valves	(30)	56.63	69 (7, 0)	65 (6, 0)	460 (8, 11)	715 (0, 22)	38 (4, 0)	39 (4, 0)	339 (4, 6)	673 (0, 21)
Expansion	(30)	7501.87	216 (299, 0)	10 (15, 0)	38 (7, 0)	12 (3, 0)	64 (295, 0)	14 (54, 0)	4 (4, 0)	3 (1, 0)
Repair	(30)	6750.73	76 (48, 0)	15 (47, 0)	71 (3, 2)	8 (2, 0)	8 (43, 0)	3 (11, 0)	1 (1, 0)	1 (1, 0)
Diagnosis	(30)	1669.00	196 (341, 3)	76 (66, 0)	43 (4, 0)	118 (3, 2)	19 (338, 0)	2 (39, 0)	0 (1, 0)	0 (1, 0)
$\varnothing(\varnothing, \Sigma)$			190 (129, 11)	130 (48, 6)	315 (6, 45)	217 (2, 31)	93 (105, 5)	72 (18, 10)	168 (3, 18)	101 (1, 21)

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- $asprin_w$+f

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- s — sign heuristic
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Ricochet	(30)	20.00	432 (8, 4)	407 (7, 4)	68 (1, 0)	71 (1, 0)	365 (8, 3)	461 (7, 10)	69 (1, 0)	71 (1, 0)
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Valves	(30)	56.63	69 (7, 0)	65 (6, 0)	460 (8, 11)	715 (0, 22)	38 (4, 0)	39 (4, 0)	339 (4, 6)	673 (0, 21)
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Diagnosis	(30)	1669.00	196 (341, 3)	76 (66, 0)	43 (4, 0)	118 (3, 2)	19 (338, 0)	2 (39, 0)	0 (1, 0)	0 (1, 0)
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Outline

asprin versus *clingo* and *metasp*

(B,D,R&S; AAAI)

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Ricochet	(30)	20.00	104.74 (0)	174.26 (0)	113.45 (0)	811.32 (24)	175.71 (0)	109.91 (0)
Timetabling	(12)	23687.75	35.82 (0)	490.39 (5)	694.92 (8)	798.75 (10)	142.03 (0)	12.01 (0)
Puzzle	(7)	580.57	77.00 (0)	77.39 (0)	96.70 (0)	34.79 (0)	17.06 (0)	17.22 (0)
Crossing	(24)	211.92	48.43 (0)	105.64 (1)	67.50 (0)	62.33 (0)	0.50 (0)	0.46 (0)
Valves	(30)	56.63	52.53 (0)	72.85 (0)	78.11 (0)	900.00 (30)	45.01 (0)	39.31 (0)
Expansion	(30)	7501.87	91.53 (0)	373.56 (2)	241.05 (7)	900.00 (30)	292.57 (0)	21.12 (0)
Repair	(30)	6750.73	71.78 (0)	102.19 (0)	43.94 (0)	900.00 (30)	6.88 (0)	2.19 (0)
Diagnosis	(30)	1669.00	84.96 (0)	254.19 (3)	101.33 (0)	181.71 (6)	41.55 (0)	1.56 (0)
$\varnothing(\Sigma)$			70.85 (0)	206.31 (11)	179.63 (15)	573.61 (130)	90.16 (0)	25.47 (0)

- *clingo* (using branch-and-bound)
- *asprin*$_w$
- *asprin*$_w$ `-f`
- w — weight-based
- `-f` — no phase saving

- *metasp* (using disjunction)
- *asprin*$_s$
- *asprin*$_s$ `-f`
- s — subset-based
- `-f` — no phase saving

asprin versus *clingo* and *metasp*

(B,D,R&S; AAAI)

Benchmark \ System			*clingo*	*asprin*$_w$	*asprin*$_w$ -f	*metasp*	*asprin*$_s$	*asprin*$_s$ -f
Ricochet	(30)	20.00	104.74 (0)	174.26 (0)	113.45 (0)	811.32 (24)	175.71 (0)	109.91 (0)
Timetabling	(12)	23687.75	35.82 (0)	490.39 (5)	694.92 (8)	798.75 (10)	142.03 (0)	12.01 (0)
Puzzle	(7)	580.57	77.00 (0)	77.39 (0)	96.70 (0)	34.79 (0)	17.06 (0)	17.22 (0)
Crossing	(24)	211.92	48.43 (0)	105.64 (1)	67.50 (0)	62.33 (0)	0.50 (0)	0.46 (0)
Valves	(30)	56.63	52.53 (0)	72.85 (0)	78.11 (0)	900.00 (30)	45.01 (0)	39.31 (0)
Expansion	(30)	7501.87	91.53 (0)	373.56 (2)	241.05 (7)	900.00 (30)	292.57 (0)	21.12 (0)
Repair	(30)	6750.73	71.78 (0)	102.19 (0)	43.94 (0)	900.00 (30)	6.88 (0)	2.19 (0)
Diagnosis	(30)	1669.00	84.96 (0)	254.19 (3)	101.33 (0)	181.71 (6)	41.55 (0)	1.56 (0)
$\varnothing(\Sigma)$			70.85 (0)	206.31 (11)	179.63 (15)	573.61 (130)	90.16 (0)	25.47 (0)

- *clingo* (using branch-and-bound)
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- w — weight-based
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- *metasp* (using disjunction)
- *asprin*$_s$
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- s — subset-based
- `-f` — no phase saving

aso versus *asprin*

n	*aso*	aso_r	$asprin_a$	$asprin_{r+a}$
350	9 (0)	17 (0)	4 (0)	5 (0)
360	14 (0)	22 (0)	48 (0)	50 (0)
370	15 (0)	25 (0)	38 (0)	39 (0)
380	10 (0)	23 (0)	8 (0)	9 (0)
390	59 (0)	72 (0)	50 (1)	52 (1)
400	22 (0)	33 (0)	28 (0)	30 (0)
410	87 (1)	96 (1)	124 (2)	125 (2)
420	97 (1)	108 (1)	60 (0)	62 (0)
430	68 (0)	79 (0)	144 (0)	147 (0)
440	165 (3)	175 (3)	165 (2)	167 (2)
450	45 (0)	61 (0)	52 (0)	54 (0)
460	112 (1)	125 (1)	117 (2)	120 (2)
470	201 (4)	210 (4)	161 (2)	162 (2)
480	152 (2)	165 (2)	70 (1)	72 (1)
490	206 (2)	218 (2)	265 (4)	267 (4)
$\varnothing(\Sigma)$	84 (14)	95 (14)	89 (14)	91 (14)

- *aso* — dedicated system
- aso_r — dedicated system with ranks
- $asprin_a$
- $asprin_{r+a}$ — with ranks

satpref versus *asprin*

Benchmark\System	*satpref*	*satpref*+s	*satpref*+H	*asprin*$_p$	*asprin*$_p$+s	*asprin*$_p$+H
0.0	0 (29, 0)	0 (1, 0)	0 (1, 0)	1 (16, 0)	0 (2, 0)	0 (1, 0)
0.00621	0 (35, 0)	0 (1, 0)	90 (1, 6)	1 (17, 0)	1 (2, 0)	1 (1, 0)
0.01243	1 (75, 0)	1 (3, 0)	118 (1, 7)	6 (26, 0)	2 (3, 0)	3 (1, 0)
0.02486	8 (388, 0)	6 (10, 0)	635 (1, 38)	55 (74, 0)	9 (8, 0)	64 (1, 4)
0.04972	67 (1463, 2)	16 (36, 0)	900 (0,100)	318 (203, 16)	26 (17, 0)	176 (1,14)
1.0	850 (10315,88)	243 (590,10)	177 (1, 12)	856 (323, 92)	174 (96, 0)	280 (1,24)
$\varnothing(\varnothing,\Sigma)$	154 (2051,90)	44 (107,10)	320 (1,163)	206 (110,108)	35 (21, 0)	88 (1,42)
MAXSAT	54 (8849, 0)	9 (7, 0)	62 (1, 0)	835 (957, 31)	109 (31, 3)	171 (1, 6)
PBO/pbo-mqc-nencdr	5 (267, 0)	2 (2, 0)	664 (1, 88)	150 (207, 14)	9 (2, 0)	244 (1,20)
PBO/pbo-mqc-nlogencdr	3 (228, 0)	1 (2, 0)	237 (1, 21)	110 (214, 3)	5 (2, 0)	141 (1,15)
PSEUDO/primes	110 (396,18)	110 (1,18)	110 (1, 18)	215 (334, 27)	106 (5,17)	110 (1,17)
PSEUDO/routing	346 (409, 4)	49 (1, 0)	50 (1, 0)	85 (475, 0)	4 (1, 0)	86 (1, 1)
Partial-MINONE	14 (2, 0)	14 (2, 0)	7 (1, 0)	24 (2, 0)	24 (1, 0)	25 (1, 0)
$\varnothing(\varnothing,\Sigma)$	88 (1692,22)	31 (2,18)	188 (1,127)	236 (365, 75)	43 (7,20)	129 (1,59)

- *satpref*
- *satpref*+s
- *satpref*+H
- s — sign heuristic
- H — complex heuristic

- *asprin*$_p$
- *asprin*$_p$+s
- *asprin*$_p$+H
- s — sign heuristic
- H — complex heuristic

Outline

Summary

- asprin stands for "ASP for Preference handling"
- asprin is a general, flexible, and extendable framework for preference handling in ASP
- asprin caters to
  - off-the-shelf users using the preference relations in *asprin*'s library
  - preference engineers customizing their own preference relations
- asprin can be boosted by *clingo*'s heuristic framework
- https://github.com/potassco/asprin

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