Declaring Local-Search Neighbourhoods in MiniZinc

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Goal

- Extend the MiniZinc language with declarative neighbourhoods.
- Allow rapid prototyping with local search strategies.
- Recreate known local search strategies in MiniZinc.

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This presentation

Some background and a short walkthrough of our new MiniZinc syntax.

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MiniZinc

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MiniZinc

Constraint-based declarative modelling language.

Solver and technology independent: more than 15 backends.

High-level syntax.

Free and open-source under MPL 2.0.

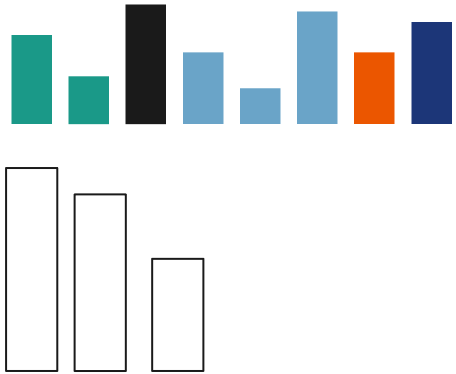
Annual MiniZinc Challenge.

www.minizinc.org

Running Example – Steel Mill Slab Design

Given

- orders of steel, each having a *size* and *colour*, to be cut from slabs
- available slab sizes



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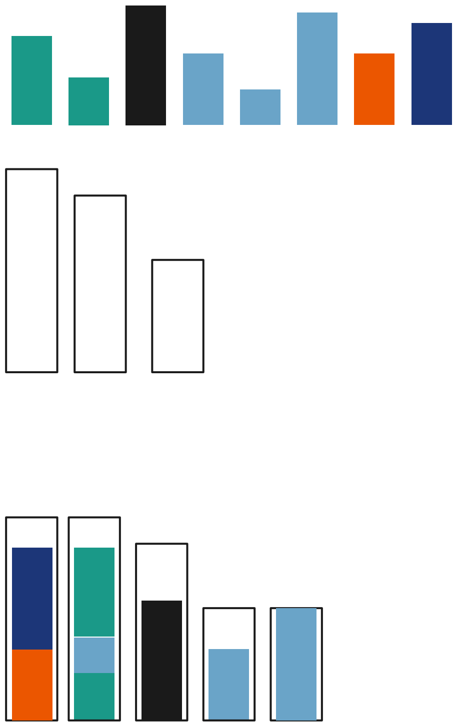
Decide

- how many slabs to use
- the size of each slab
- the slab each order is placed in



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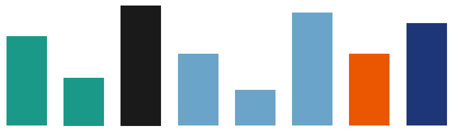

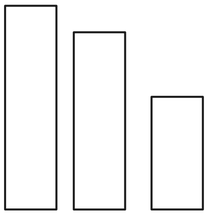

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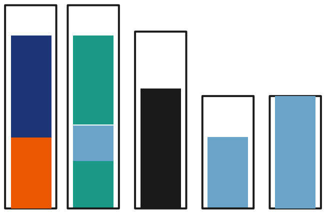
Such that

- at most two colours on each slab
- the total slack in the slabs is minimal



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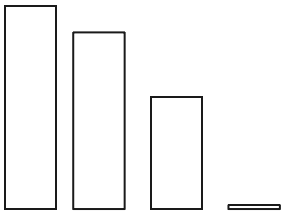

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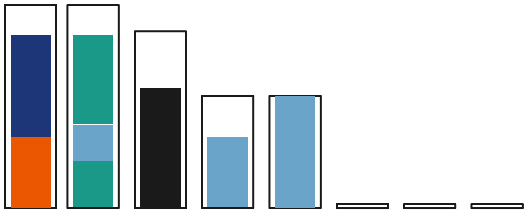

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MiniZinc Model

```
% Some parameters omitted
...
array [Orders] of int: size;
array [Orders] of Colors: color;
array [0..maxCapa] of 0..maxCapa: slack = ... ;
% Variables:
array [Orders] of var Slabs: placedIn;
% Constraints:
array [Slabs]  of var 0..maxCapa: load;
constraint bin_packing_load(load, placedIn, size);
array [Slabs]  of var 0..2: nColors;
constraint forall(s in Slabs)(nColors[s] = ... );
% Objective:
var int: objective = sum(s in Slabs)(slack[load[s]]);
solve minimize objective;
```

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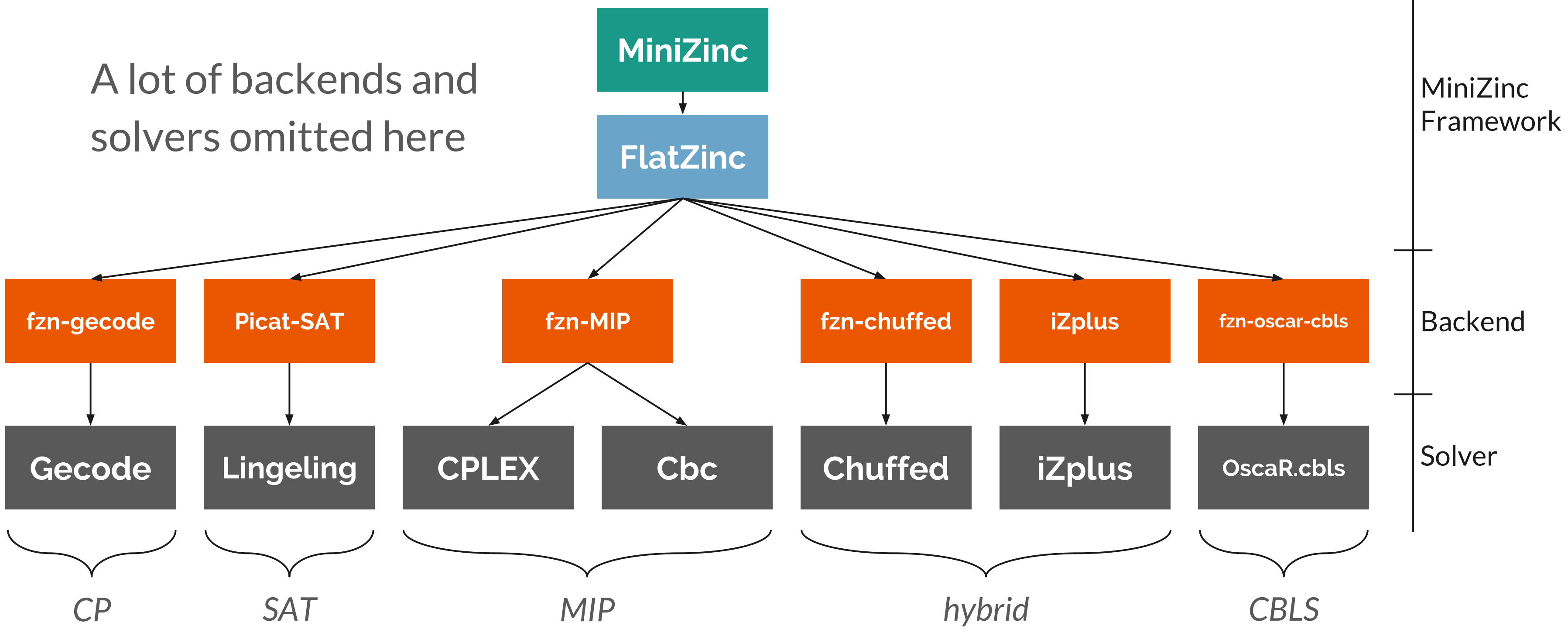
Current Landscape

A lot of backends and solvers omitted here



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(Constraint-Based) Local Search

Local Search

1. Start from an initial assignment of all variables
2. While some condition holds:
   a. Generate a neighbourhood of similar assignments
   b. Move to a best neighbour
3. Return the best solution found

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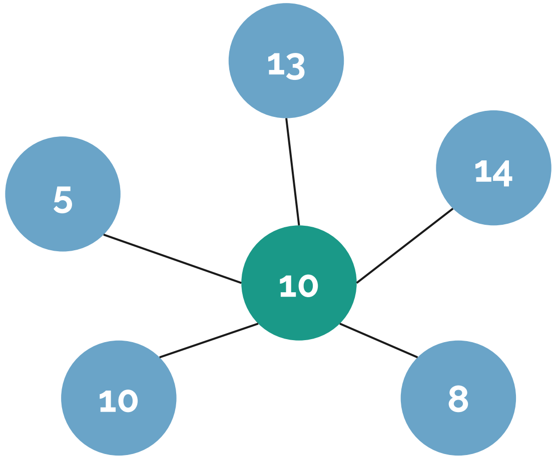

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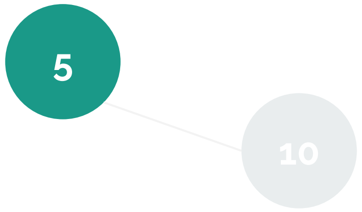

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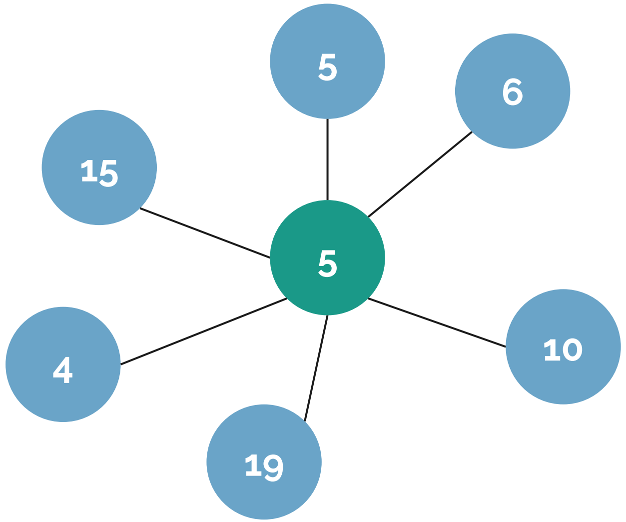

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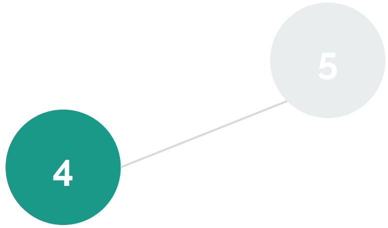

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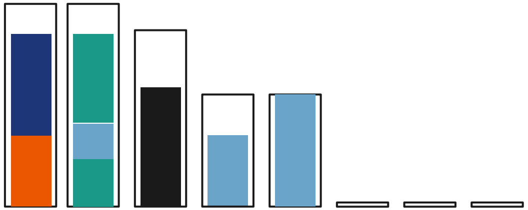
Steel Mill Slab Design



An initial assignment

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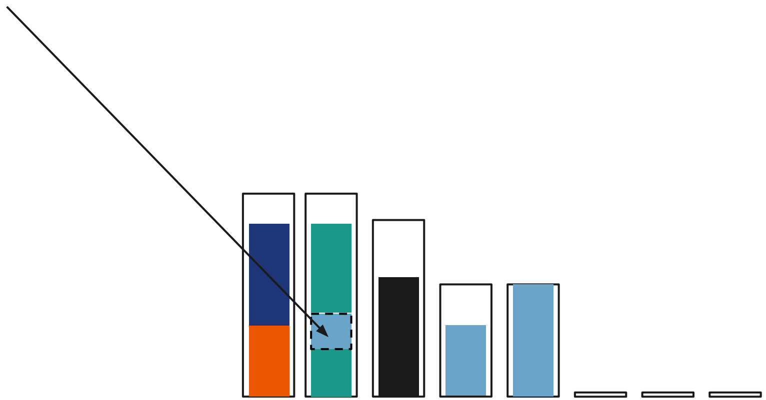
Steel Mill Slab Design

Move an order to another slab.



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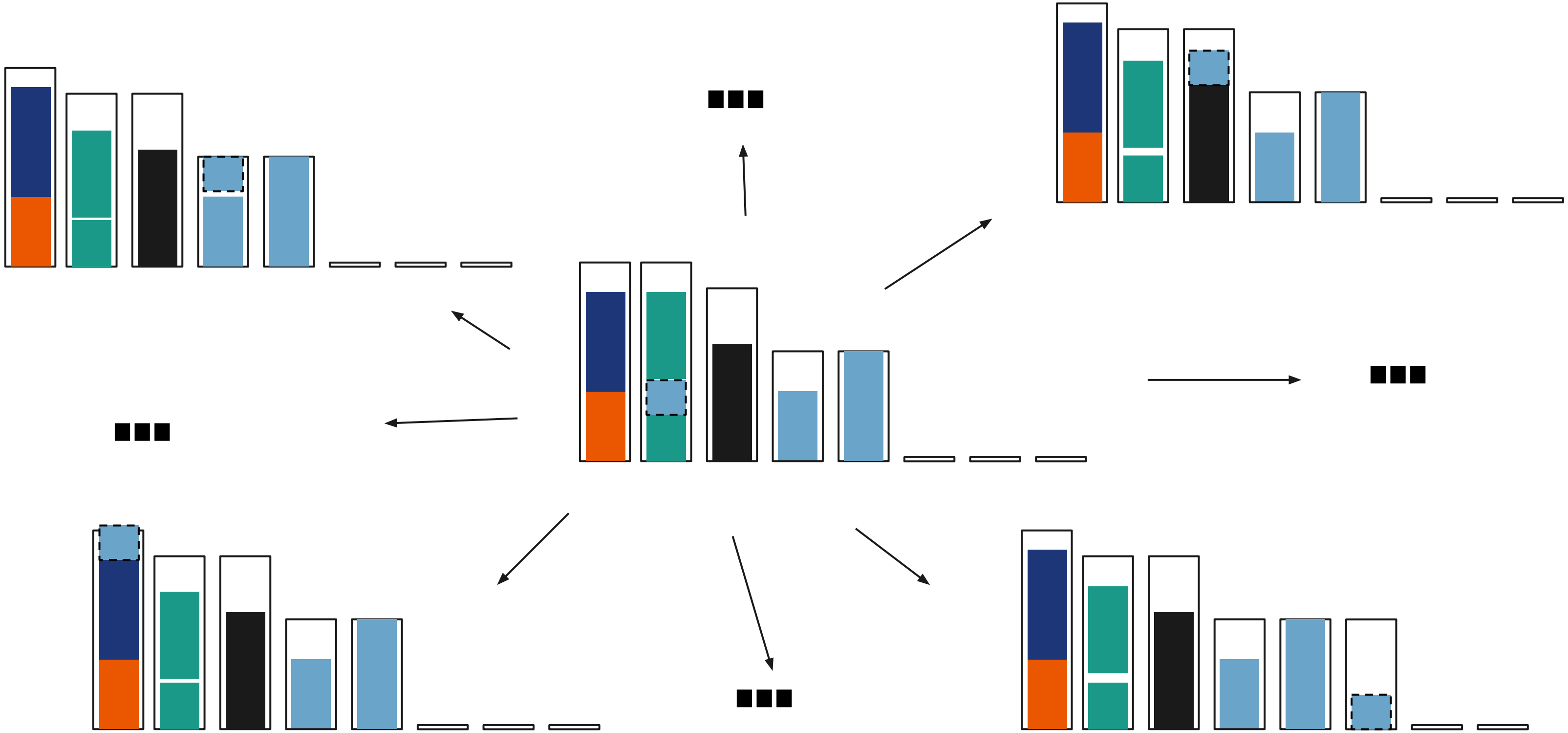

Design Aspects

Initialisation and neighbourhood

- How do we initialise?
- What are the moves?

Heuristic

- How do we explore the neighbourhood?

Meta-heuristic

- How do we prevent the search from getting stuck?

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Constraint-Based Local Search (CBLS)

CBLS = CP-style declarative modelling + local search

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CBLS for MiniZinc

MiniZinc is a modelling language: must use black-box local search.
Works well but can be hit and miss.

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CBLS for MiniZinc

MiniZinc is a modelling language: must use black-box local search.
Works well but can be hit and miss.

Idea

Allow modellers to define (part of) a local search strategy in MiniZinc.

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Declarative Neighbourhoods in MiniZinc

What is a Neighbourhood?

A neighbourhood is a set of moves.

For example:

$\{X \leftarrow v \mid v \in 1 \,..\, 10\}$ i.e., $\{X \leftarrow 1,\ X \leftarrow 2,\ \ldots\ ,\ X \leftarrow 10\}$

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- how to explore the neighbourhood
- how to evaluate the quality of a move
- which move to select

These are heuristics.

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We provide syntax only for defining the neighbourhood, not heuristics.

Basic Syntax

Move operators

```
X := v
X[i] := v
X :=: Y
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```
moves(v in 1..10)(X := v)
```

Compound moves

```
moves(i,j in Idx)(Xs[i] := Xs[j] /\ Xs[j] := Xs[i])
```

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Pre- and Post-Conditions

Moves can have pre- and post-conditions in the form of CSPs.

Pre-condition

```
moves(i in Idx, v in Dom where Xs[i] > v)(Xs[i] := v)
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moves(i in Idx, v in Dom where Xs[i] > v)(Xs[i] := v)
```

Post-condition

```
moves(i in Idx, v in Dom)(
    Xs[i] := v /\ ensuring(alldifferent(Xs))
```

Initialisation

A neighbourhood can have an initialisation post-condition that must hold upon the initial assignment (and restarts).

Permutation neighbourhood

```
initially(alldifferent(Xs)) /\
moves(i, j in Idx where i < j)(Xs[i] :=: Xs[j])
```

Union of Neighbourhoods

The union of two neighbourhoods can be expressed.

Swaps and assigns

```
moves(i in Idx, v in Dom)(Xs[i] := v)
union
moves (i, j in Idx where i < j)(Xs[i] :=: Xs[j])
```

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moves(o in Orders, s in Slabs)(placedIn[o] := s)
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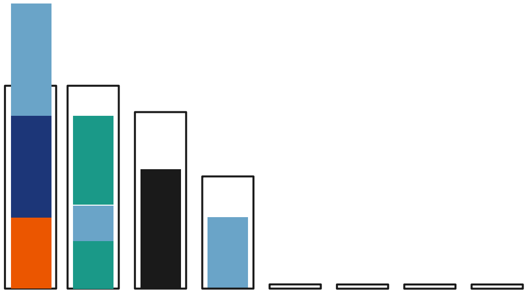

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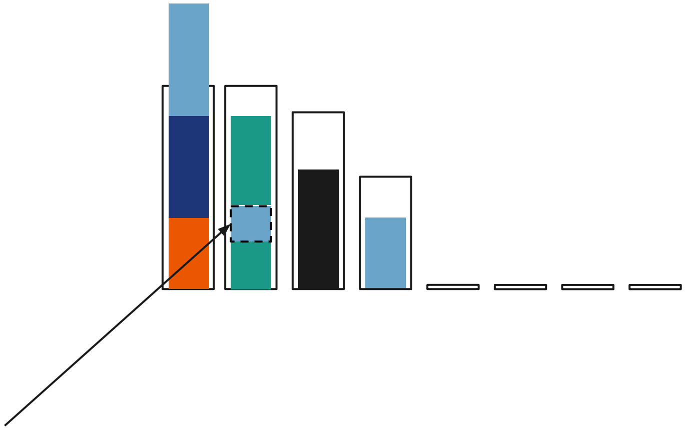

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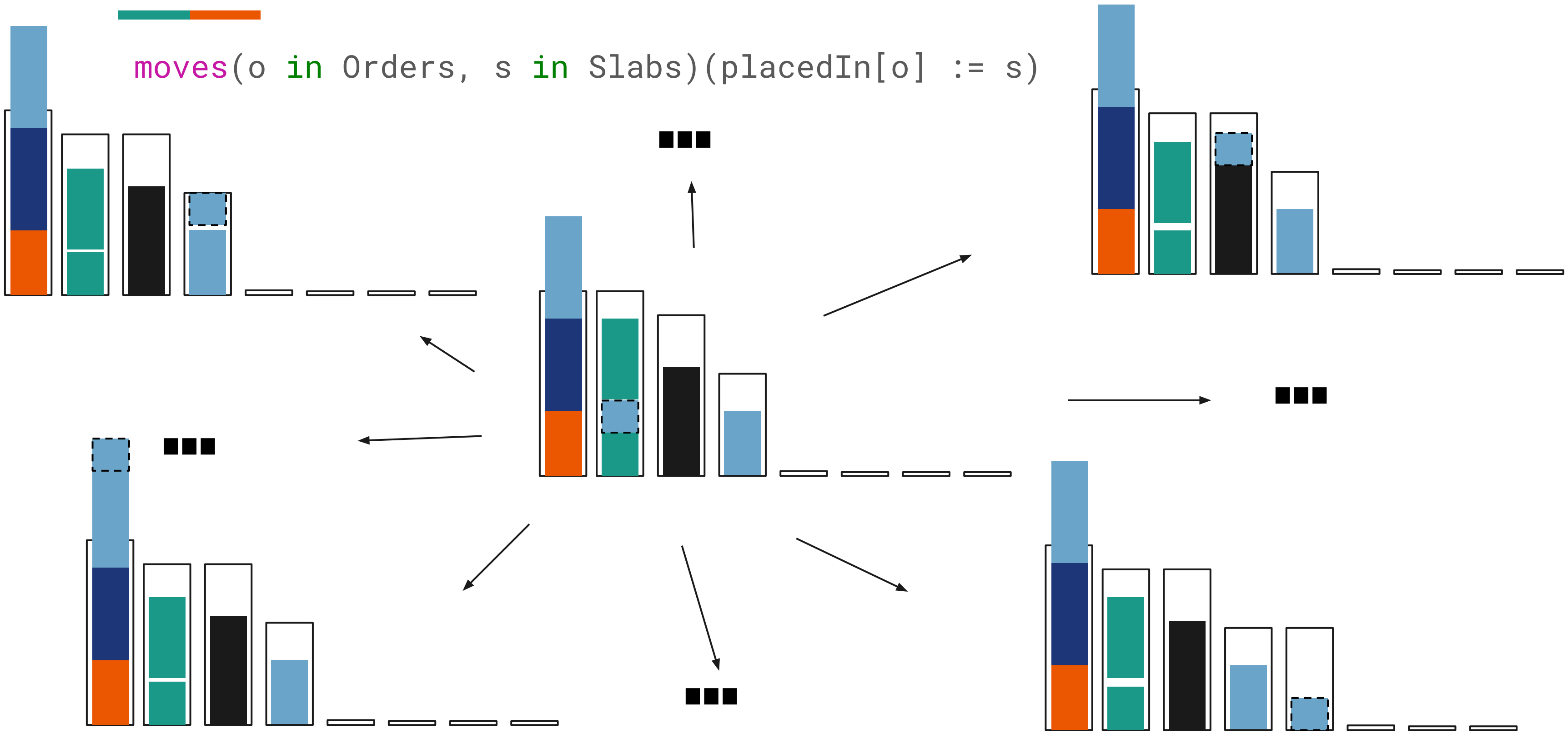

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Example 2 – Only Feasible Solutions

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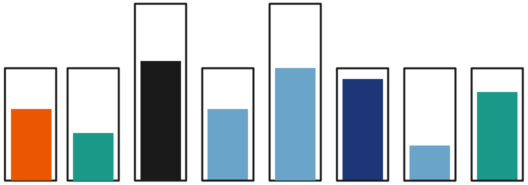

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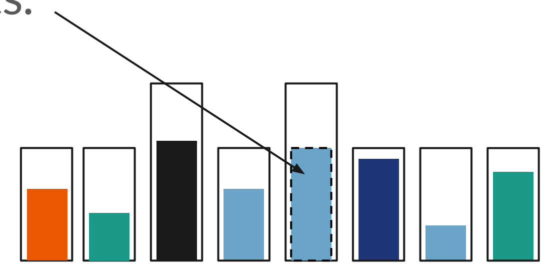
Move an order to another slab, preserving the colour and capacity constraints.



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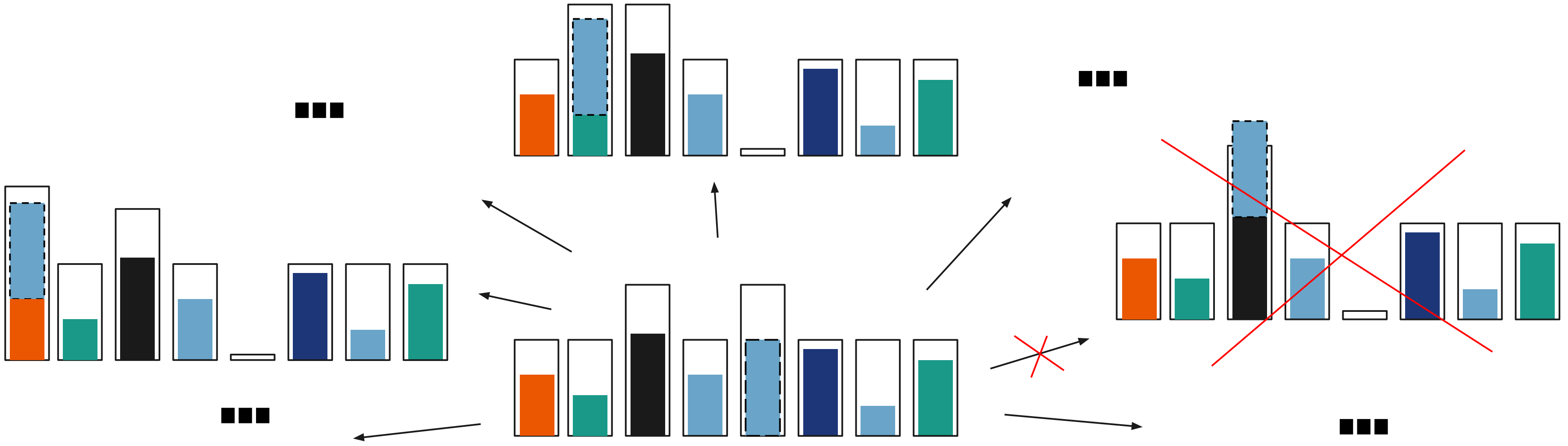

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Under the Hood

Some Highlights

We extend FlatZinc with flat functions.

Initialisation done using the CP solver OscaR.cp.

Move pre- and post-conditions checked using OscaR.cbls constraint system.

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Experimental Evaluation

Setup

1. Steel mill slab design is solved using CBLS in [1].
   We recreated their neighbourhoods in MiniZinc.
2. We added neighbourhoods to existing MiniZinc models.

We only compare the results versus fzn-oscar-cbls (black-box).

1. Schaus, P., Van Hentenryck, P., Monette, J.N., Coffrin, C., Michel, L., Deville, Y.: Solving steel mill slab problems with constraint-based techniques: CP, LNS, and CBLS. Constraints 16(2), 125–147 (April 2011).

Results Compared to Black-Box

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About 20% improvement in objective value compared to black-box neighbourhood.

For more complex neighbourhoods, we see overall:

- a decrease in terms of iterations per second
- a speedup in terms of time until best solution found
- an improvement in terms of quality

For neighbourhoods similar to the black-box ones:

- an overall slowdown
- this is expected

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Conclusion & Future Work

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A good starting point

- Grey-box
- Declarative neighbourhoods are expressive and powerful
- One can now experiment with neighbourhoods in MiniZinc

More to do

- White-box
- Declarative language for expressing heuristics and meta-heuristics
- Overheads to trim

Questions?

Thank You!