Constraint Relationships

Language Features

Overview

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These slides show some features of the language/library

To familiarize yourself with basics, consider looking at:

- Step-by-Step enhancing a MiniZinc model (establishes the core elements)
- Case Studies (for some specific examples)

`http://isse-augsburg.github.io/constraint-relationships/`

SoftConstraints in MiniZinc (HelloWorld)

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```
% X: {x,y,z} D_i = {1,2,3}, i in X
%    * c1: x + 1 = y * c2: z = y + 2 * c3: x + y <= 3
% (c) ISSE
% isse.uni-augsburg.de/en/software/constraint-relationships/
include "soft_constraints/minizinc_bundle.mzn";

var 1..3: x; var 1..3: y; var 1..3: z;

% read as "soft constraint c1 is satisfied iff x + 1 = y"
constraint x + 1 = y <-> satisfied[1];
constraint z = y + 2 <-> satisfied[2];
constraint x + y <= 3 <-> satisfied[3];

% soft constraint specific for this model
nScs = 3; nCrEdges = 2;
crEdges = [| 2, 1 | 3, 1 |]; % read c2 is less important than c1

solve minimize penSum; % minimize the sum of penalties
```

Step 4: Switch to PVS Architecture

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Idea Many soft constraint formalisms are generalized by partial valuation structures (Gadducci et al., 2013) that give the codomain of the objective function an *algebraic structure*.

- A partially ordered valuation structure is described by $(M, \oplus_M, \leq_M, \varepsilon_M)$ where
  - M ... is a set of violation/satisfaction degrees, e.g., $\mathbb{N}$ for weights, $[0, 1]$ for probabilities etc.
  - $\oplus_M$ ... is a binary *combination* operation to aggregate values from M, e.g., $3 \oplus_M 5 \equiv 3 + 5$
  - $\leq_M$ ... is a partial *order* over M operation to rank values from M, e.g., $5 \leq_M 3 \equiv 5 \geq 3$, $m \leq_M n$ means m *is worse* than n
  - $m \leq_M \varepsilon_M$ ... for every $m \in M$, i.e. ε_M is the *best* possible solution, e.g. 0 violation
- Similar (Bistarelli et al., 1999): c-semirings and (total) valuation structures (`toulbar2`)

PVS–Idea

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Concrete PVS	M	$\oplus_M$	$\leq_M$	ε_M
Weighted CSP	$\mathbb{N}$	$+$	$\geq$	0
Fuzzy CSP	$[0,1]$	min	$\leq$	1
Constraint Relationships[1]	2^{C_s}	$\cup$	$\subseteq_{\text{SPD}}$	$\emptyset$

Main Idea

Implement search strategies (BaB and LNS) for partially ordered valuation structures. Instantiate for concrete problems.

From now on we rely on MiniSearch (`www.minizinc.org/minisearch/`).

[1] C_s is the set of soft constraints, $\subseteq_{\text{SPD}}$ is the SPD-ordering on sets.

Step 5: Use PVS-based Search

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```
% only declare predicate for worsening
predicate isWorse(var set of int: leftViolatedScs,
                  var set of int: rightViolatedScs);
function ann: strictlyBetterBAB(var set of SOFTCONSTRAINTS: violatedScs)
=     repeat(
          if next() then
              let { set of SOFTCONSTRAINTS: lb = sol(violatedScs);} in (
                print("Intermediate solution:") /\ print() /\
                commit() /\ post(isWorse(lb, violatedScs))
              )
          else break endif);
```

Only relies on `isWorse`!

```
[... inside pvs_spd.mzn]
predicate isWorse(var set of int: leftViolatedScs,
                  var set of int: rightViolatedScs) = (
  spd_worse(leftViolatedScs, rightViolatedScs, SOFTCONSTRAINTS, crEdges)
);
```

Search types

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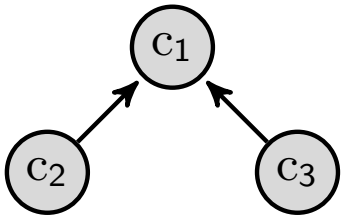
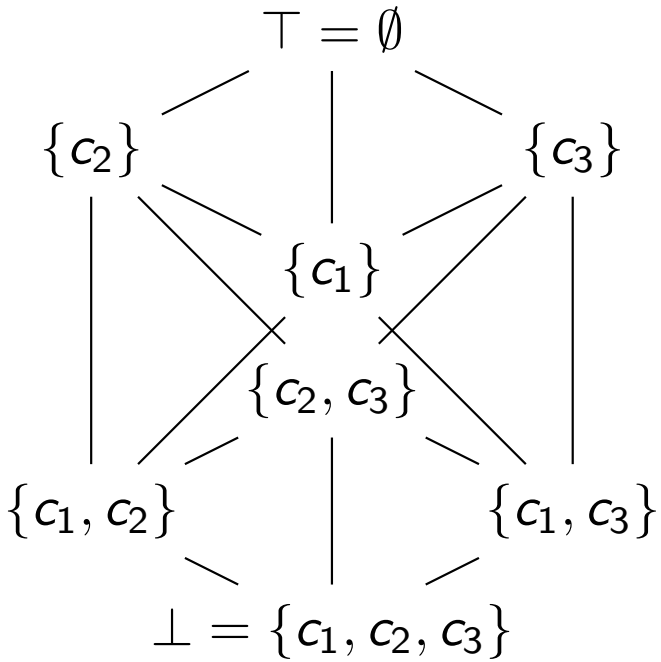
The whole valuation space (partially ordered)






```
%
% Typical Optimization Routine (Branch and Bound):
%
%  1. Look for the first feasible solution
%  2. Impose restrictions on the next feasible solution
%  3. Repeat
```

Search types: Strictly better

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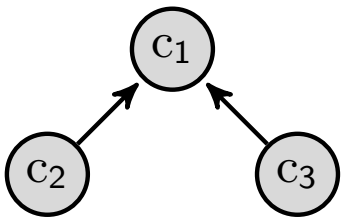

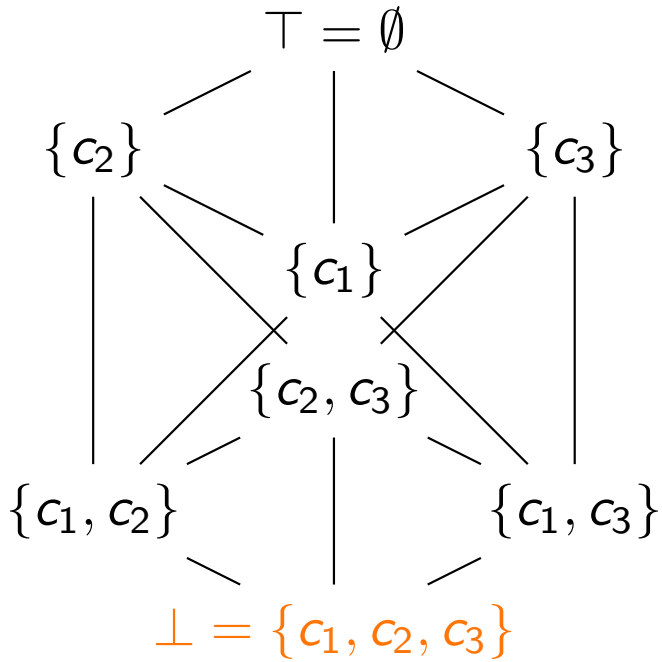


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function ann: strictlyBetterBAB(var set of SOFTCONSTRAINTS: vScs)
     = repeat(
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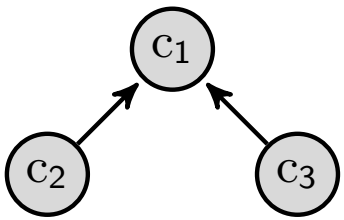

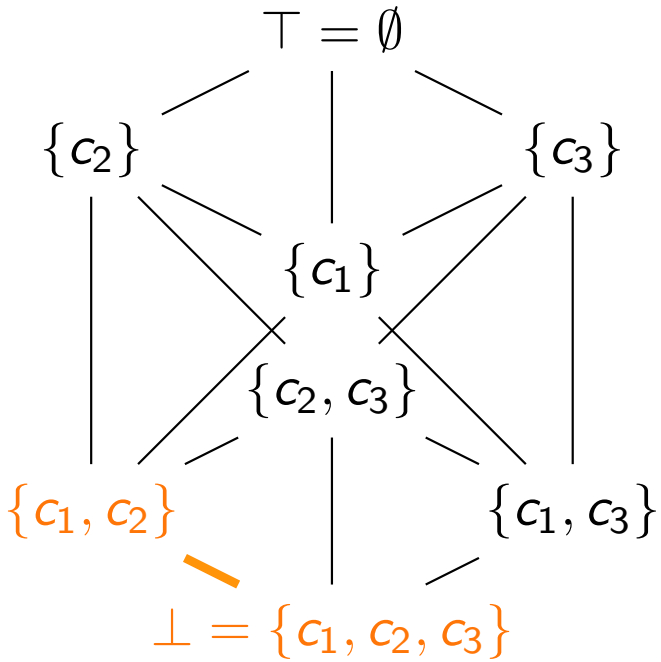


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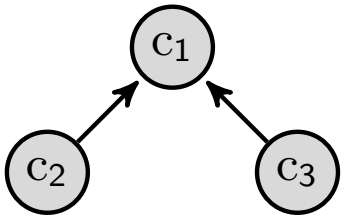

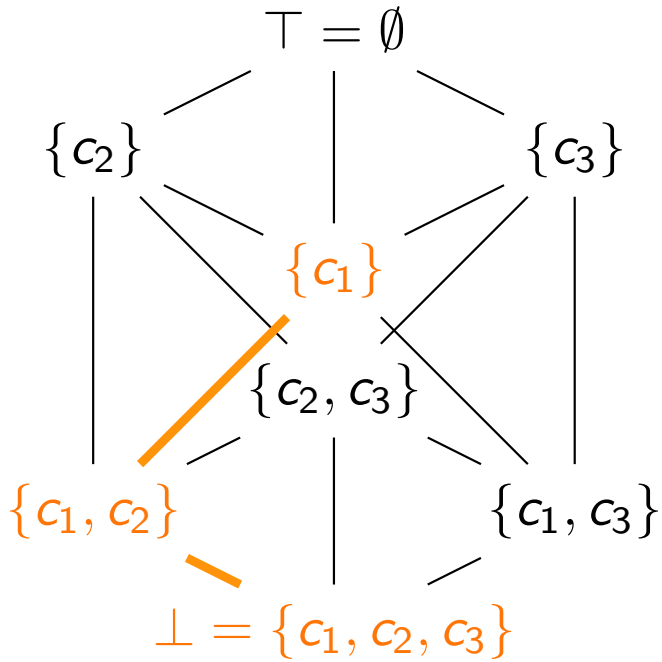


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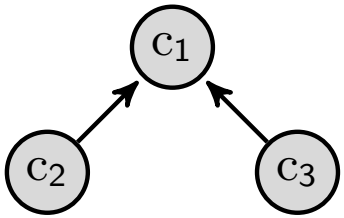

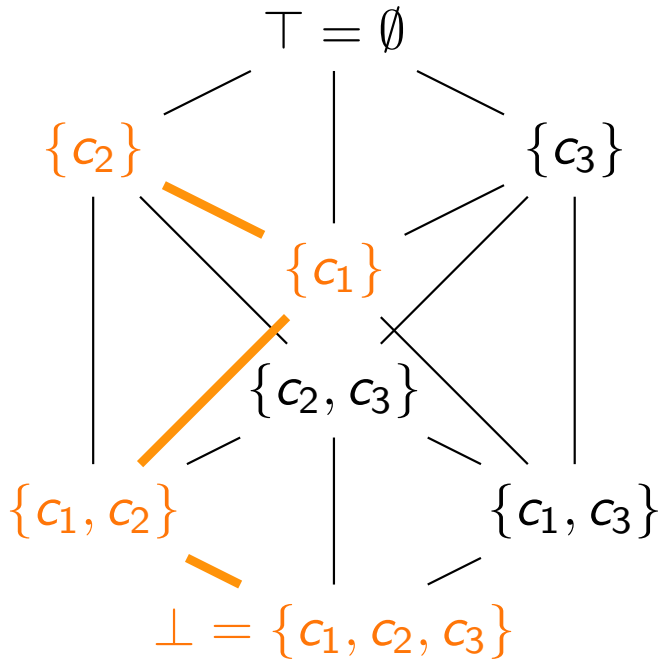


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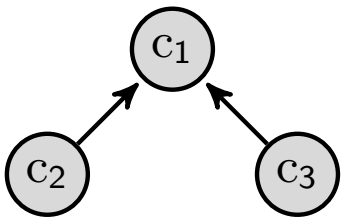

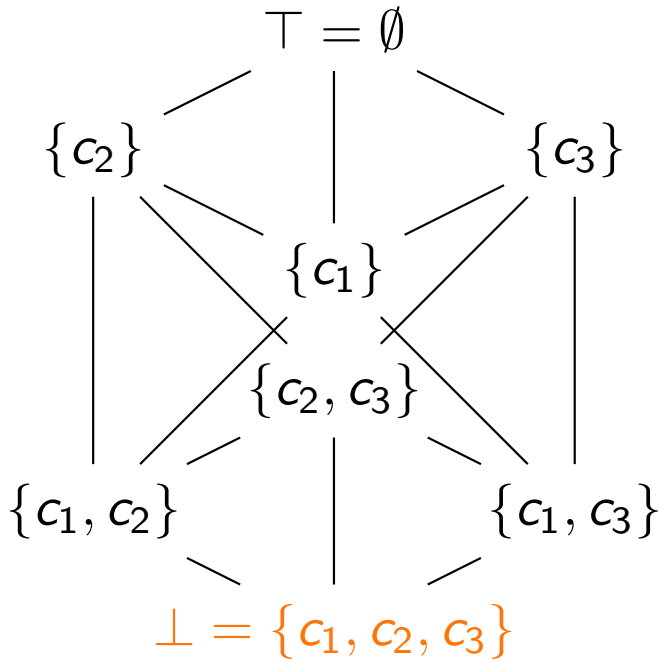


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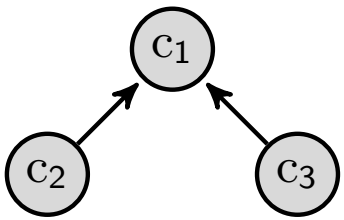

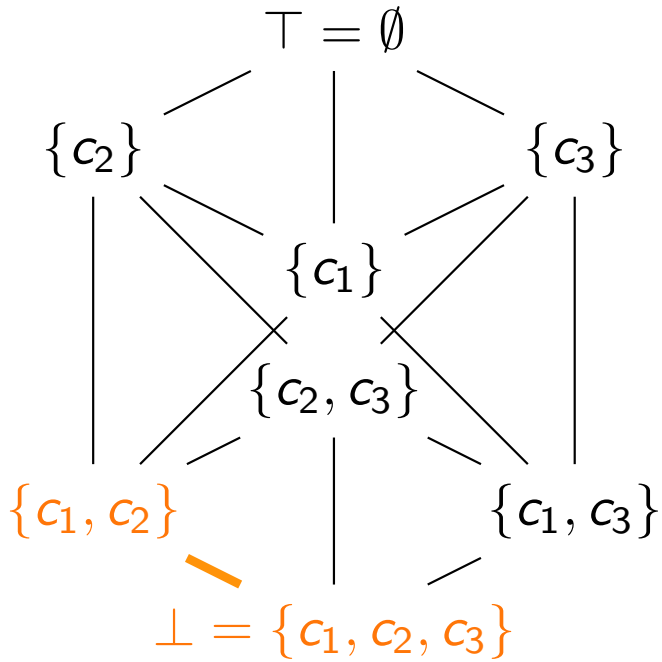


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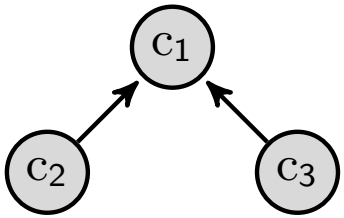

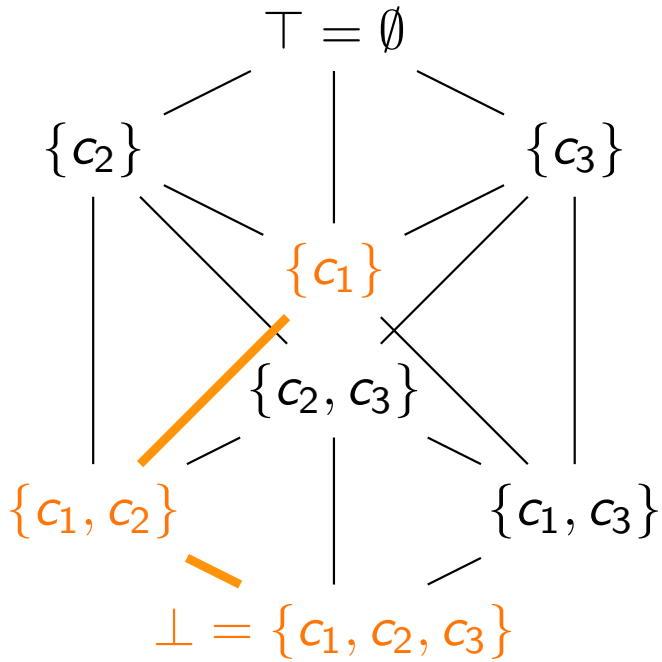


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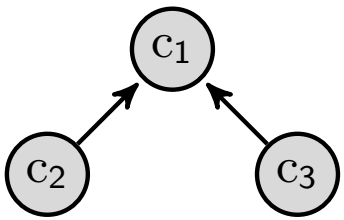

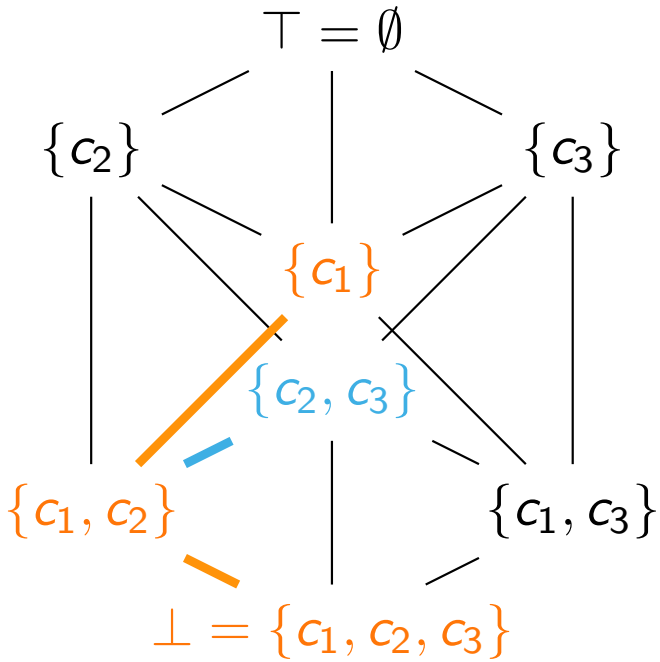


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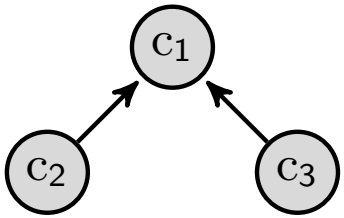

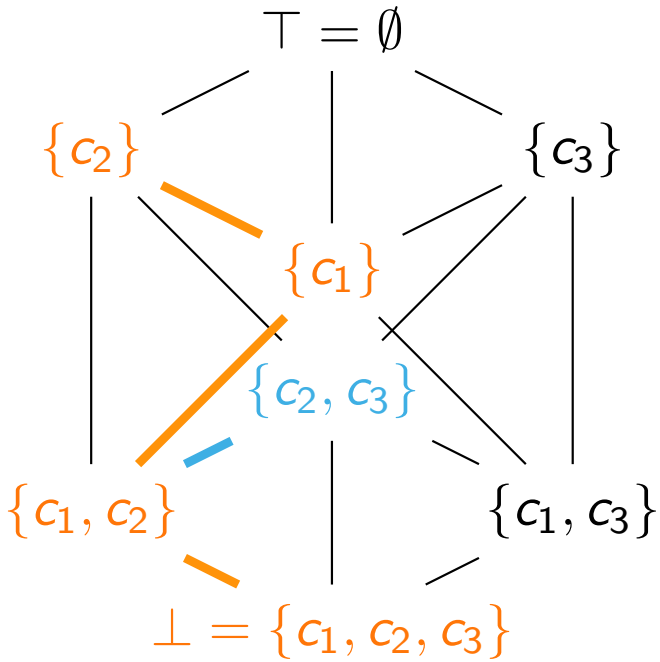


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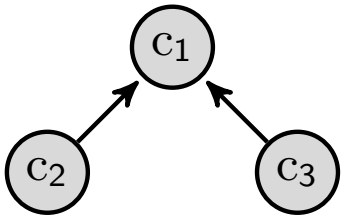

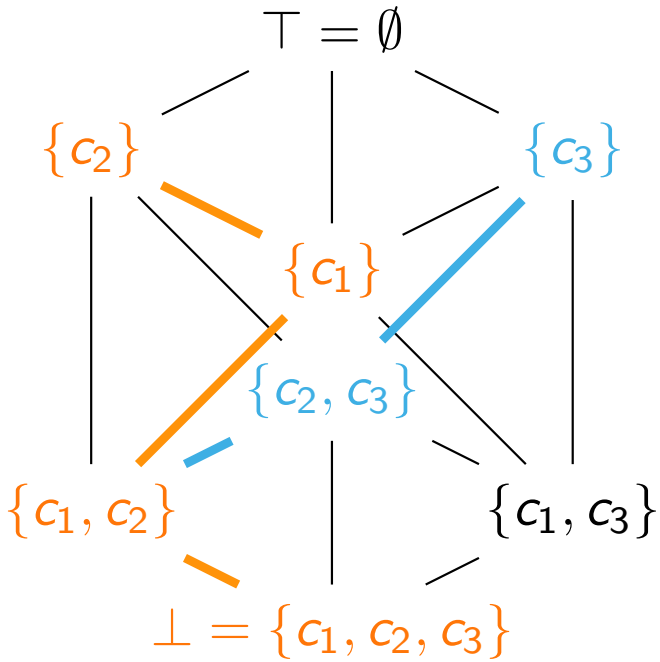


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         else break endif     );
```

Search Demo: Model

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```
include "minisearch.mzn";
include "soft_constraints/soft_constraints.mzn";
include "soft_constraints/pvs_search.mzn";
include "soft_constraints/tpd_worse.mzn";
include "soft_constraints/pvs_tpd.mzn";
nScs = 3; var 1..3: x;

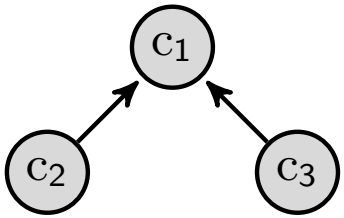
constraint x = 1 <-> violated[1];
constraint x = 2 <-> violated[2];
constraint x = 3 <-> violated[3];

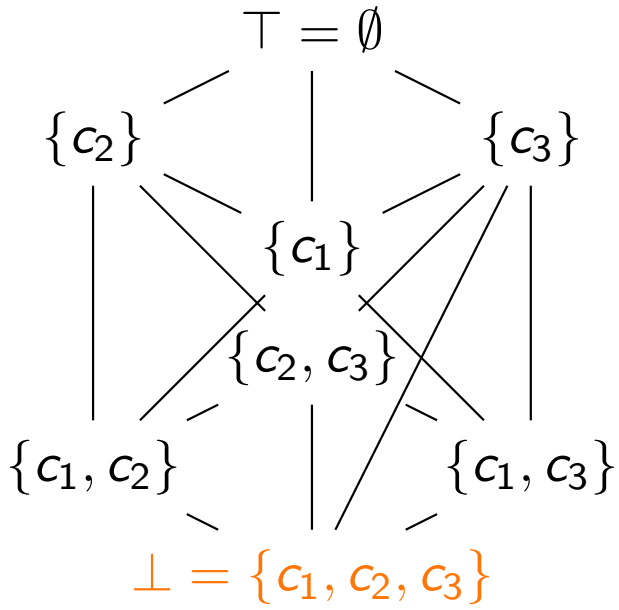
nCrEdges = 2; crEdges = [| 2, 1 | 3, 1 |];
% solution degrees are explored in order {3}, {2}, {1}
solve
:: int_search([x], input_order, indomain_max, complete)
search strictlyBetterBAB(violatedScs);
%search onlyNotDominatedBAB(violatedScs);

output [" Obj: \(penSum) violating {\(violatedScs)}: x=\(x)"];
```

Search Demo: Strictly better

Execute `minisearch diff-BAB-sb.mzn`
(explores in order $\{c_3\}, \{c_2\}, \{c_1\}$)






```
% just sees {c_3} then finds no better solution and stops
%
Intermediate solution: Obj: 1 violating {3..3}: x=3
----------
==========
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```

Search Demo: Strictly better

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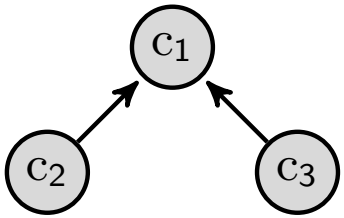

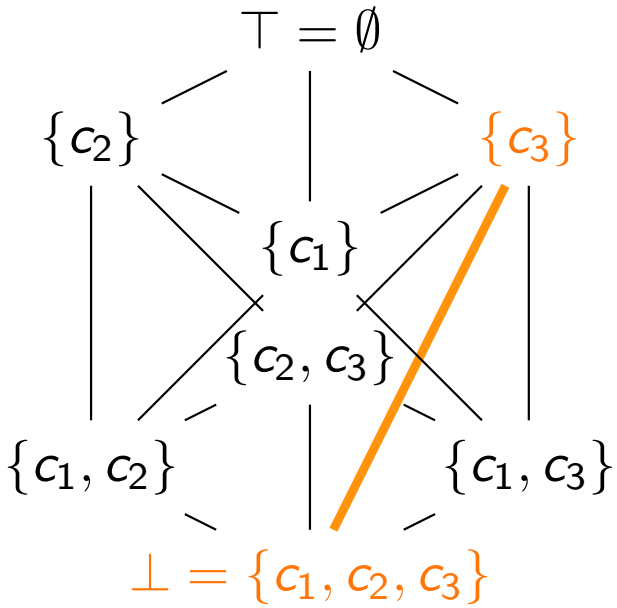


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```
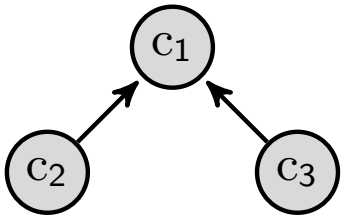
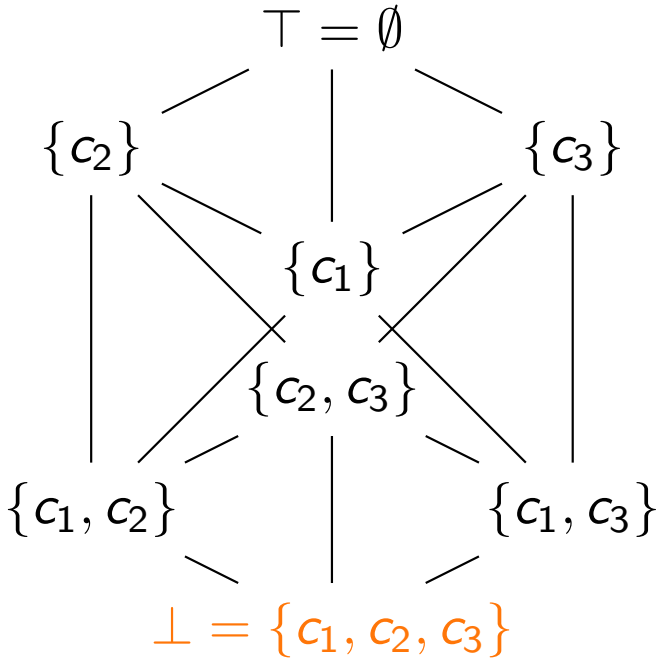

Search Demo: Only not dominated

Execute `minisearch smallexample-ond.mzn`



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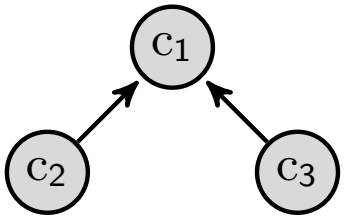

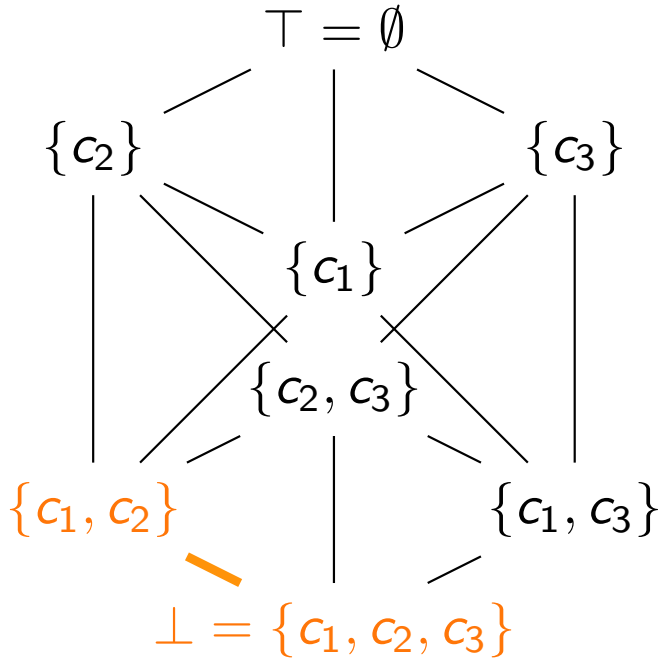


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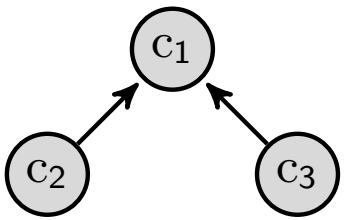

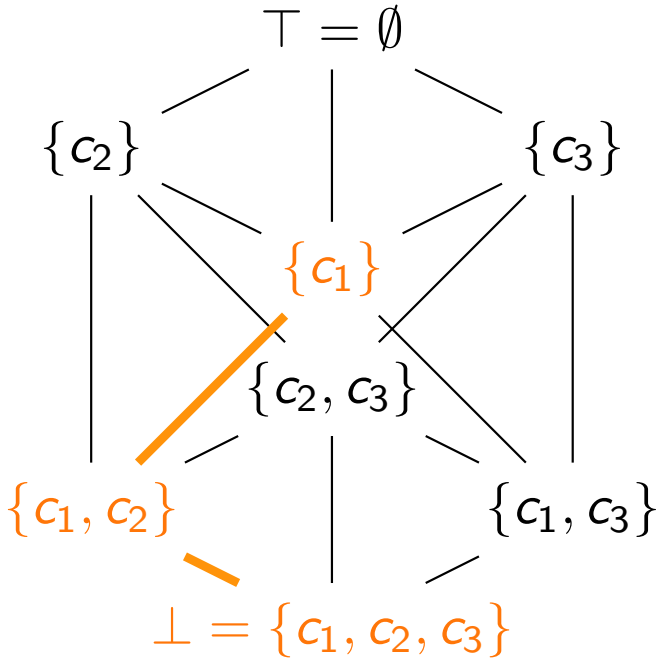


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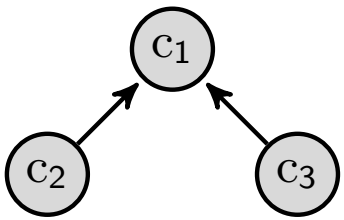

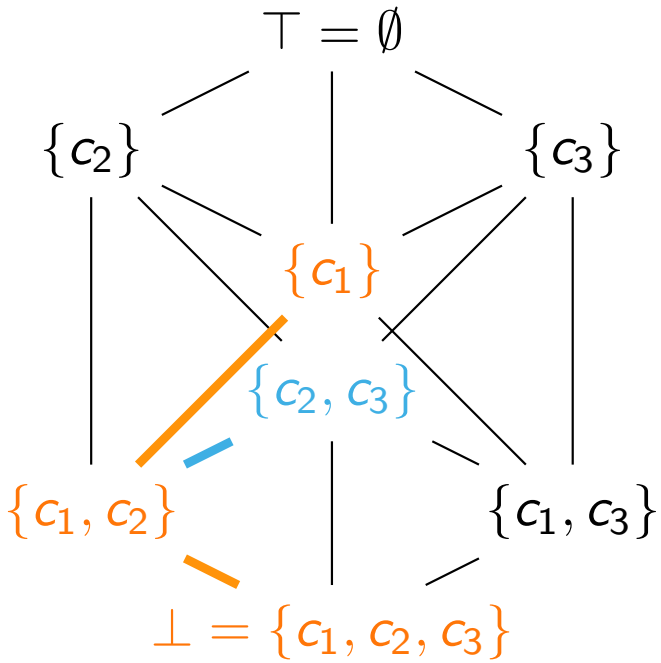


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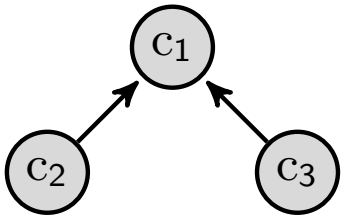
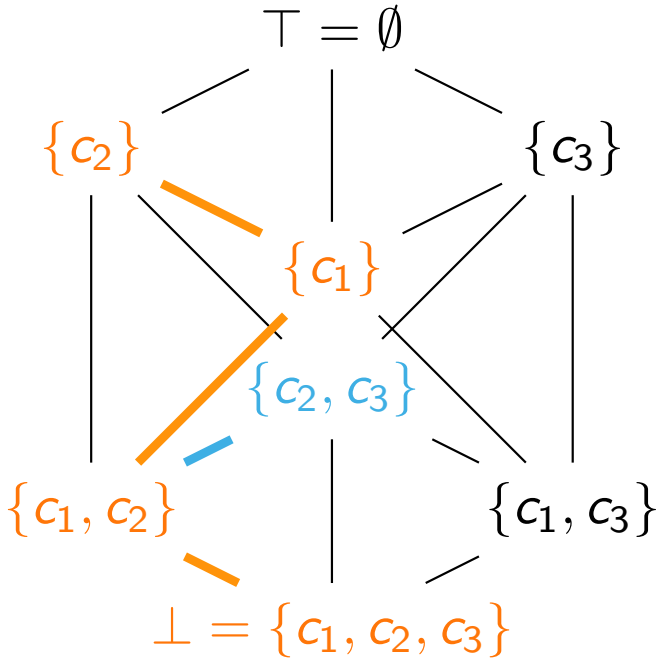
Execute `minisearch smallexample-ond.mzn`

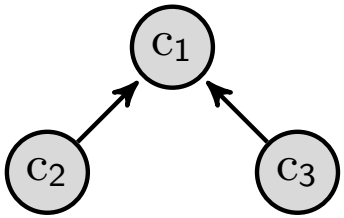


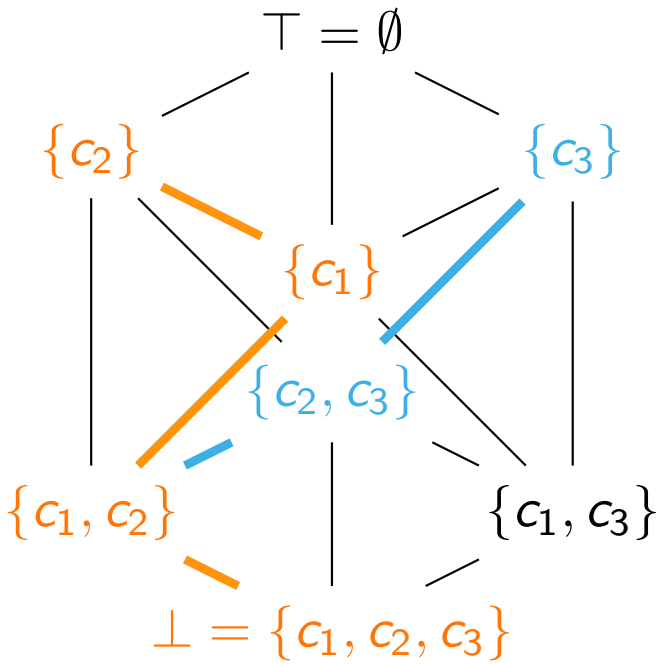



```
function ann: onlyNotDominatedBAB(var set of SOFTCONSTRAINTS: vScs)
      = repeat(
          if next() then
            commit() /\
            post((isWorse(vScs, sol(vScs)) \/ vScs = sol(vScs)))
          else break endif     );
```

Search Demo: Only not dominated

Execute `minisearch smallexample-ond.mzn`






```
function ann: onlyNotDominatedBAB(var set of SOFTCONSTRAINTS: vScs)
      = repeat(
          if next() then
            commit() /\
            post((isWorse(vScs, sol(vScs)) \/ vScs = sol(vScs)))
          else break endif     );
```

Switching PVS Type

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Concrete PVS are instantiated by importing the appropriate `pvs_x.mzn` file.

```
include "minisearch.mzn";
include "soft_constraints/soft_constraints.mzn";
include "soft_constraints/spd_worse.mzn";
include "soft_constraints/pvs_spd.mzn"; %pvs_tpd.mzn, pvs_weighted.mzn
include "soft_constraints/pvs_search.mzn";

var 0..10: x; var 0..10: y;
nScs = 2; nCrEdges = 1; crEdges = [| 2, 1 |];
constraint x < y <-> satisfied[1];
constraint x + 4 = y <-> satisfied[2];

solve
search strictlyBetterBAB(violatedScs) /\ print();
output["x = \(x), y = \(y), violatedScs = \(violatedScs)"];
```

Consistency Checks

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Vital, when designing constraint relationships: avoid cycles!

`model-inconsistent.mzn`

```
%include "minisearch.mzn";
include "soft_constraints/soft_constraints.mzn";
include "soft_constraints/spd_worse.mzn";
include "soft_constraints/pvs_spd.mzn";
%include "soft_constraints/pvs_search.mzn";

var 0..10: x; var 0..10:y;

nScs = 2;
nCrEdges = 2; crEdges = [| 2, 1 | 1, 2 |];
constraint x < y <-> satisfied[1];
constraint x + 4 = y <-> satisfied[2];

solve satisfy;
%search strictlyBetterBAB(violatedScs) /\ print();
output["x = \(x), y = \(y), violatedScs = \(violatedScs)"];
```

Consistency Checks

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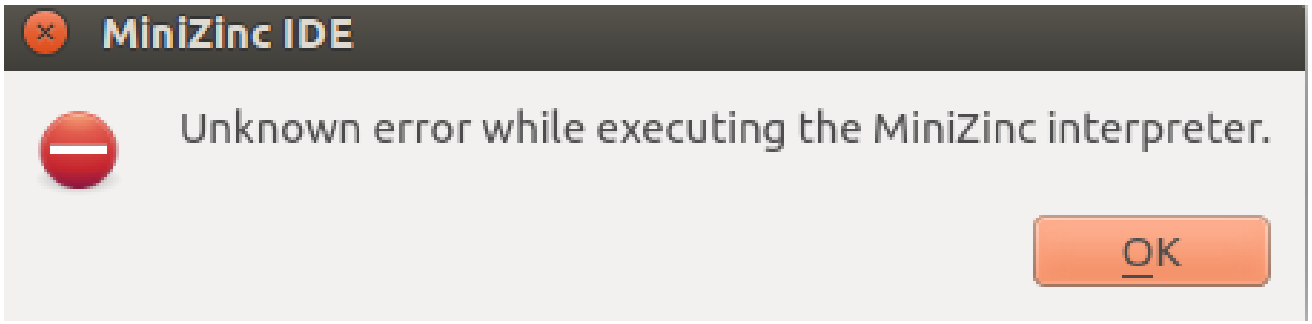

Better: Add model checks to detect cyclic relationships!

Consistency Checks: Assertions

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model-inconsistent-safe.mzn

```
include "minisearch.mzn";
include "soft_constraints/soft_constraints.mzn";
include "soft_constraints/spd_worse.mzn";
include "soft_constraints/pvs_spd.mzn";
include "soft_constraints/pvs_search.mzn";
include "soft_constraints/cr_consistency.mzn";
var 0..10: x; var 0..10:y;
nScs = 2;
nCrEdges = 2; crEdges = [| 2, 1 | 1, 2 |];

constraint x < y <-> satisfied[1];
constraint x + 4 = y <-> satisfied[2];
constraint assert(consistentCR(SOFTCONSTRAINTS, crEdges),
                  "Constraint relationship is not consistent");
solve
search strictlyBetterBAB(violatedScs) /\ print();
output["x = \(x), y = \(y), violatedScs = \(violatedScs)"];
```

Consistency Checks: Assertions

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```
minisearch model-inconsistent-safe.mzn


minizinc/std/soft_constraints/cr_consistency.mzn:46:
  in call 'assert'
  Assertion failed: Relationship is cyclic!
```

Language Features: Variable Ordering

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Language Features: Redundant Constraints

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Language Features: Custom Search

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Summary

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This concludes our overview of some language features

Make sure to check out our other slides about:

- Step-by-Step enhancing a MiniZinc model (establishes the core elements)
- Case Studies (for some specific examples)

`http://isse-augsburg.github.io/constraint-relationships/`

References I

Bistarelli, S., Montanari, U., Rossi, F., Schiex, T., Verfaillie, G., and Fargier, H. (1999).
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Constraints, 4(3):199–240.

Gadducci, F., Hölzl, M., Monreale, G., and Wirsing, M. (2013).
Soft constraints for lexicographic orders.
In Castro, F., Gelbukh, A., and González, M., editors, *Proc. 12th Mexican Int. Conf. Artificial Intelligence (MICAI'2013)*, Lect. Notes Comp. Sci. 8265, pages 68–79. Springer.