Applications of Answer Set Programming

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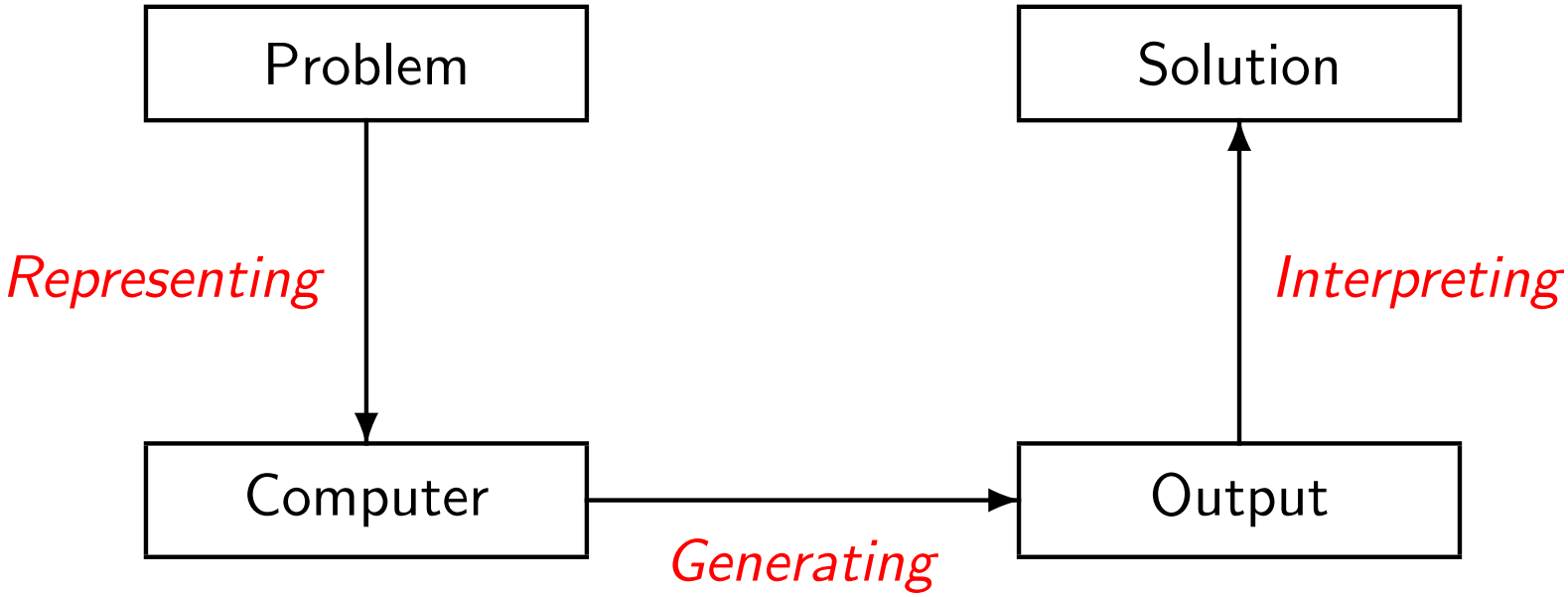
Outline

1. Motivation
2. ASP in a Nutshell
3. Linux Package Configuration
4. Conclusion

Computer Programming

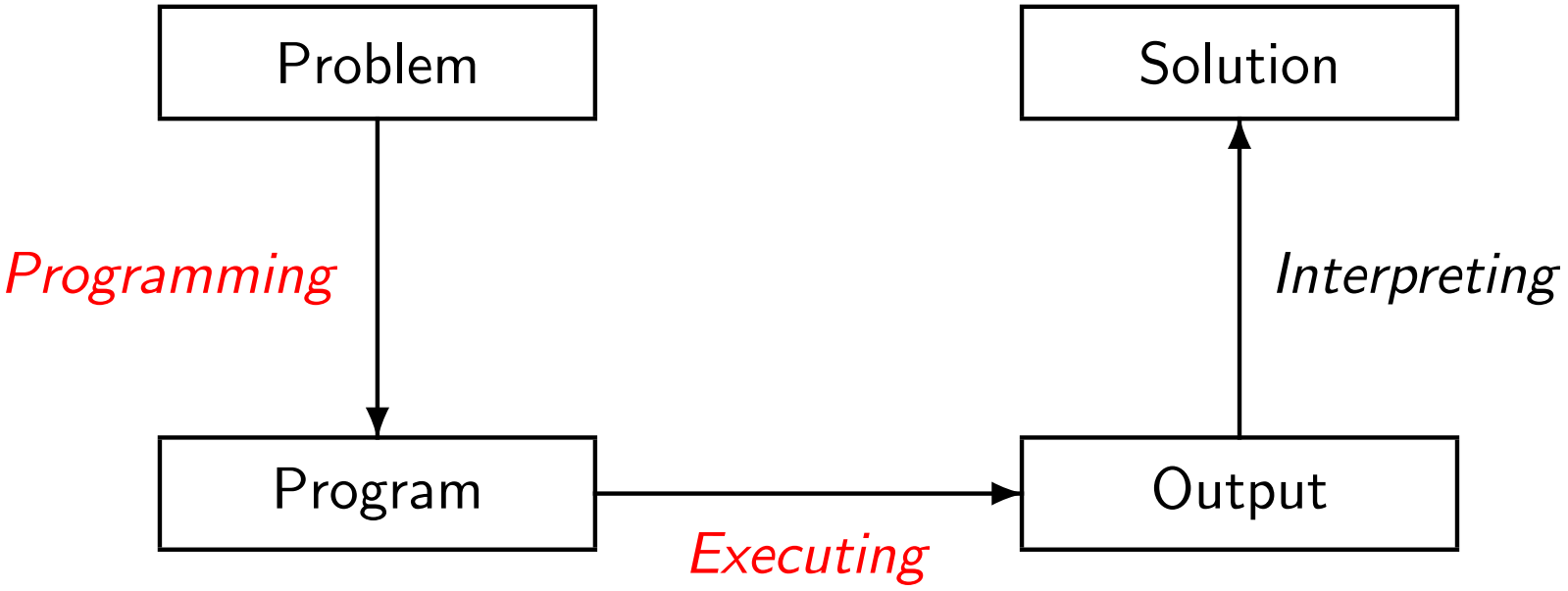


"How to solve the problem?"

versus

"What is the problem?"

"Traditional" Programming



"How to solve the problem?"

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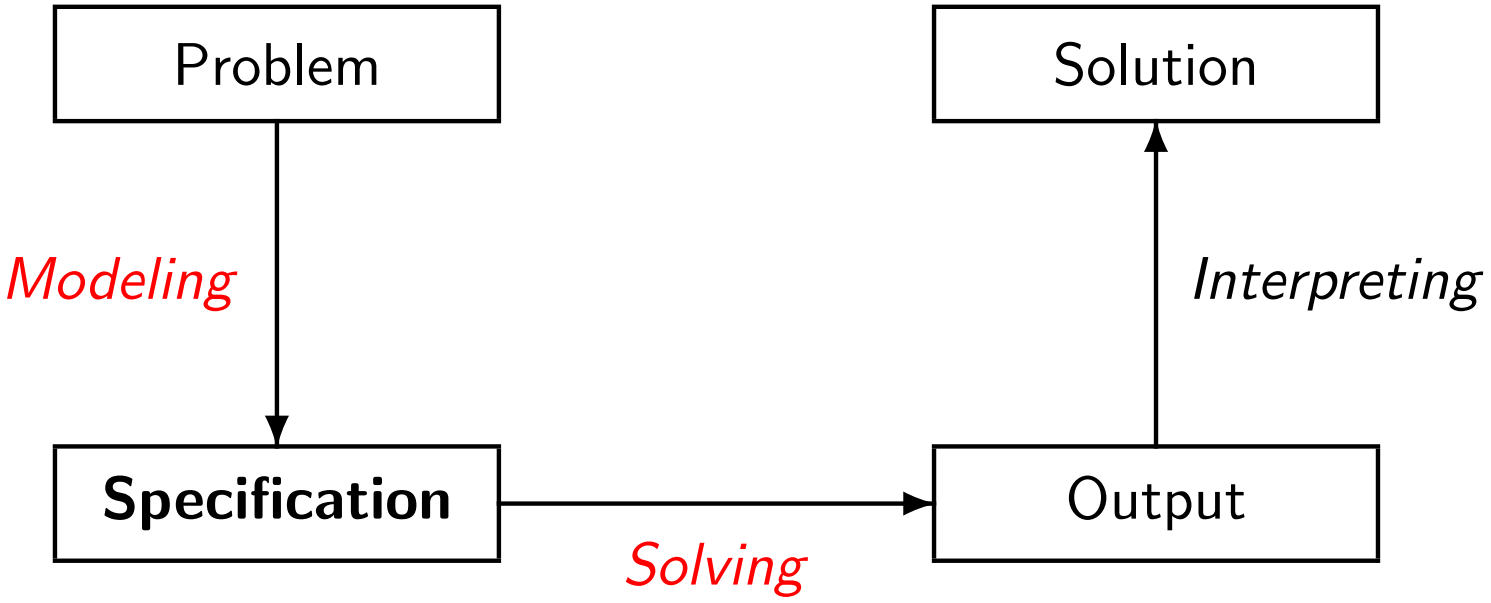
Declarative Programming



"How to solve the problem?"

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"What is the problem?"

Answer Set Programming (ASP)

- Attractive tool for Knowledge Representation and Reasoning
  - Integration of deductive database, logic programming, knowledge representation and satisfiability solving techniques
  - Combinatorial search problems in the realm of NP and NP^{NP}
    - decision, optimization and query answering tasks
  - Succinct, elaboration-tolerant problem representations
    - rapid application development tool
  - Easy handling of knowledge-intensive applications
    - data, defaults, exceptions, frame axioms, reachability, etc.
- Efficient and versatile off-the-shelf solving technology
  - `https://potassco.org/`
  - `https://www.mat.unical.it/DLV2/`
- ASP has a growing range of applications, and it's good fun!

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Industrial Applications

- Airport infrastructure planning
- Business partner matchmaking
- Call routing
- Embedded system design
- Nurse rostering
- Production process scheduling
- Radio spectrum reallocation
- Safety system configuration
- Shift planning
- Software package management
- Space shuttle maneuvering
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Call Center Shift Planning

Planning context	"Hard" constraints	"Soft" constraints
Workload	4	1
Shift sequence	6	1
Times of absence	2	2
Quality of service	0	3
Free days	0	5
Total	12	12

- Each solution/shift plan must satisfy all hard constraints
- Soft constraints distinguish/select preferred solutions
  - Successive improvement through "anytime" solving algorithms
  - Guaranteed optimality on termination
- Monthly shift planning

  Manual: about one person-week of work

  Automated: "good-quality" shift plans within one hour

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"The weekly working hours must stay in the legal limit."

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  "Single free days in-between two workdays shall be avoided."

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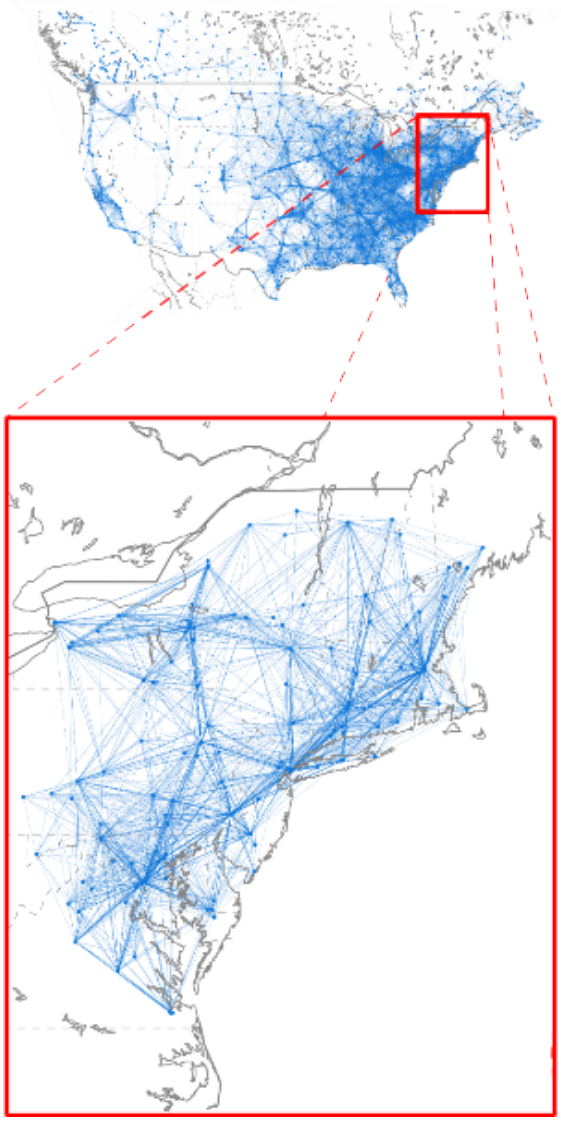
Radio Spectrum Reallocation



- Complex incentive auction by the US Federal Communications Commission
  - $\sim$ 3000 sending stations
  - $\sim$ 3 million interference restrictions

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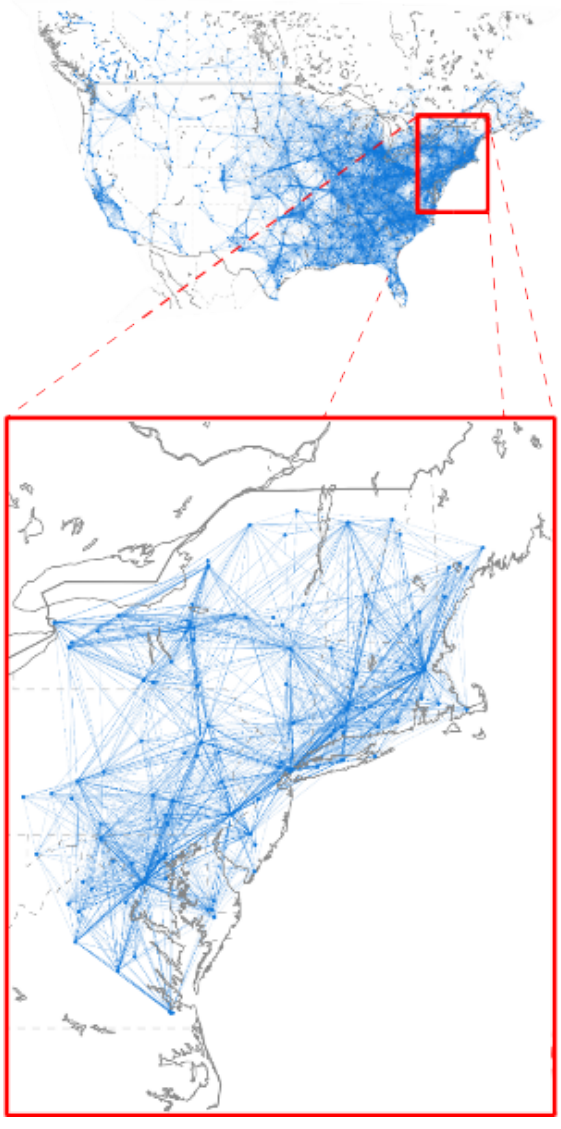

- Complex incentive auction by the US Federal Communications Commission
  - ∼ 3000 sending stations
  - ∼ 3 million interference restrictions

Over 13 months in 2016–17 the US Federal Communications Commission conducted an "incentive auction" to repurpose radio spectrum from broadcast television to wireless internet. In the end, the auction yielded $19.8 billion, $10.05 billion of which was paid to 175 broadcasters for voluntarily relinquishing their licenses across 14 UHF channels. Stations that continued broadcasting were assigned potentially new channels to fit as densely as possible into the channels that remained. The government netted more than $7 billion (used to pay down the national debt) after covering costs. A crucial element of the auction design was the construction of a solver, dubbed SATFC, that determined whether sets of stations could be "repacked" in this way; it needed to run every time a station was given a price quote. This

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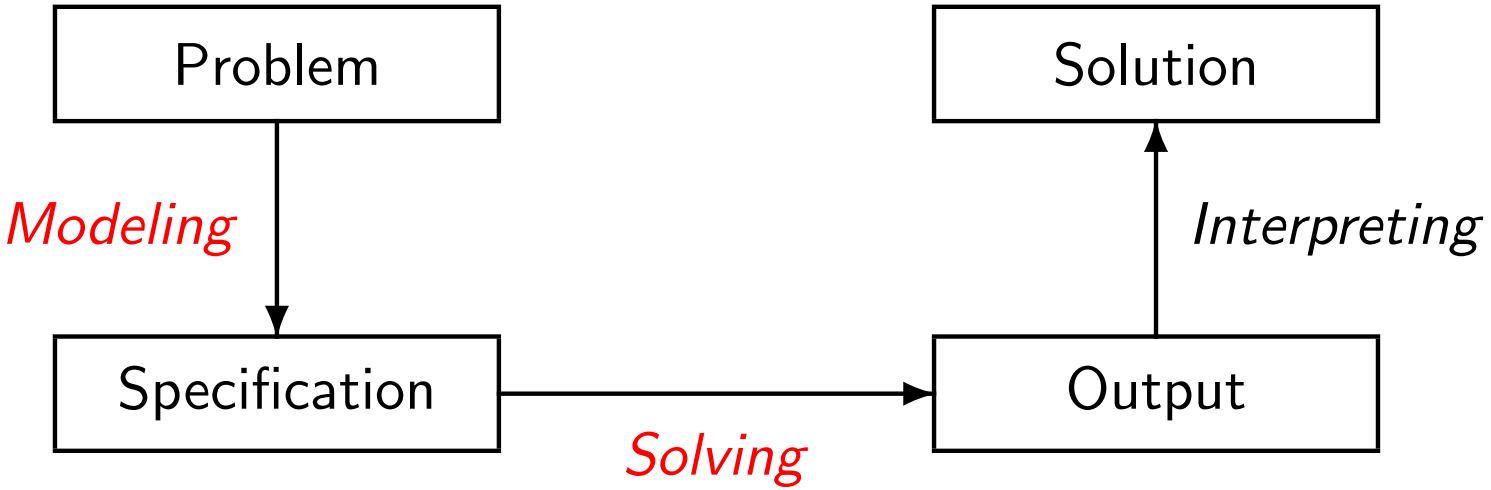
Basic Workflow



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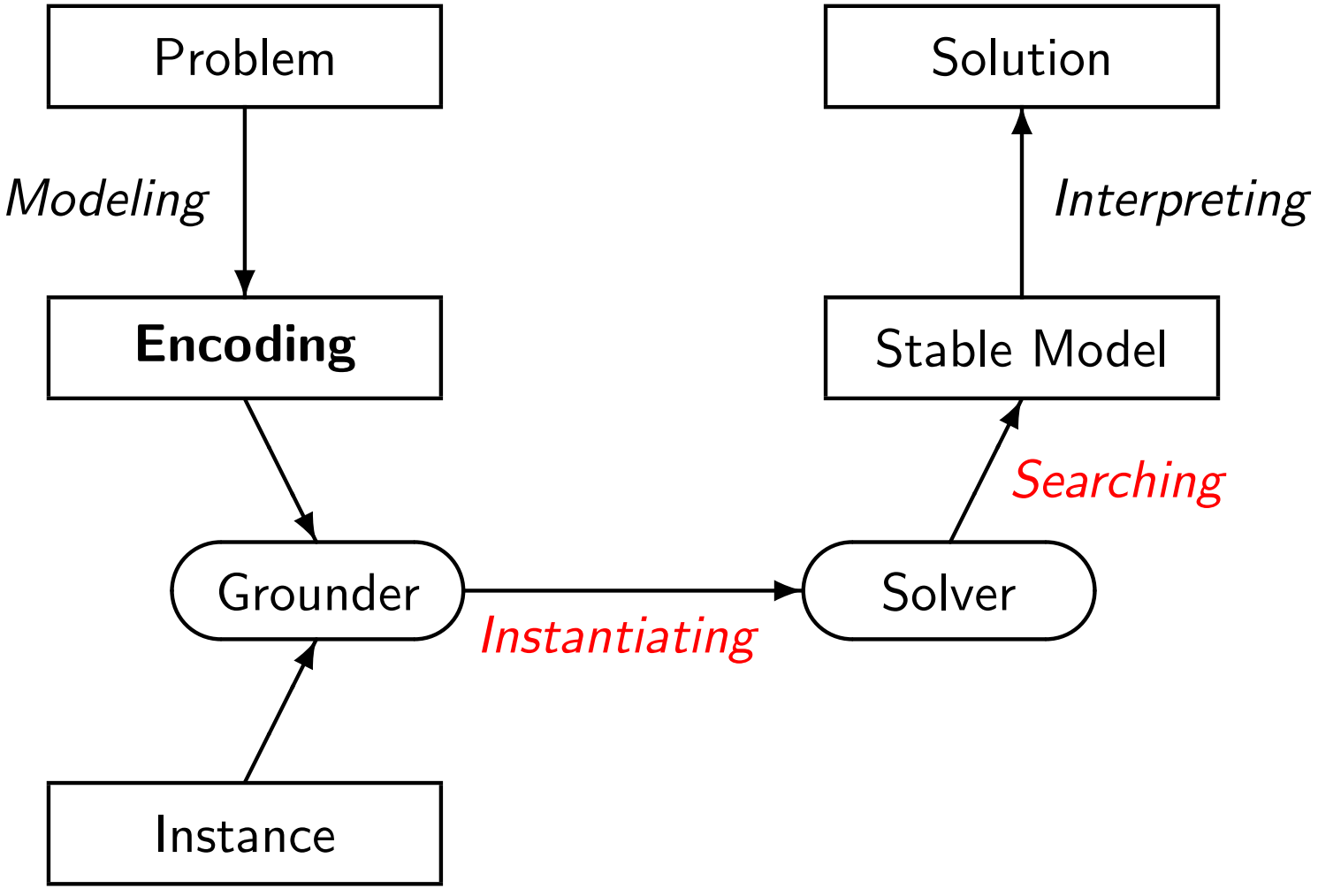

Modeling Language

- Facts `p(0).`
- Normal rules `p(1) :- p(0).`
- Choice rules `{p(2); p(3)} = 1 :- p(1).`
- Integrity constraints `:- p(3).`
- Default negation `:- not p(2).`
- First-order variables `q(X) :- p(X).`
- Arithmetics `r(X+1) :- p(X).`
- Conjunctions `s(X) :- q(X), r(X).`
- Aggregates `t(N) :- #sum{X : s(X)} = N.`
- Conditional literals `{u(X) : r(X), X < N} :- t(N).`
- Optimization `:~ u(X). [X]`

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  Instantiation

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```

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r(4) :- p(3).
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- (Relevant) Instantiation

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s(2) :- q(2), r(2).
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(Relevant) Instantiation

```
t(0) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 0.
t(1) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 1.
t(2) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 2.
t(3) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 3.
t(4) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 4.
t(5) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 5.
t(6) :- #sum{1 : s(1); 2 : s(2); 3 : s(3)} = 6.
```

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(Relevant) Instantiation

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{u(1) : r(1)} :- t(2).
{u(1) : r(1); u(2) : r(2)} :- t(3).
{u(1) : r(1); u(2) : r(2); u(3) : r(3)} :- t(4).
{u(1) : r(1); u(2) : r(2); u(3) : r(3); u(4) : r(4)} :- t(5).
{u(1) : r(1); u(2) : r(2); u(3) : r(3); u(4) : r(4)} :- t(6).
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```
:~ u(1). [1]
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:~ u(3). [3]
:~ u(4). [4]
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- Optimization `:~ u(X). [X]`

Optimum $\{p(0), p(1), p(2), q(0), \ldots, s(1), s(2), t(3)\}$

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{u(X) : r(X), X < N} :- t(N).
```
- Multi-criteria Optimization
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:~ u(X). [X@1]
:~ #count{X : u(X)} = 0. [1@2]
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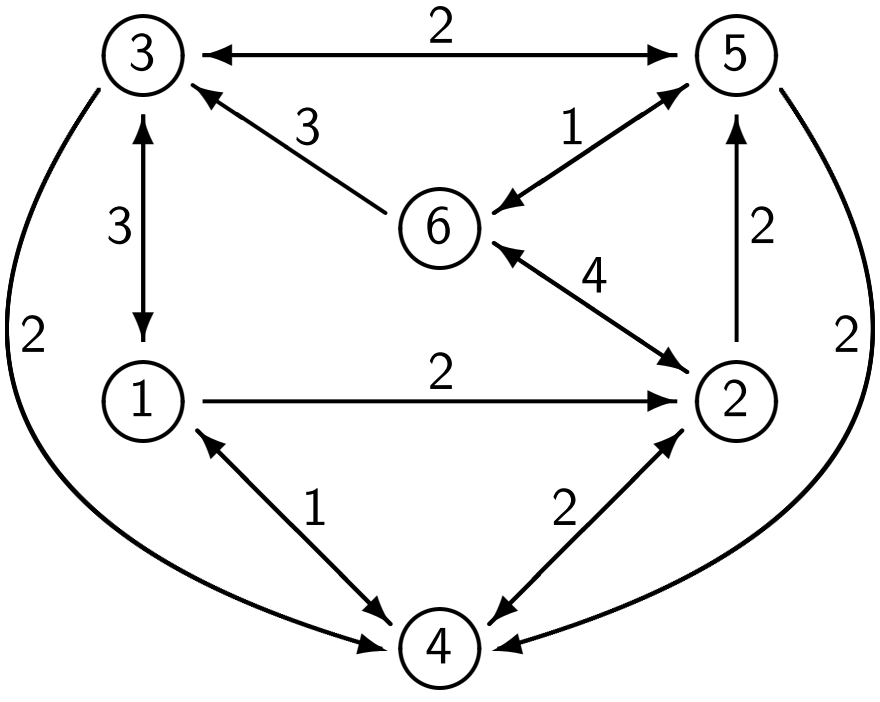
- Conditional literals `{u(X) : r(X), X < N} :- t(N).`
- Multi-criteria Optimization `:~ u(X). [X@1]`
  `:~ #count{X : u(X)} = 0. [1@2]`

  Optimum $\{p(0), p(1), p(2), q(0), \ldots, s(1), s(2), t(3), u(1)\}$

Traveling Salesperson (TSP) Example



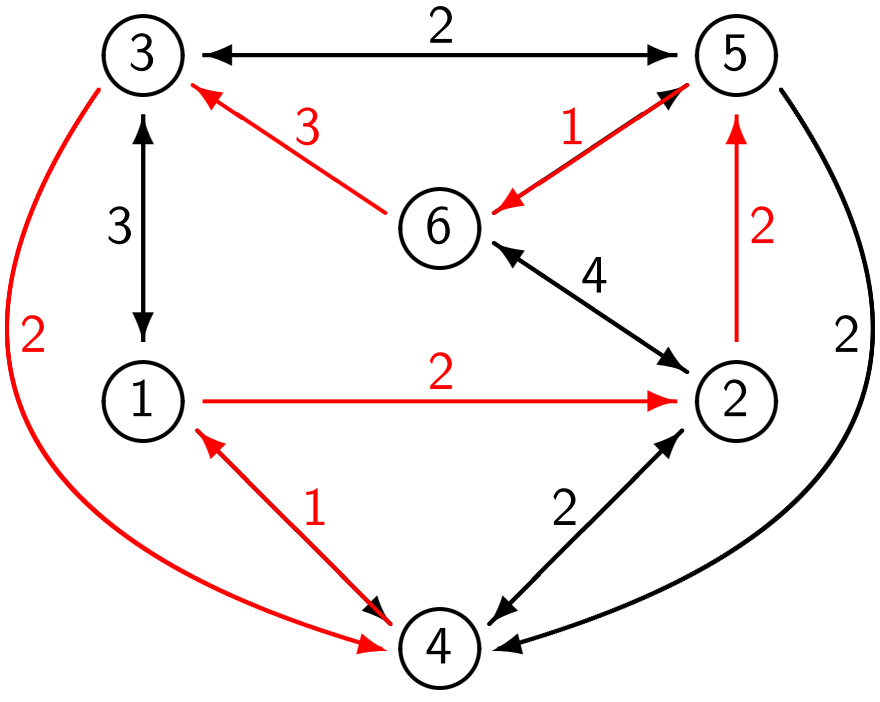
Total Cost: 11

Instance Representation

```
node(1). node(2). node(3).
node(4). node(5). node(6).

edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).
edge(2,4,2). edge(4,2,2).
edge(2,5,2).
edge(2,6,4). edge(6,2,4).
edge(3,4,2).
edge(3,5,2). edge(5,3,2).
edge(5,4,2).
edge(5,6,1). edge(6,5,1).
edge(6,3,3).
```

Traveling Salesperson (TSP) Example



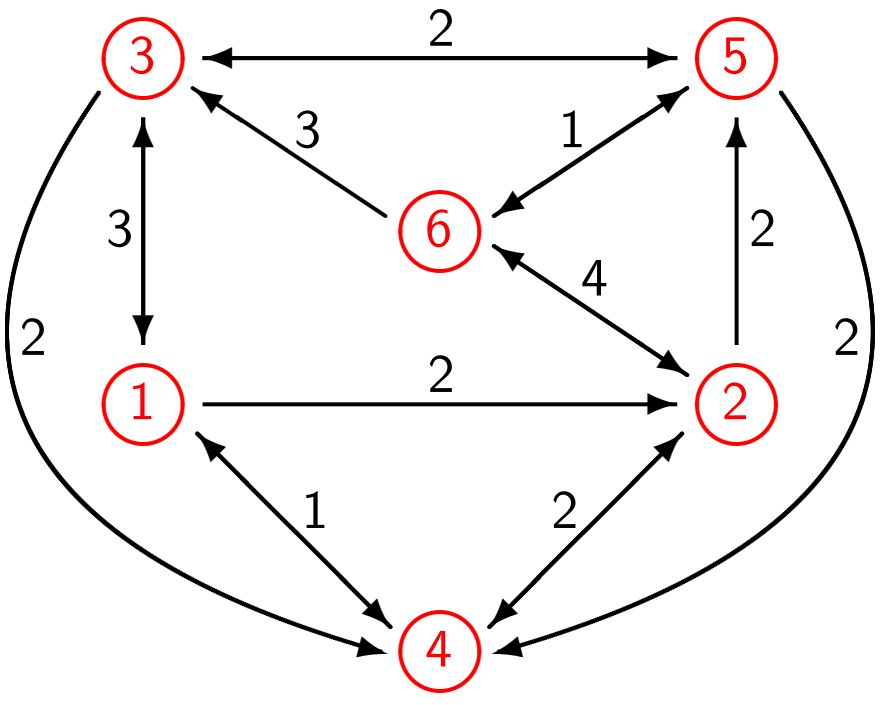
Total Cost: 11

Instance Representation

```
node(1). node(2). node(3).
node(4). node(5). node(6).

edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).
edge(2,4,2). edge(4,2,2).
edge(2,5,2).
edge(2,6,4). edge(6,2,4).
edge(3,4,2).
edge(3,5,2). edge(5,3,2).
edge(5,4,2).
edge(5,6,1). edge(6,5,1).
edge(6,3,3).
```

Traveling Salesperson (TSP) Example



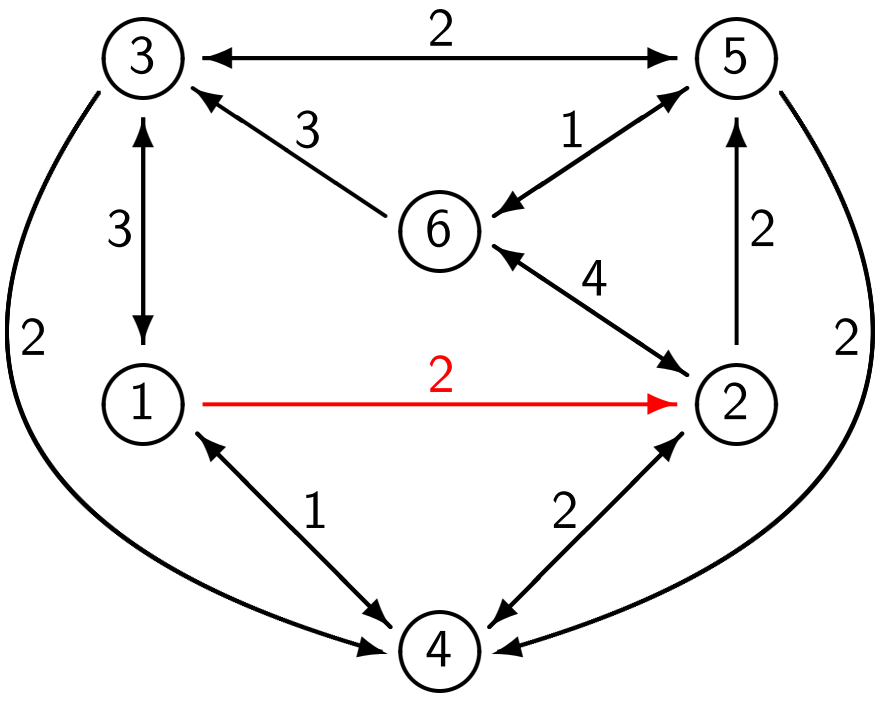
Total Cost: 11

Instance Representation

```
node(1). node(2). node(3).
node(4). node(5). node(6).

edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).
edge(2,4,2). edge(4,2,2).
edge(2,5,2).
edge(2,6,4). edge(6,2,4).
edge(3,4,2).
edge(3,5,2). edge(5,3,2).
edge(5,4,2).
edge(5,6,1). edge(6,5,1).
edge(6,3,3).
```

Traveling Salesperson (TSP) Example



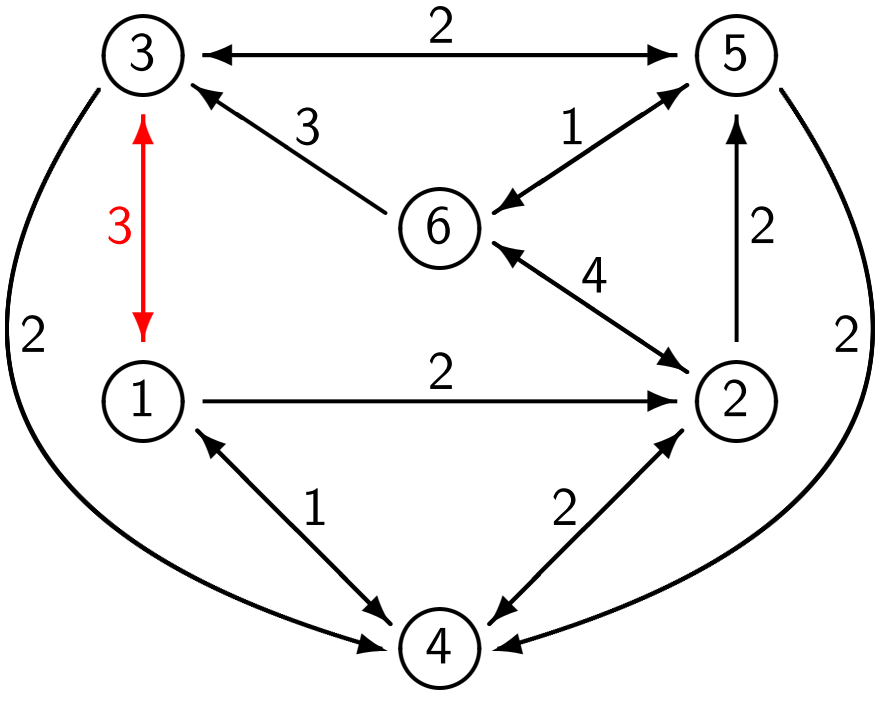
Total Cost: 11

Instance Representation

```
node(1). node(2). node(3).
node(4). node(5). node(6).

edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).
edge(2,4,2). edge(4,2,2).
edge(2,5,2).
edge(2,6,4). edge(6,2,4).
edge(3,4,2).
edge(3,5,2). edge(5,3,2).
edge(5,4,2).
edge(5,6,1). edge(6,5,1).
edge(6,3,3).
```

Traveling Salesperson (TSP) Example



Total Cost: 11

Instance Representation

```
node(1). node(2). node(3).
node(4). node(5). node(6).

edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).
edge(2,4,2). edge(4,2,2).
edge(2,5,2).
edge(2,6,4). edge(6,2,4).
edge(3,4,2).
edge(3,5,2). edge(5,3,2).
edge(5,4,2).
edge(5,6,1). edge(6,5,1).
edge(6,3,3).
```

TSP Solution Specification

1. Exactly one outgoing edge per node
2. Exactly one incoming edge per node
3. All nodes reached from (arbitrary) start node
4. Minimum sum of edge costs

Problem Encoding

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X,Y]
```

☞ More encoding “optimization” feasible

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1. Exactly one outgoing edge per node
2. Exactly one incoming edge per node
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```

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```

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X,Y]
```

☞ More encoding “optimization” feasible

TSP Solution Specification

1. Exactly one outgoing edge per node
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{cycle(X,Y) : edge(X,Y,C)} = 1 :- node(X).
{cycle(X,Y) : edge(X,Y,C)} = 1 :- node(Y).

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X,Y]
```

☞ More encoding "optimization" feasible

TSP Solution Specification

1. Exactly one outgoing edge per node
2. Exactly one incoming edge per node
3. All nodes reached from (arbitrary) start node
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Problem Encoding

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X,Y]
```

☞ More encoding "optimization" feasible

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1. Exactly one outgoing edge per node
2. Exactly one incoming edge per node
3. All nodes reached from (arbitrary) start node
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Problem Encoding

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X,Y]
```

☞ More encoding “optimization” feasible

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

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

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.
{cycle(X,Y) : edge(X,Y,C)} = 1 :- node(Y).

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.
{cycle(X,1) : edge(X,1,C)} = 1 :- node(1).

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.
{cycle(3,1); cycle(4,1)} = 1.

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(X) :- #min{Y : node(Y)} = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(X) :- #min{1 : ; 2 : ; 3 : ; 4 : ; 5 : ; 6 : } = X.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1) :- #min{1 : ; 2 : ; 3 : ; 4 : ; 5 : ; 6 : } = 1.
reached(Y) :- cycle(X,Y), reached(X).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(Y) :- cycle(X,Y), reached(X).
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```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(Y) :- cycle(1,Y), reached(1).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

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reached(Y) :- cycle(1,Y), reached(1).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
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{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).  ...
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
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(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
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edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).  ...
:- node(Y), not reached(Y).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
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edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).  ...
:- not reached(1).  ...  :- not reached(6).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
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(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
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{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).  ...
:- not reached(1).  ...  :- not reached(6).

:~ cycle(X,Y), edge(X,Y,C). [C,X]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).  ...
:- not reached(1).  ...  :- not reached(6).

:~ cycle(1,2). [2,1]  ...  :~ cycle(1,4). [1,1]
```

(Intelligent) Grounding

Ground Instantiation

```
node(1). node(2). node(3). node(4). node(5). node(6).
edge(1,2,2).
edge(1,3,3). edge(3,1,3).
edge(1,4,1). edge(4,1,1).  ...

{cycle(1,2); cycle(1,3); cycle(1,4)} = 1.  ...
{cycle(3,1); cycle(4,1)} = 1.  ...

reached(1).
reached(2) :- cycle(1,2), reached(1).
reached(3) :- cycle(1,3), reached(1).
reached(4) :- cycle(1,4), reached(1).  ...
:- not reached(1).  ...   :- not reached(6).

:~ cycle(1,2). [2,1]  ...   :~ cycle(1,4). [1,1]  ...
```

(Pseudo-)Boolean Optimization

Model-guided Approach

```
$ clingo <instance> <encoding>

Answer: 1
cycle(1,4) cycle(4,2) cycle(2,6) cycle(6,5) cycle(5,3) cycle(3,1)
Optimization: 13

Answer: 2
cycle(1,4) cycle(4,2) cycle(2,5) cycle(5,6) cycle(6,3) cycle(3,1)
Optimization: 12

Answer: 3
cycle(1,2) cycle(2,5) cycle(5,6) cycle(6,3) cycle(3,4) cycle(4,1)
Optimization: 11

Time : 0.002s
Conflicts : 12
```

(Pseudo-)Boolean Optimization

Model-guided Approach

```
$ clingo <instance> <encoding>

Answer: 1
cycle(1,4) cycle(4,2) cycle(2,6) cycle(6,5) cycle(5,3) cycle(3,1)
Optimization: 13

Answer: 2
cycle(1,4) cycle(4,2) cycle(2,5) cycle(5,6) cycle(6,3) cycle(3,1)
Optimization: 12

Answer: 3
cycle(1,2) cycle(2,5) cycle(5,6) cycle(6,3) cycle(3,4) cycle(4,1)
Optimization: 11

Time : 0.002s
Conflicts : 12
```

(Pseudo-)Boolean Optimization

Model-guided Approach

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$ clingo <instance> <encoding>

Answer: 1
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(Pseudo-)Boolean Optimization

Core-guided Approach

```
$ clingo <instance> <encoding> --opt-strategy=usc
Progression : [3;inf]
Progression : [5;inf]
Progression : [6;inf]
Progression : [7;inf]
Progression : [8;inf]
Progression : [9;inf]
Progression : [10;inf]
Progression : [11;inf]

Answer: 1
cycle(1,2) cycle(2,5) cycle(5,6) cycle(6,3) cycle(3,4) cycle(4,1)
Optimization: 11

Time : 0.002s
Conflicts : 10
```

(Pseudo-)Boolean Optimization

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Outline

1 Motivation

2 ASP in a Nutshell

3 Linux Package Configuration

4 Conclusion

Free and Open Source Software Management

- Maintaining packages in modern Linux distributions is difficult
  - Complex dependencies
  - Large package repositories
  - Ever changing in view of software development
- Challenges for package configuration tools
  - Large problem size
  - Soft (and hard) constraints
  - Multiple optimization criteria

☞ Targeted in the EU research project *Mancoosi*

- Contributions of ASP
  - Uniform modeling by encoding plus instances
  - Solving techniques for (multi-criteria) optimization

☞ *Instead of the standard* `apt-get install libreoffice` *that failed to propose a decent upgrade, as detailed later, I typed* `apt-get --solver aspcud install libreoffice` *that returned this pretty good solution . . .*

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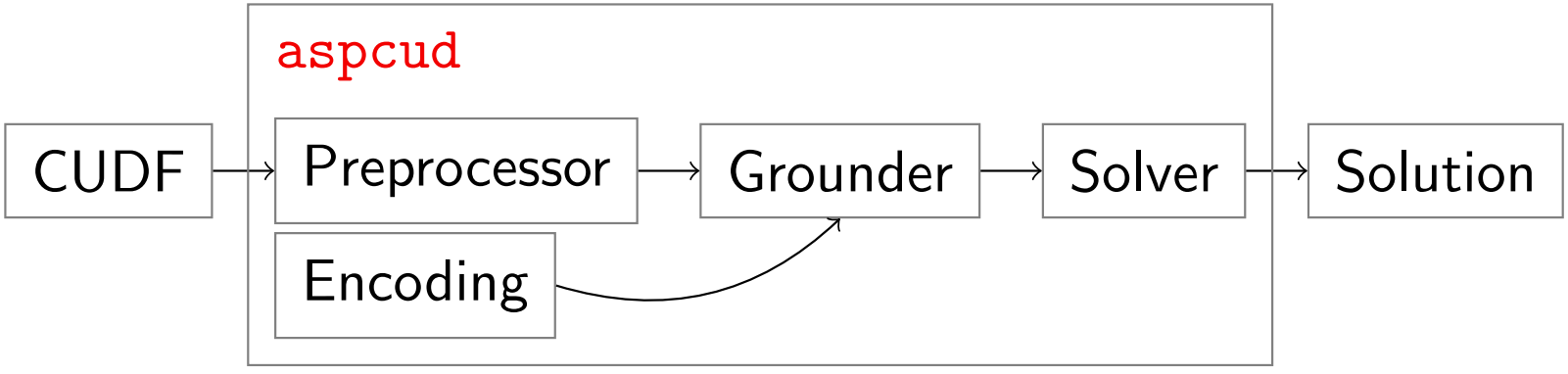
Linux Package Configurator aspcud



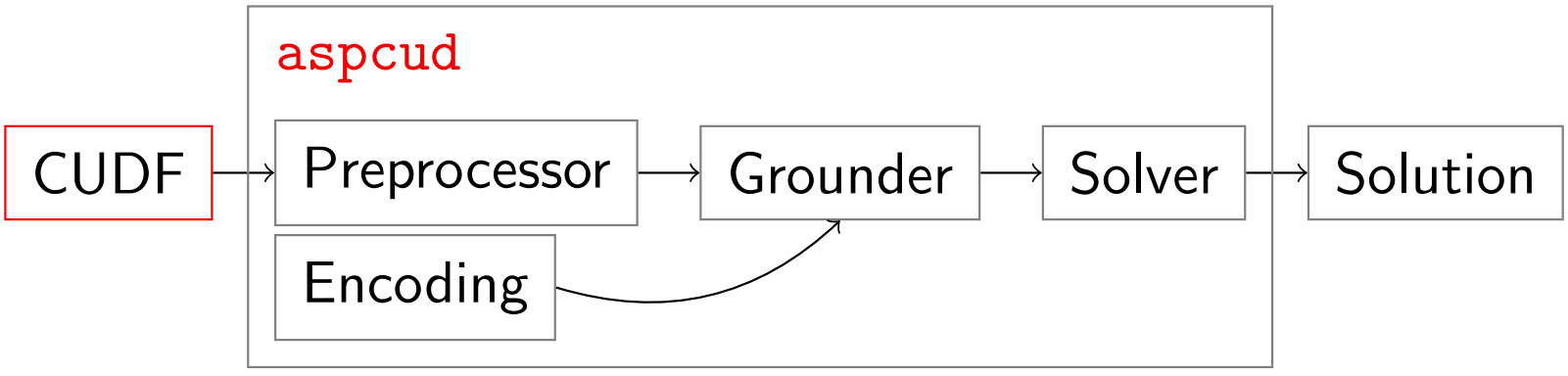
Preprocessor Converts CUDF input to ASP instance

Encoding First-order problem specification

Grounder Instantiates first-order variables

Solver Searches for (optimal) answer sets

Linux Package Configurator aspcud : Input



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Common Upgradability Description Format (CUDF)

- Language to represent package interdependencies
  - Conflicts
  - Dependencies
  - Recommendations
- and user goals
  - Installation
  - Removal
  - Upgrade
- subject to optimization
  - Package deletions
  - Package additions
  - Package recommendations
  - Version changes
  - Version up-to-dateness
  - Version coherence
  - Installation size

CUDF Input

```
package:     firefox
version:     3
conflicts:   firefox
depends:     xserver > 2

recommends:  thunderbird

request:
install:     firefox
remove:      firefox < 3

upgrade:     firefox > 2
```

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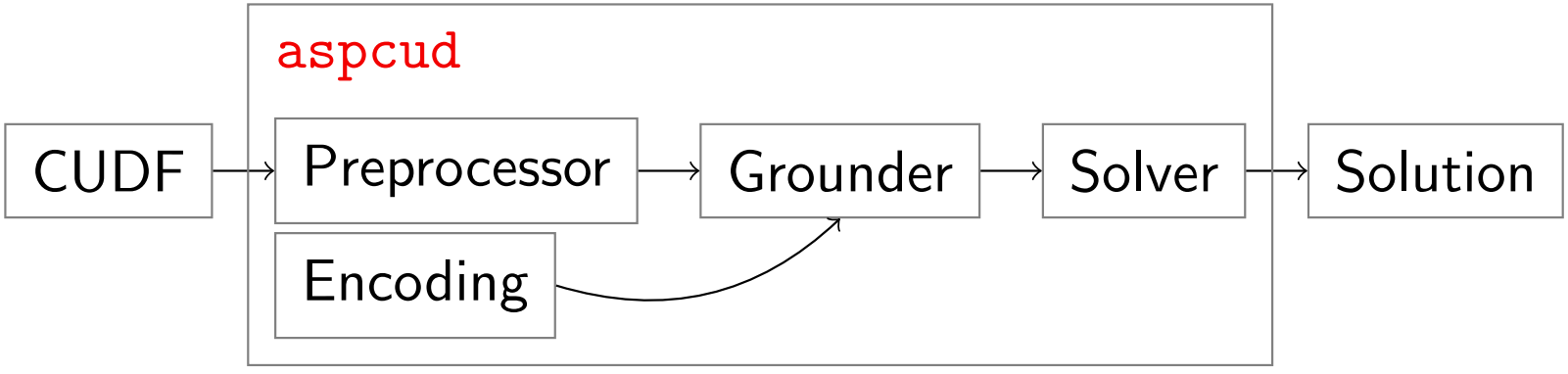

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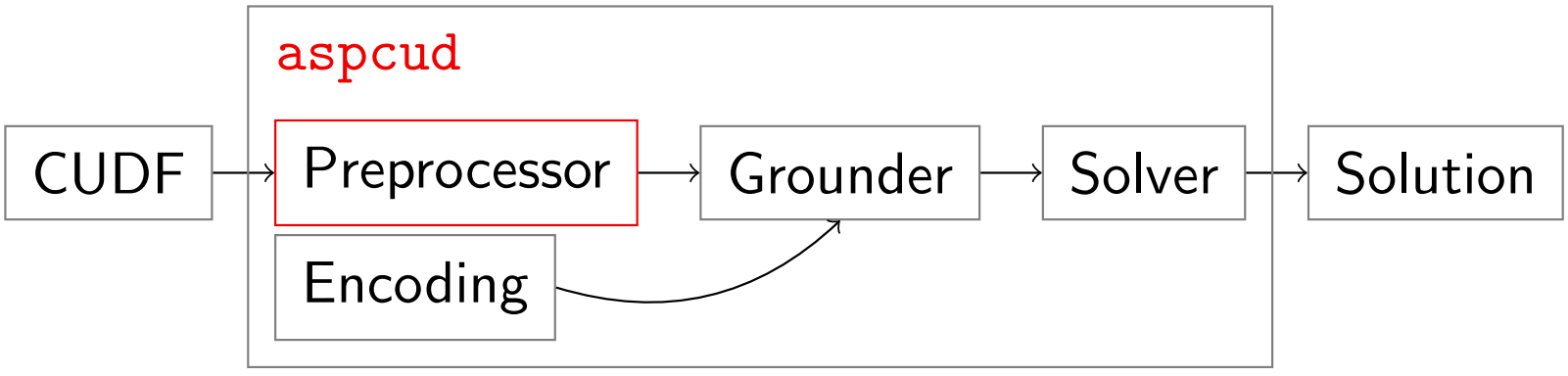

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Setting the Focus

Scenario

- Modern Linux distributions are large (50K packages or more)

☞ Problem representation and search space are of significant size

Observations

- Some packages can't be installed (`remove` or `upgrade` goals)
- An empty installation is conflict-free and thus valid

☞ Packages to install should serve (hard) `install` or `upgrade` goals, or satisfy (soft) constraints

Approach

1. Identify packages whose installation may be of direct use
2. Saturate such packages wrt. dependencies and soft constraints
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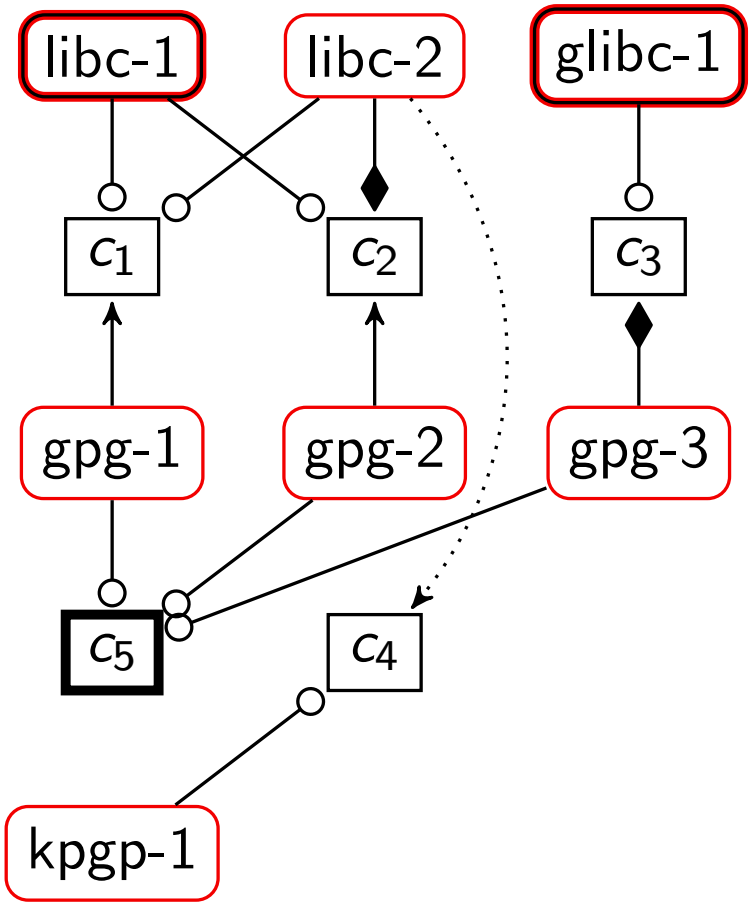


Installable Packages

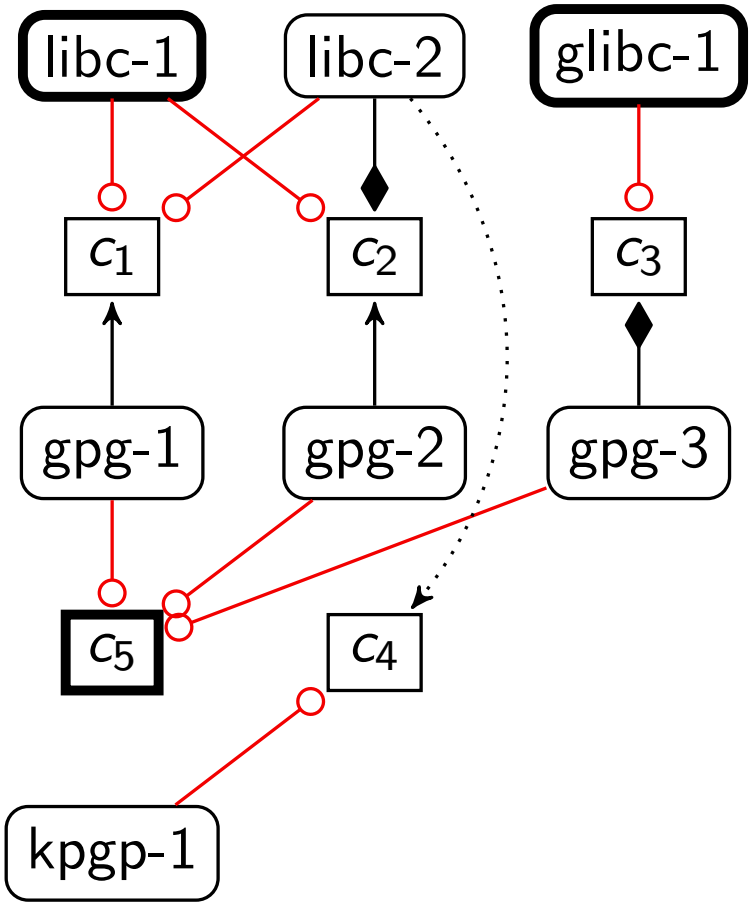
```
package(libc,1).
package(libc,2).

package(glibc,1).

package(gpg,1).
package(gpg,2).
package(gpg,3).

package(kpgp,1).
```

Instance Representation



Package Conditions

```
satisfies(libc,1,c1).
satisfies(libc,2,c1).

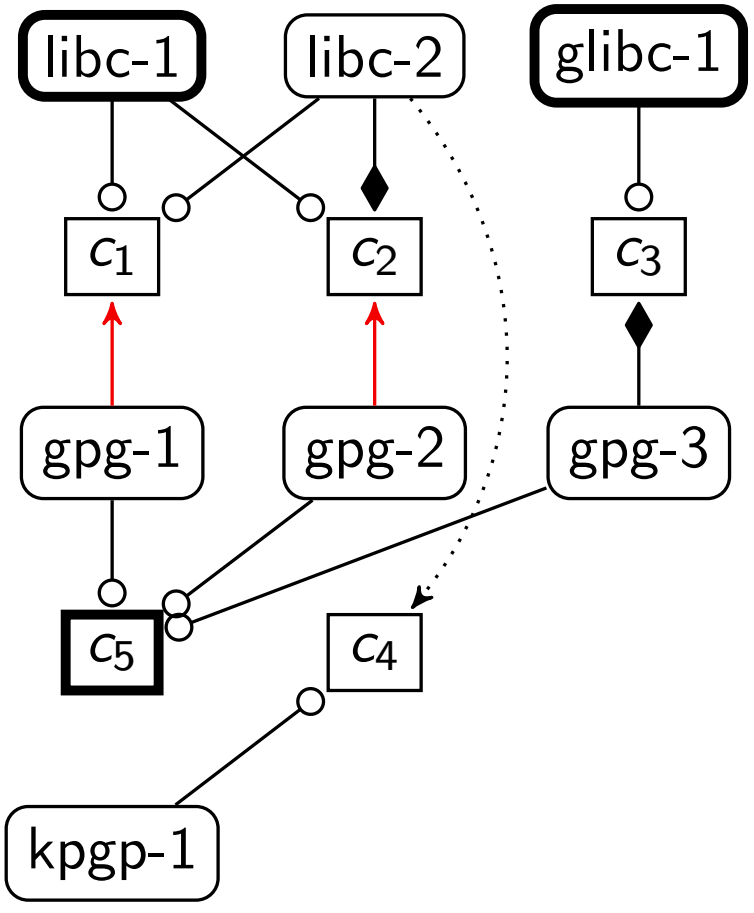
satisfies(libc,1,c2).

satisfies(glibc,1,c3).

satisfies(kpgp,1,c4).

satisfies(gpg,1,c5).
satisfies(gpg,2,c5).
satisfies(gpg,3,c5).
```

Instance Representation

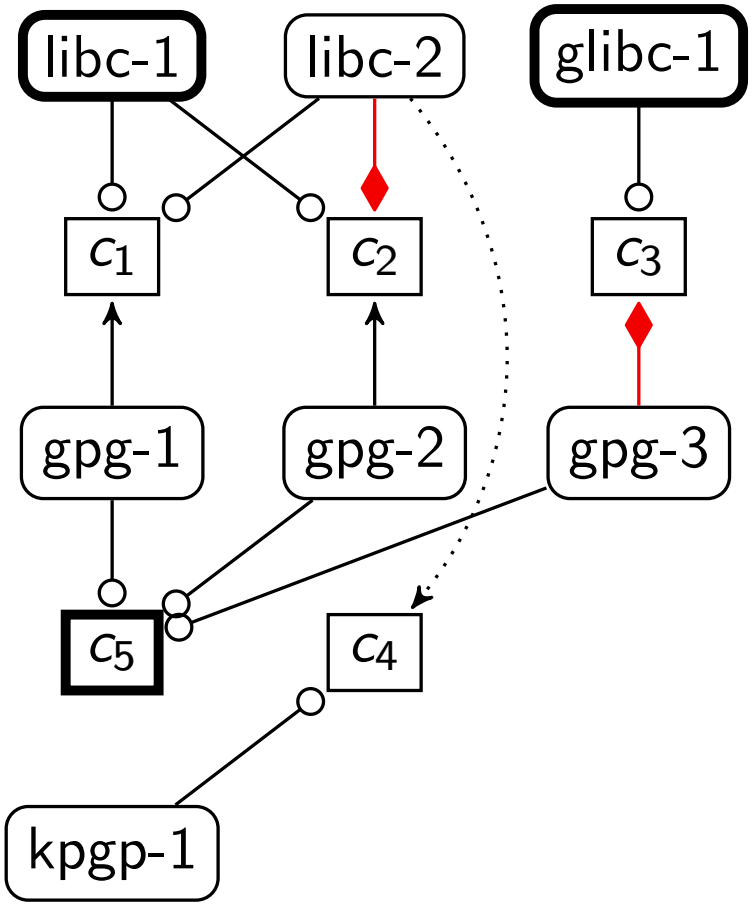


Package Dependencies

```
depends(gpg,1,c1).

depends(gpg,2,c2).
```

Instance Representation

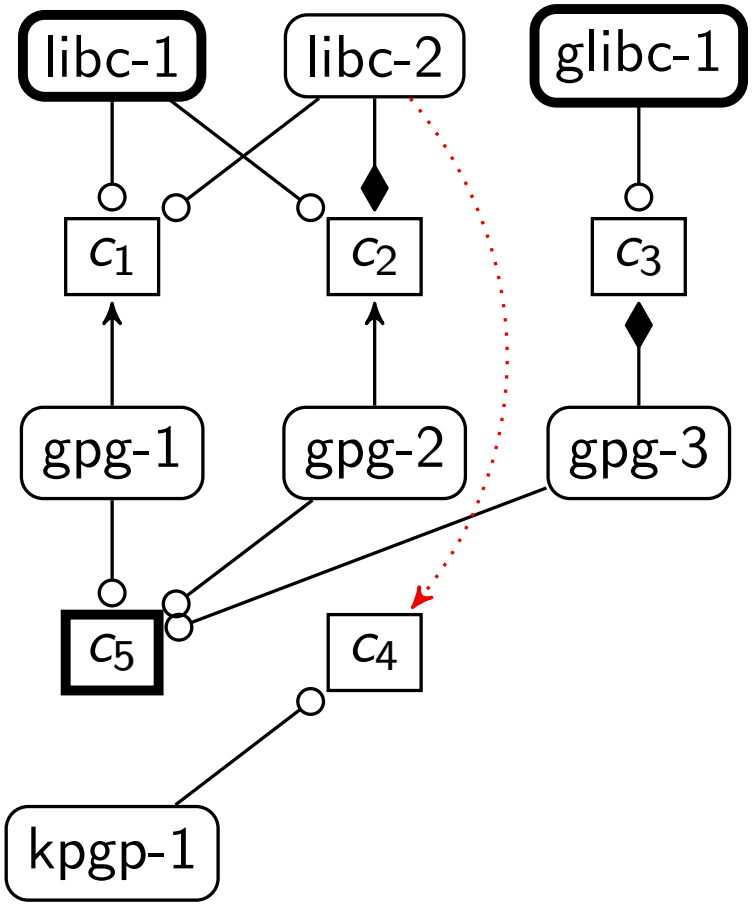


Package Conflicts

```
conflicts(libc,2,c2).

conflicts(gpg,3,c3).
```

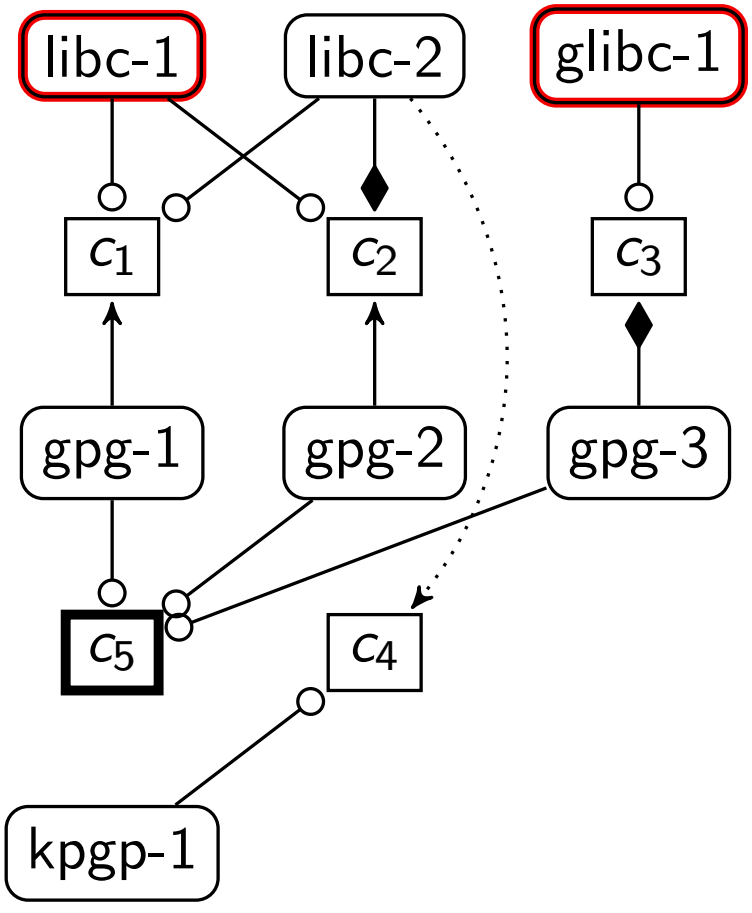
Instance Representation



Package Recommendations

```
recommends(libc,2,c4).
```

Instance Representation

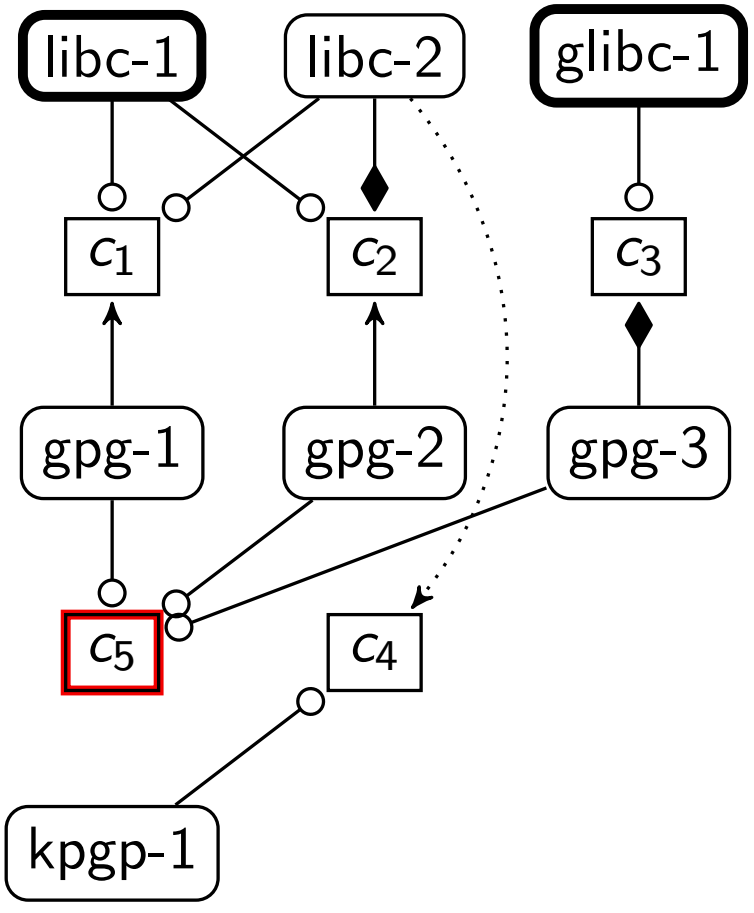


Installed Packages

```
installed(libc,1).

installed(glibc,1).
```

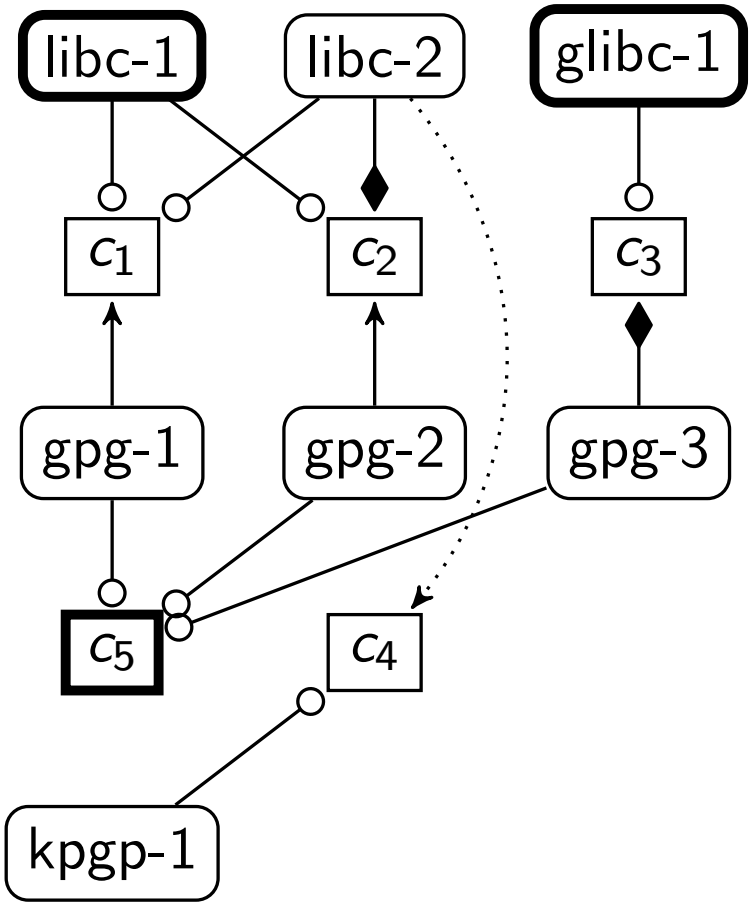
Instance Representation



User Goals

```
request(c5).
```

Instance Representation

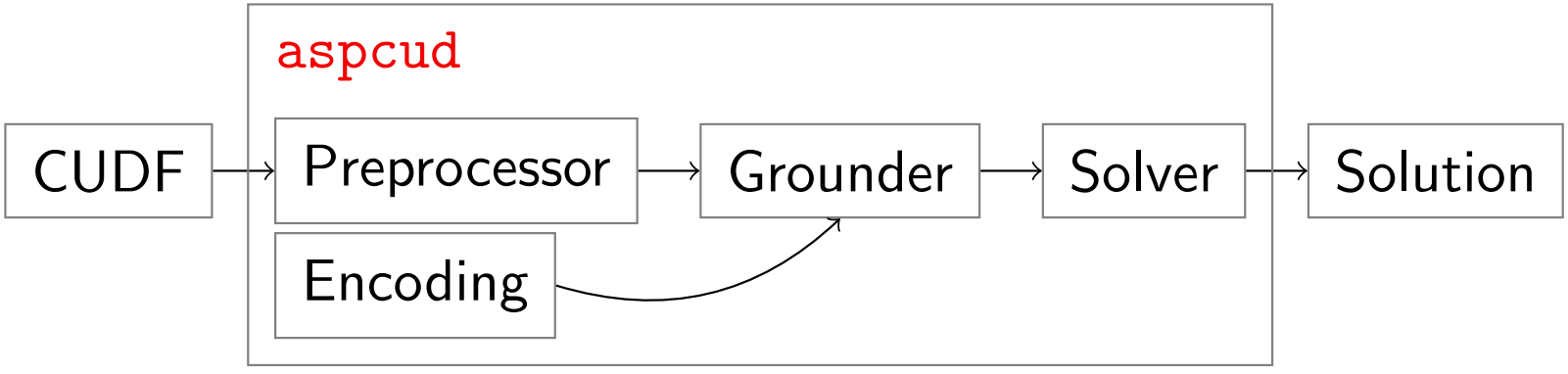


Optimization Criteria

```
utility(delete,1).

utility(change,2).
```

Linux Package Configurator aspcud



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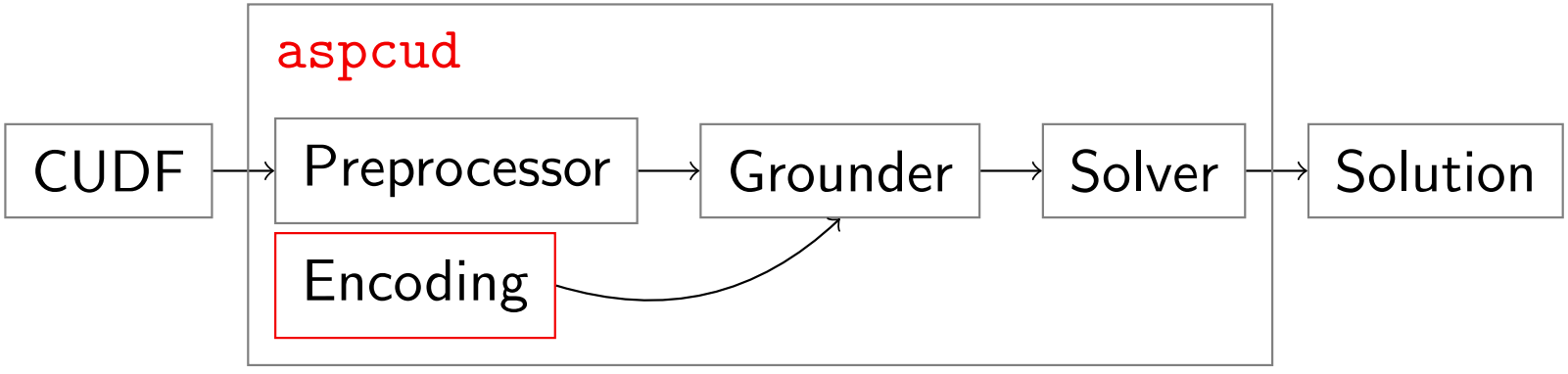
Linux Package Configurator aspcud : Encoding



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Hard Constraints

1. Can install any installable package
2. Excluded, included, and satisfied conditions (packages) follow
3. Respective conditions and user goals must be fulfilled

Problem Encoding

```
{install(P,V)} :- package(P,V).

exclude(C) :- install(P,V), conflicts(P,V,C).
include(C) :- install(P,V), depends(P,V,C).

satisfy(C) :- install(P,V), satisfies(P,V,C).

:- exclude(C),     satisfy(C).
:- include(C), not satisfy(C).
:- request(C), not satisfy(C).
```

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1. Package additions and deletions
2. Version changes

Problem Encoding (ctd)

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installed(P) :- installed(P,V).

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violate(change,L,P) :-
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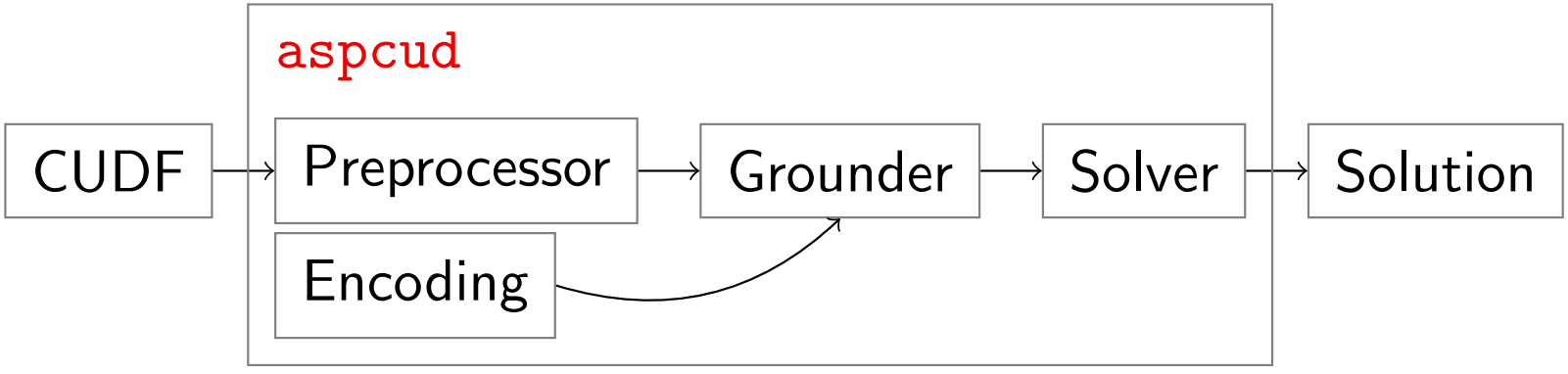
Linux Package Configurator aspcud



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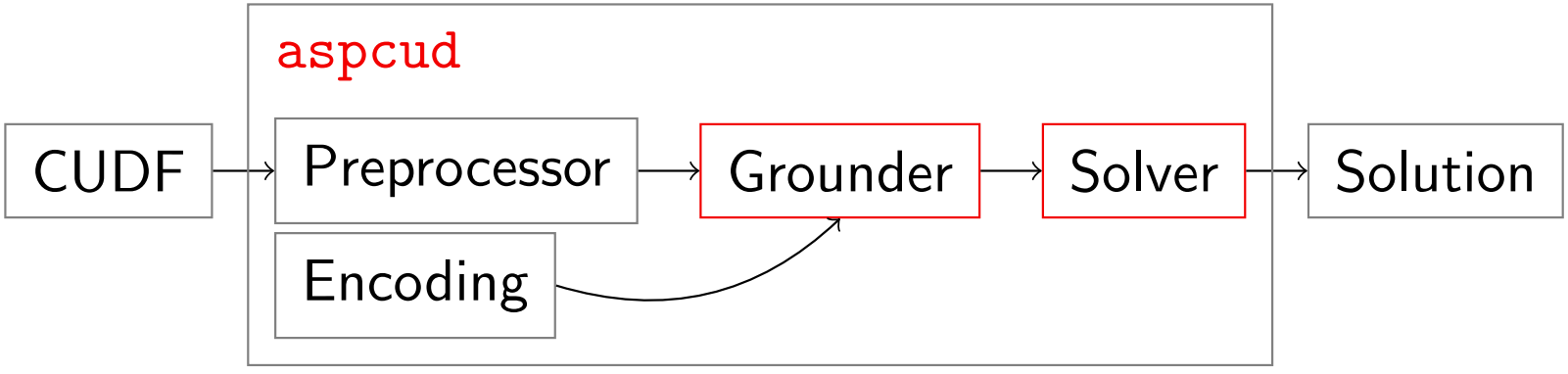
Linux Package Configurator aspcud : Reasoning



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Mancoosi International Solver Competition (MISC)

- Encoding using conflict cliques and core-guided optimization

Track: paranoid

Category	aspcud-paranoid-1.7	aspuncud-paranoid-1.7	cudf_fumax_p-0.1	p2cudf-paranoid-1.15
paranoid	104 (683.49)	98 (542.51)	154 (743.19)	248 (1161.00)
Total	**104 (683.49)**	**98 (542.51)**	**154 (743.19)**	**248 (1161.00)**

Criterion	aspcud-paranoid-1.7	aspuncud-paranoid-1.7	cudf_fumax_p-0.1	p2cudf-paranoid-1.15
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Paranoid Track (details)

Track: basic

Category	aspcud-basic-1.7	aspuncud-basic-1.7	cudf_fumax_bu-0.1	p2cudf-basic-1.15
paranoid-size	138 (8619.43)	98 (1613.55)	233 (7601.23)	294 (4094.53)
embedded	153 (7952.31)	95 (1853.69)	359 (6850.86)	280 (915.45)
Total	**291 (16571.73)**	**193 (3467.23)**	**592 (14452.09)**	**574 (5009.98)**

Criterion	aspcud-basic-1.7	aspuncud-basic-1.7	cudf_fumax_bu-0.1	p2cudf-basic-1.15
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Basic User Track (details)

Track: full

Category	aspcud-full-1.7	aspuncud-full-1.7	p2cudf-full-1.15
trendy-size	292 (32003.38)	135 (4247.64)	293 (8308.43)
dist-upgrade	130 (2912.62)	129 (1592.38)	500 (34449.24)
upgrade	131 (2935.91)	129 (1594.91)	497 (34396.18)
slowlink	239 (24293.00)	129 (3117.77)	264 (16364.54)
Total	**792 (62144.90)**	**522 (10552.71)**	**1554 (93518.40)**

Criterion	aspcud-full-1.7	aspuncud-full-1.7	p2cudf-full-1.15
trendy-size	292 (32003.38)	135 (4247.64)	293 (8308.43)
dist-upgrade	130 (2912.62)	129 (1592.38)	500 (34449.24)
upgrade	131 (2935.91)	129 (1594.91)	497 (34396.18)
slowlink	239 (24293.00)	129 (3117.77)	264 (16364.54)
Total	**792 (62144.90)**	**522 (10552.71)**	**1554 (93518.40)**

Full User Track (details)

Outline

1 Motivation

2 ASP in a Nutshell

3 Linux Package Configuration

4 Conclusion

Further Remarks

- Virtually all application problems require optimization
  - objective functions
  - lexicographic (multi-)criteria
- Complex criteria like $\subseteq$-minimality or Pareto efficiency by
  - meta-programming (disjunctive ASP)
  - `asprin` framework
- Multi-shot solving, domain heuristics and theory reasoning
  - `clingo`
  - `clingo[DL]`
  - `clingo[LP]`
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  - `DLV2`
  - `dlvhex`
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  - `EZSMT`
  - `IDP`
  - `wasp`
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Thanks!

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Questions?