PCR
PRICE COUPLING OF REGIONS

PCR Stakeholder Forum

Brussels, January 11th 2016

EPEXSPOT GME Gestore Mercati Energetici NORD POOL omie opcom OTE TGE POLISH POWER EXCHANGE

Supported by: europex association of european energy exchanges

PCR Stakeholder Forum

January 11, 2016

Agenda

- **Complexity of the problem**
  - Size of the problem;
  - Non-convexities and optimality gap;
  - Heuristics in Euphemia;
  - PRBs
- **Performance indicators**
- **Next development steps for the Euphemia algorithm**

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Introduction

From ESC meetings 2015

- Concerns expressed by stakeholders:
  - Quality of the solution
  - PRBs
    - Link with solution quality
  - Transparency
    - Heuristics
    - Indicators

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1. Complexity of the problem

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MRC

2015

53 bidding areas

67 lines

Functionalities

hourly step and interpolated orders

regular block orders

Profile block orders

Linked block orders

Exclusive block orders

Flexible block orders

Curtailable block orders

MIC orders

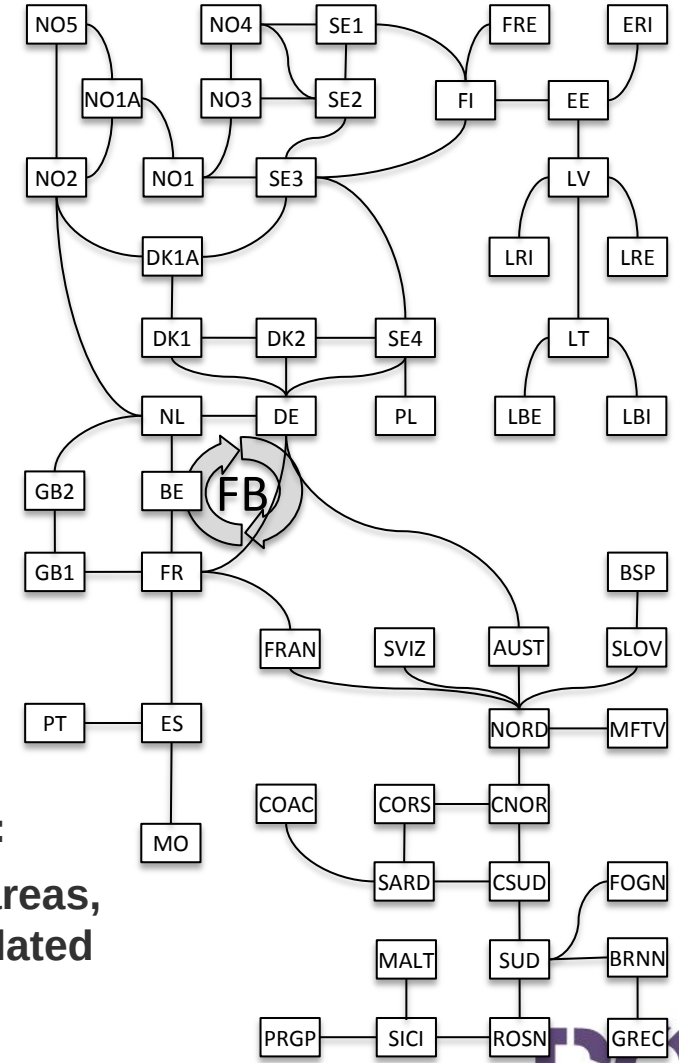
Load gradients

Scheduled stops

PUN orders

Merit orders

Flow based intuitive



The problem is solved globally :

For all bidding areas, prices are calculated during the same computation

Public Documentation on Euphemia is available for download :
https://www.epexspot.com/en/market-coupling/pcr

Block orders and complex orders

- A block is defined as a set of quantities, a single price, and optionally a minimum acceptance ratio

- In a complex order,
  - the hourly orders must be rejected if out-of-the-money and accepted if in-the-money
  - the accepted ratio can vary from one period to the other
  - The variable term (VT) has a "**block effect**"
  - You can **recover a fixed cost (FT)**

- A block
  - can lose money on some periods, as long as overall the block is not PAB
  - must have the same accepted ratio on all periods
  - A fixed cost can be implicitly integrated (as you know the minimum quantity that can be accepted)

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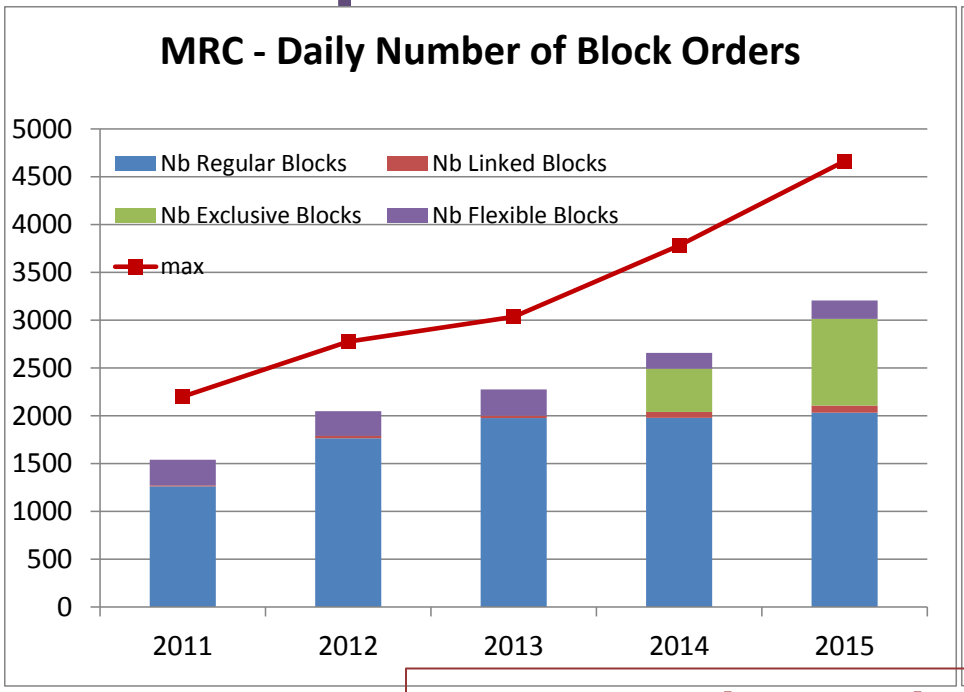
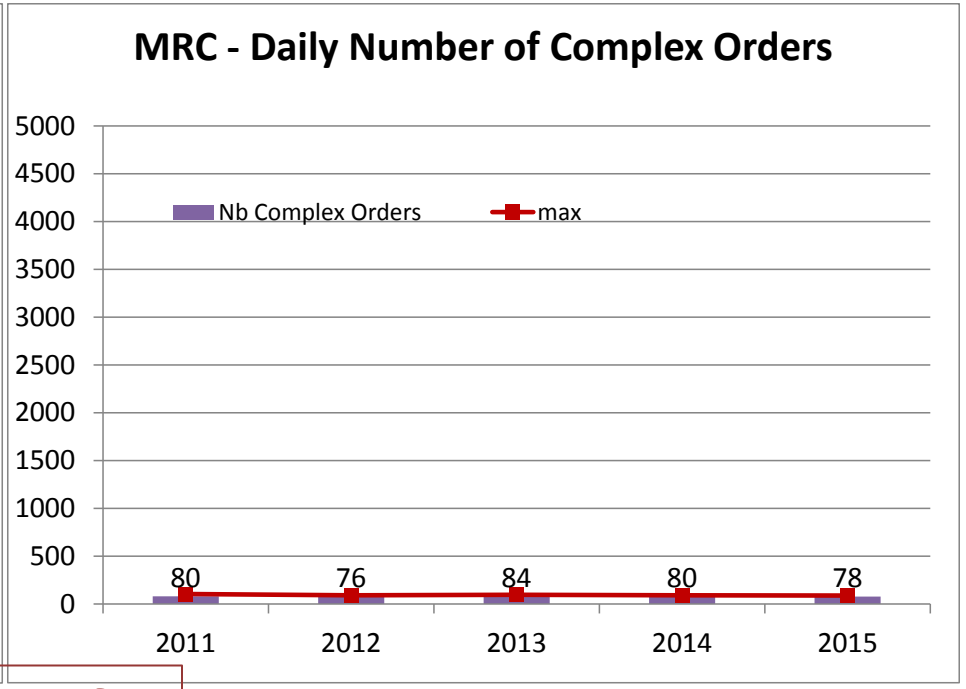
MRC Orderbook Growth – Block and Complex Orders





On MRC, the number of block orders has doubled between 2011 and 2015

2011 – 2015

#daily MRC Blocks : **x 2.08** (+1664 block orders)

Max (#daily MRC Blocks) : **x 2.12** (+2462 block orders).

#Complex orders stable

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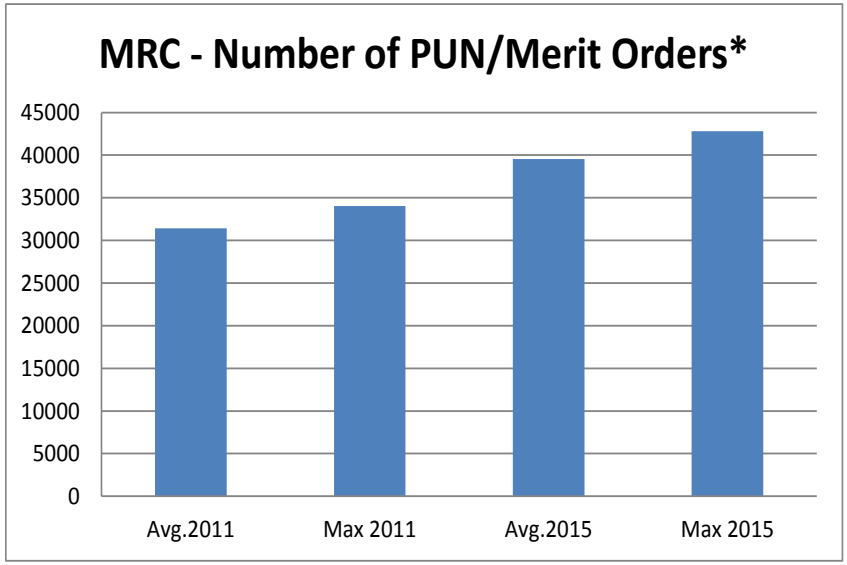
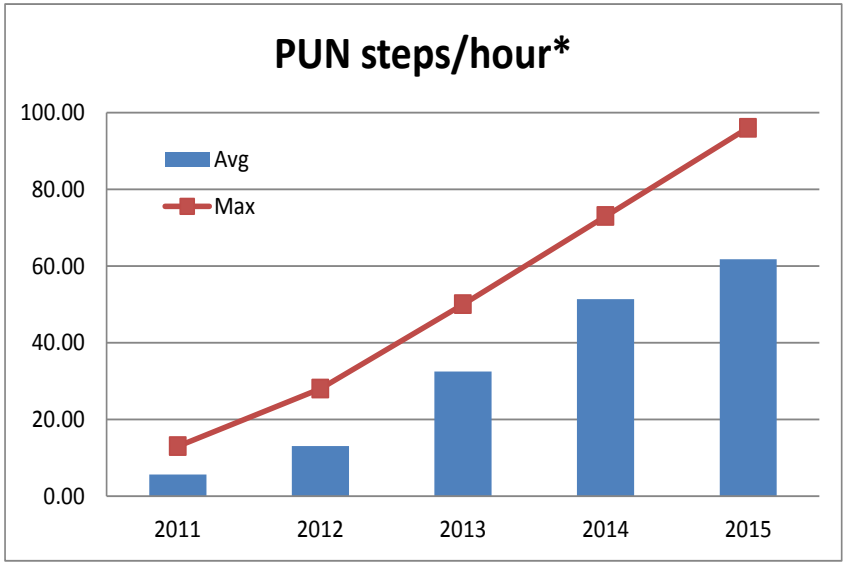
MRC Orderbook Growth – Merit/PUN orders

2011 – 2015

#Merit orders : **x 1.4**

#PUN steps cagr: **81%**





*** Period 25/02/201X – 09/07/201X**

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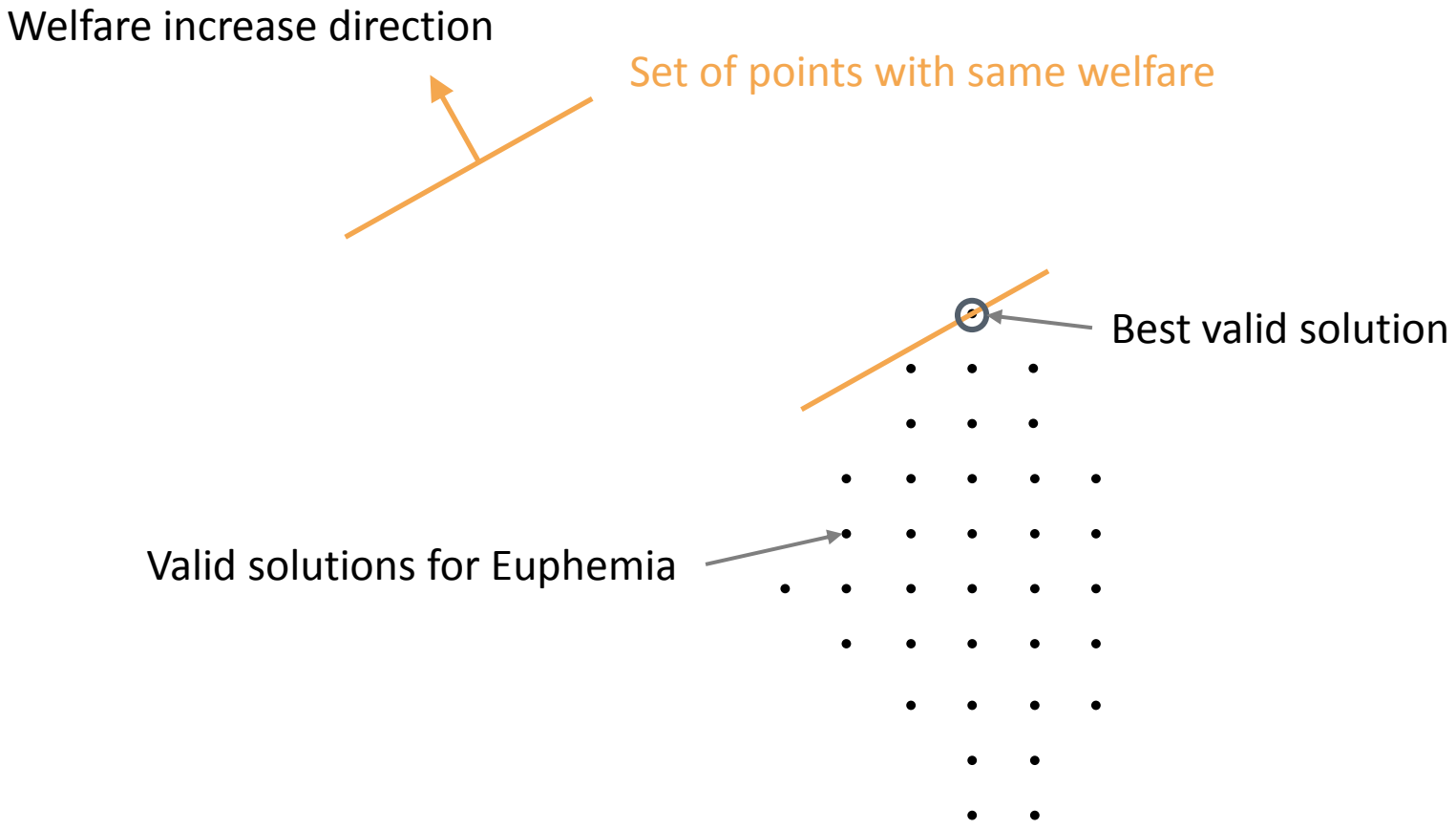
What makes it difficult to prove optimality in the current setting?

- The combinatorial nature of block and smart orders

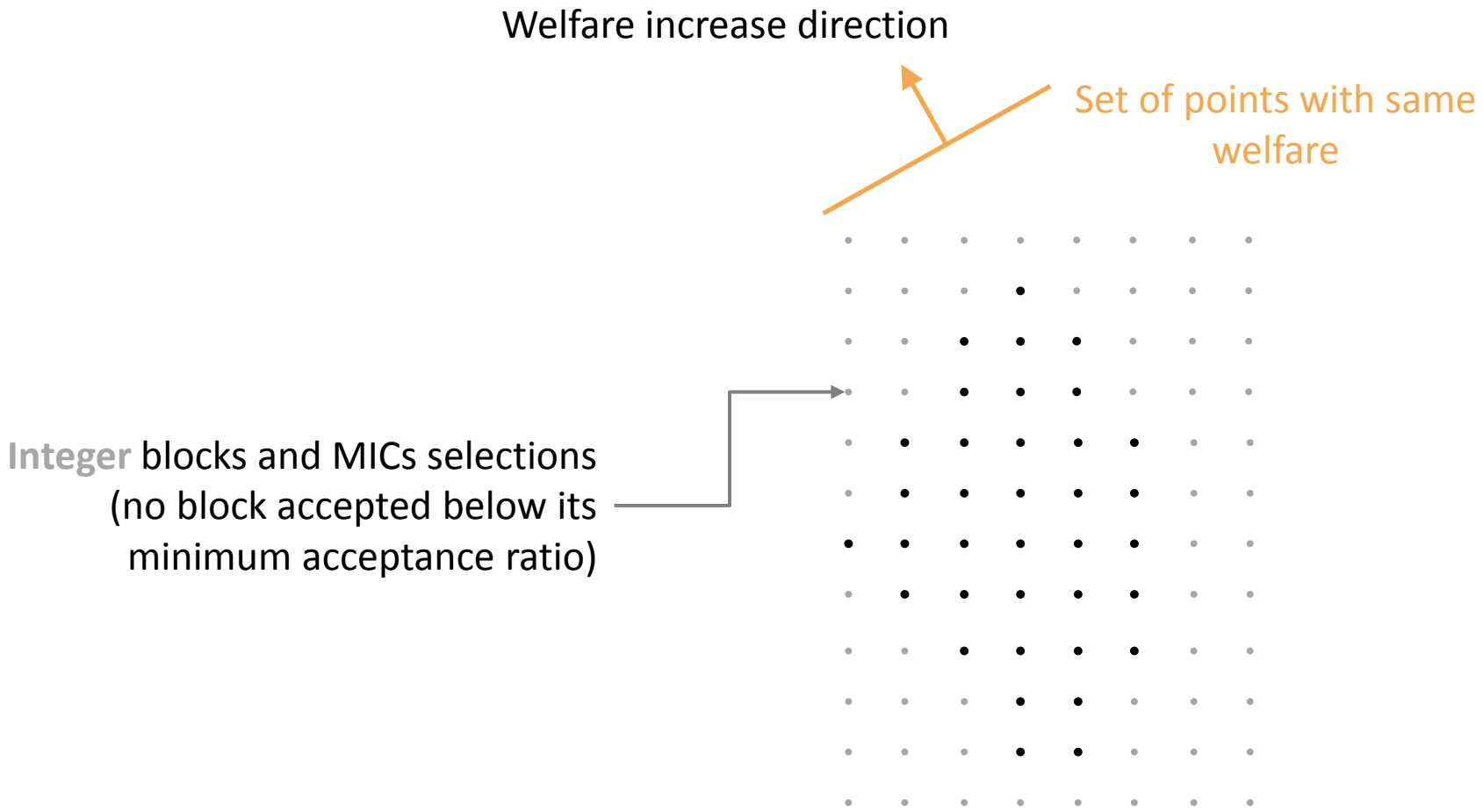
- All “non-convex” requirements
  - Strict linear pricing, no Paradoxically Accepted Block
  - The price intuitiveness requirement
  - The PUN requirement
  - The Minimum Income Condition

Taken separately, these requirements are relatively easy. Complexity comes from the combination.

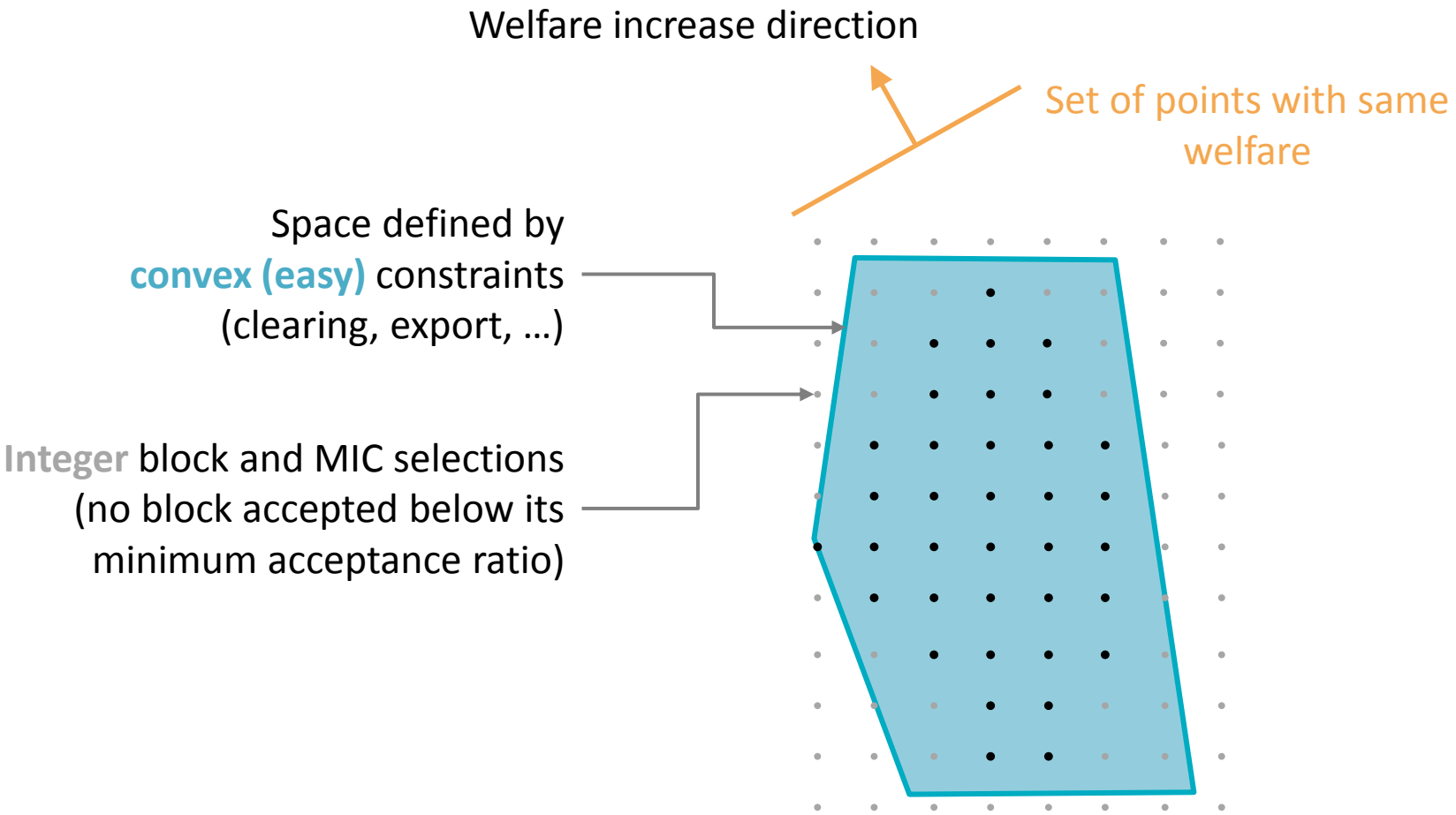
Geometric intuition



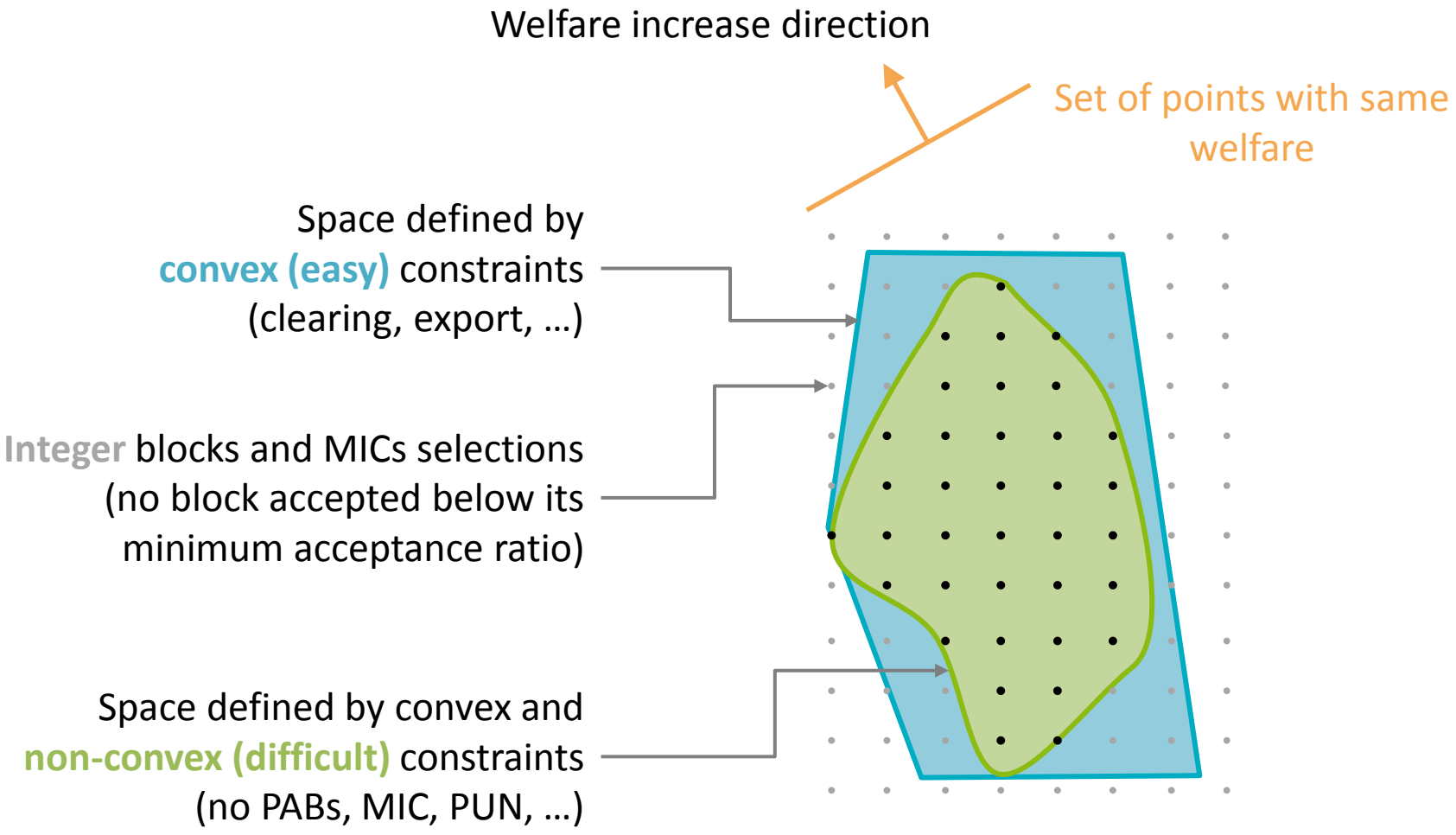
Definitions



Definitions

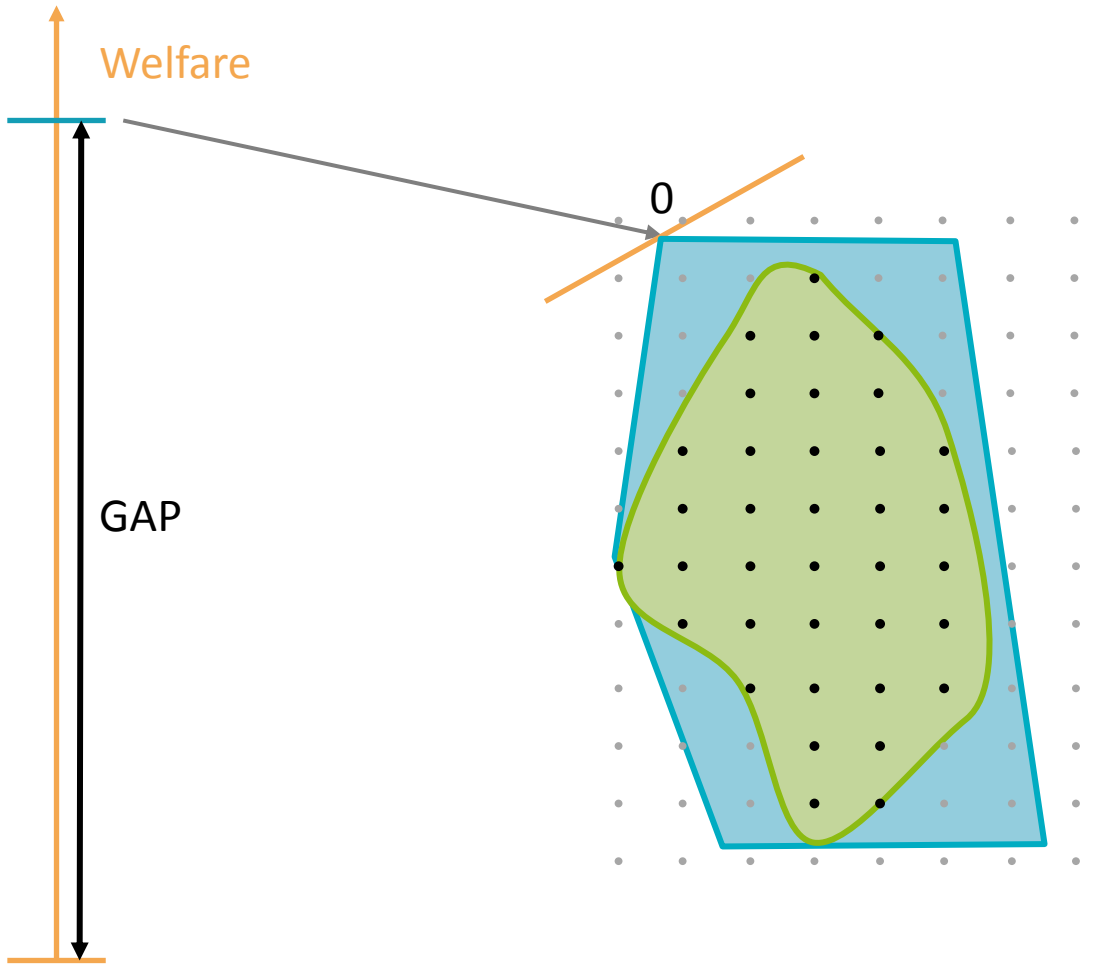


Definitions



Gap = upper bound - lower bound

Initial upper bound = Best welfare when satisfying the **convex** constraints only

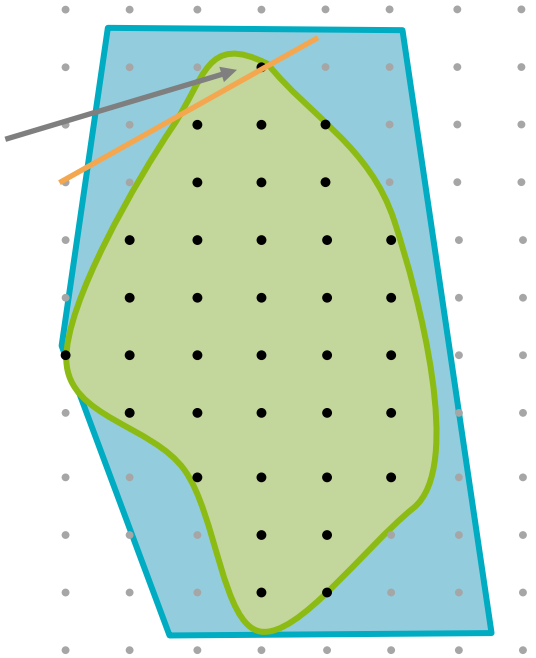


Best achievable solution

Best welfare when satisfying the **convex** constraints only

Welfare

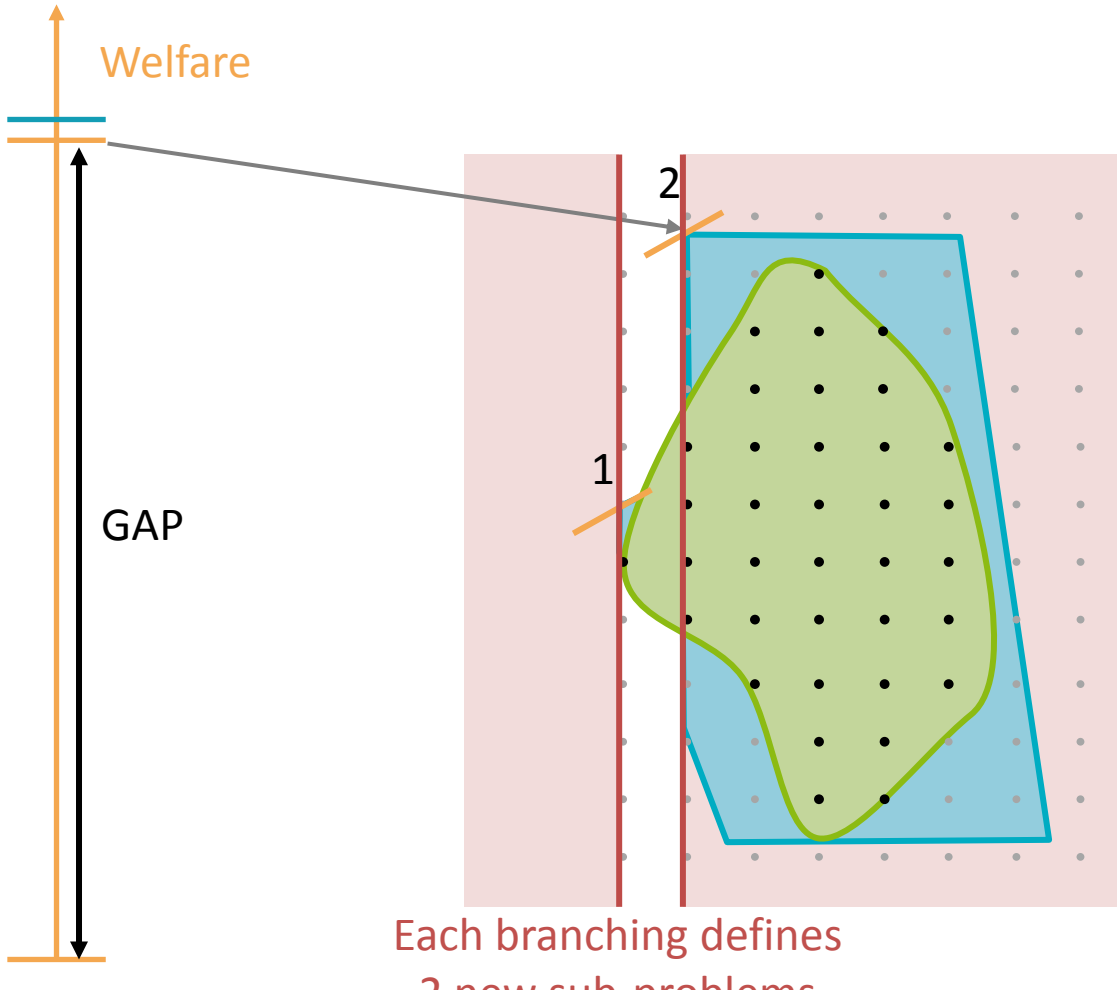
The best achievable solution of the **true problem** is unknown



Initially 0

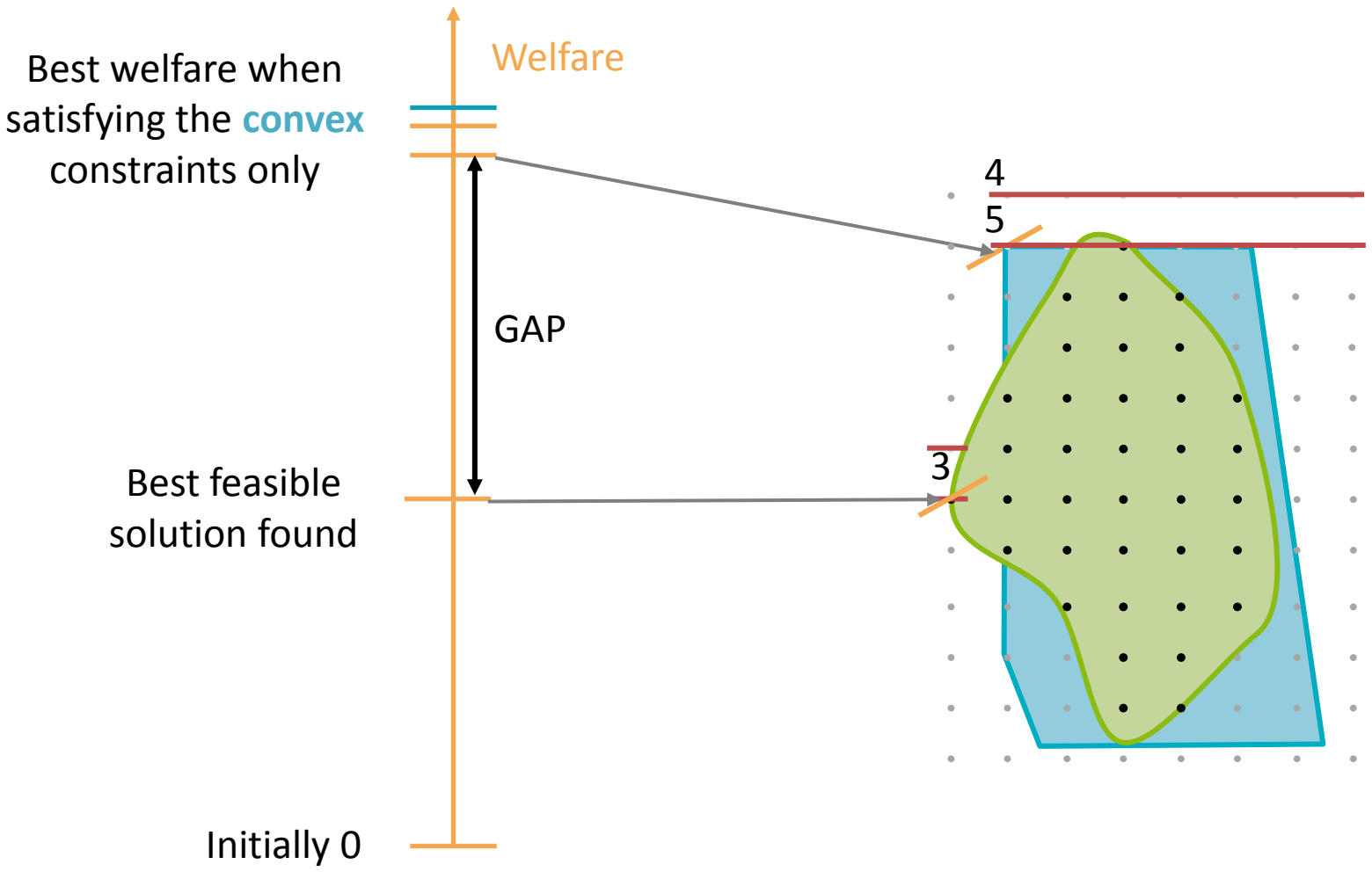
Finding a valid solution is not easy

Best welfare when satisfying the **convex** constraints only



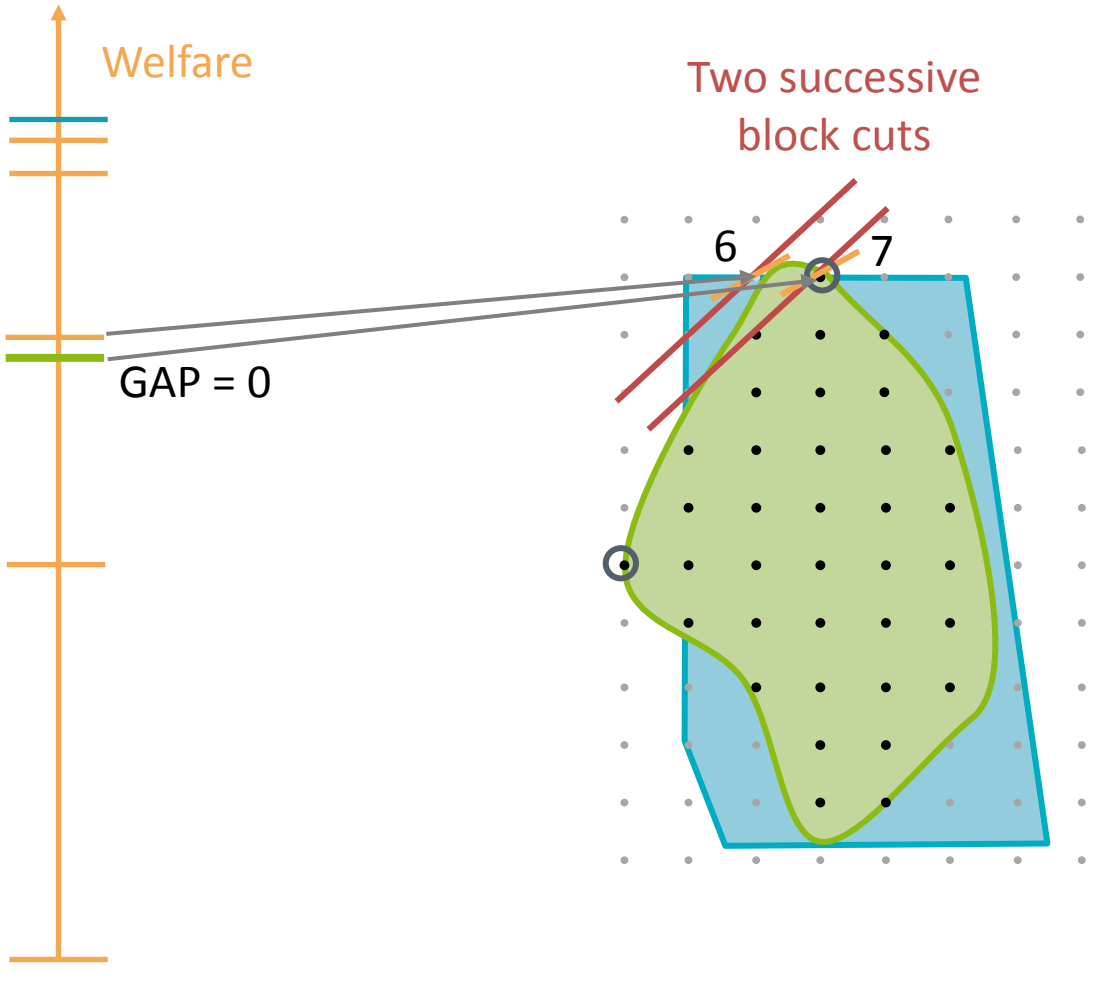
Each branching defines
2 new sub-problems
(accept/reject a block)

Decreasing the gap is not easy either

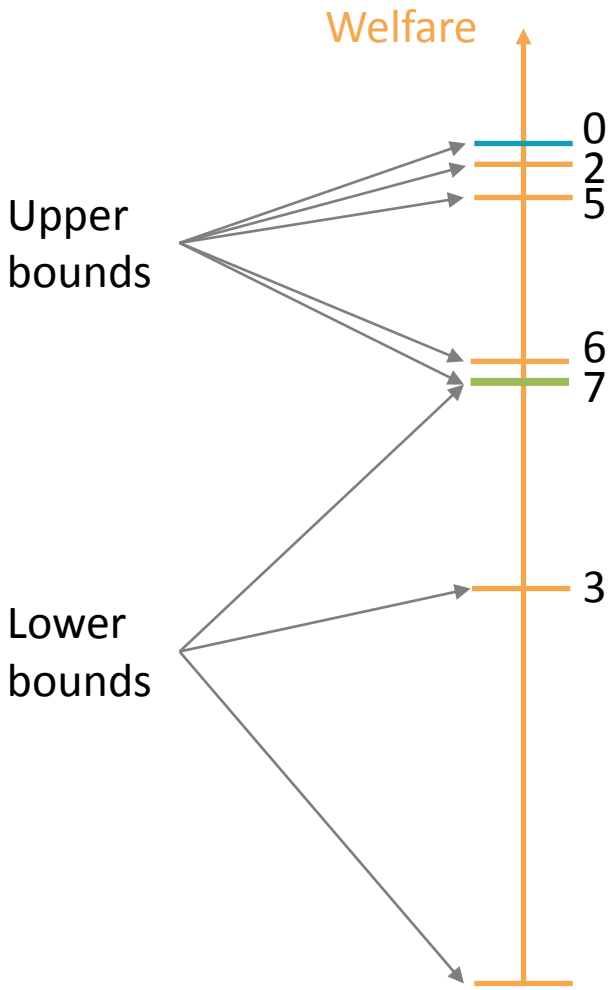


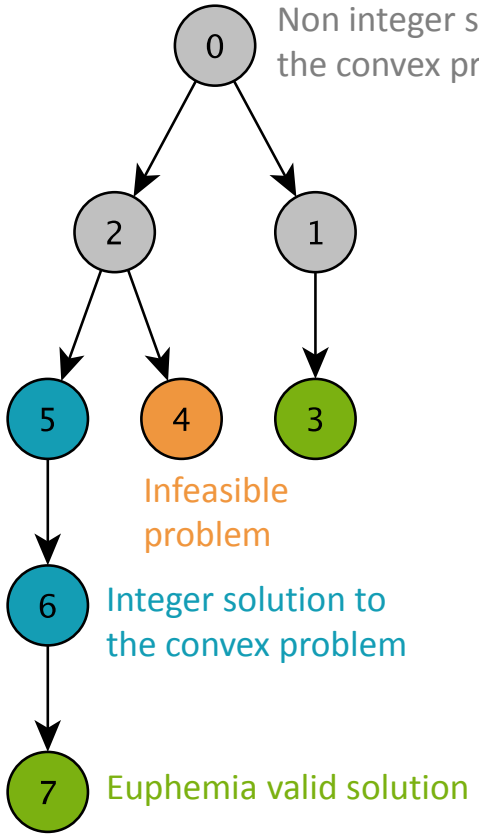
The gap is 0 when the optimal solution is reached

Best welfare when satisfying the **convex** constraints only



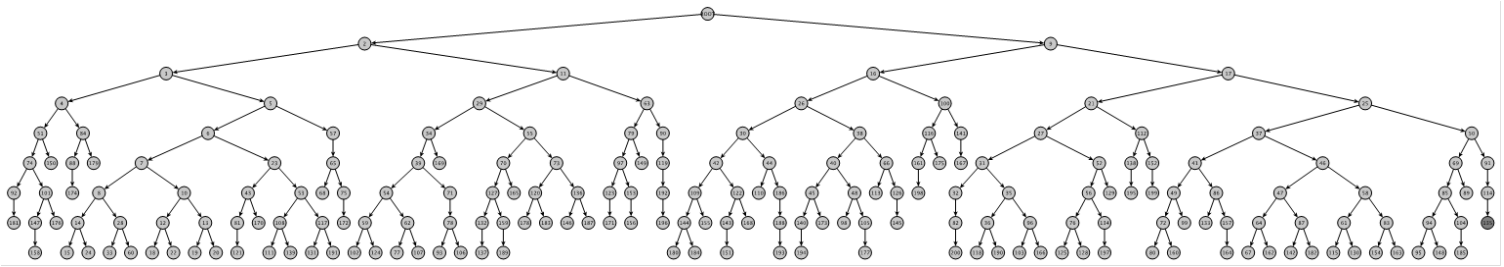
Summary: the search tree





In practice

1. Euphemia is **limited by time**
   - A real search tree has billions of nodes!



2. Euphemia has to find **at least 1 valid solution**
   - Hence we have implemented various heuristics

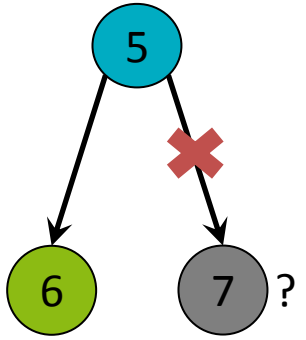
3. But because of **non-convex constraints**, we overestimate the gap
   - The optimal solutions in the convex space give upper bounds on the welfare

Euphemia's PUN search is heuristic

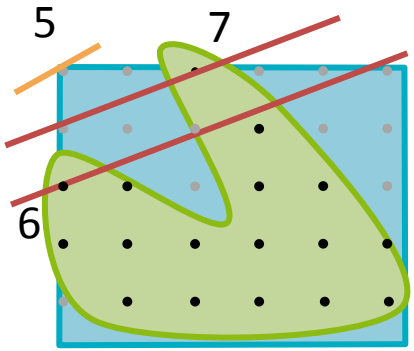
- Because we decompose the problem
  - We only look for PUN after we have found a solution for other zones
- Because even if GME were alone, we could miss some solutions
  - We do not look into some intervals where probability to find a solution is very low
- This is required if we want to find a solution fast enough
  - It gives us time to find other solutions
- Note: Euphemia's results on the GME perimeter are very similar to the UPPO algorithm used previously, and Euphemia is faster

Euphemia's treatment of the MIC condition is heuristic

- To invalidate a solution that contains paradoxically accepted MICs, we create 2 branches



- But we explore only one branch by lack of time
  - The other branch is unlikely to provide better solutions
  - The **PRMICs reinsertion module** compensates this

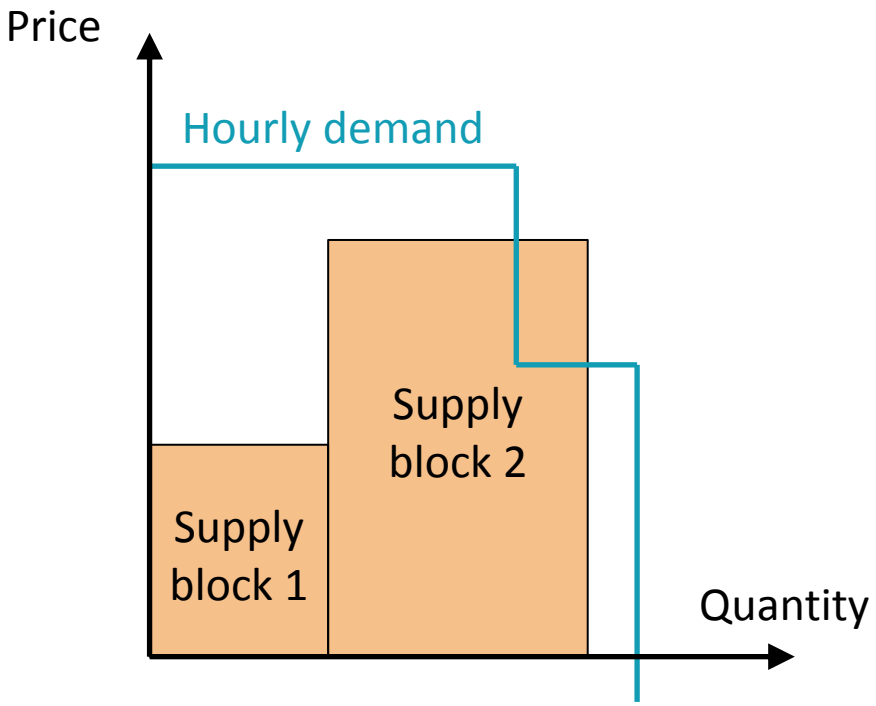


Euphemia's treatment of the intuiveness requirement is heuristic

- In flow based mode, solutions may naturally contain flows from high price zones to low price zones: this is a *non-intuitive* solution
- Euphemia detects these situations, and adds inequalities to enforce an intuitive solution
- This mechanism is proved to converge and is fast
- However, inequalities may not be added in the optimal order

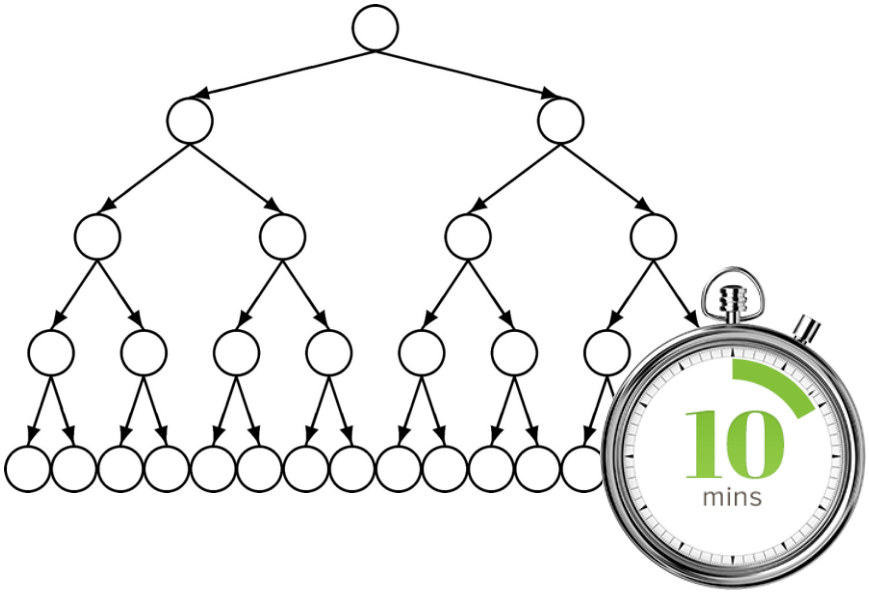
Why do we have PRBs?

1. In uniform pricing, it's either no PABs or no PRBs, but not both



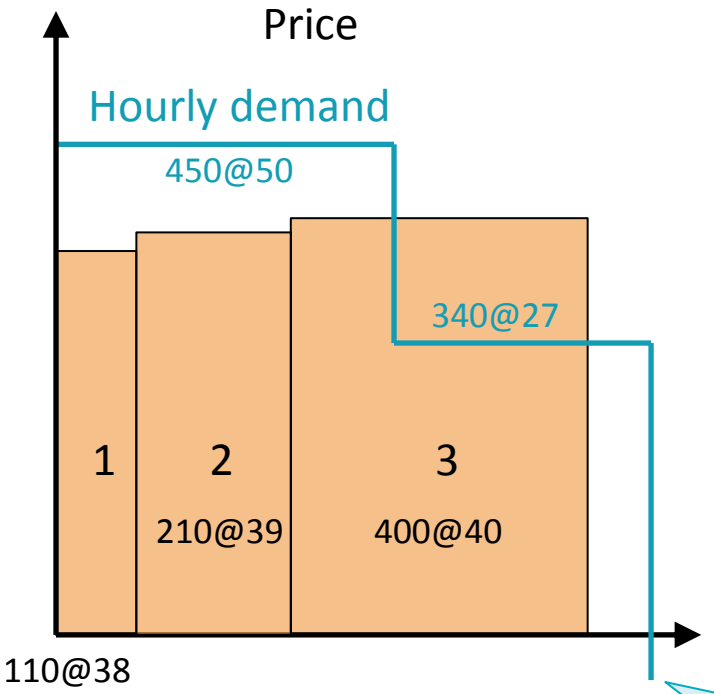
Why do we have PRBs?

1. In uniform pricing, it's either no PABs or no PRBs, but not both
2. The branch-and-bound tree solved by Euphemia is very large



A block can be PRB in the first solution found and be accepted in another better solution. It may happen that the second solution is not found within 10 minutes.

Maximizing the welfare is not equivalent to minimizing the number of PRBs



Solution with best welfare:
Block 3 accepted, 2 PRBs

Solution with min number of PRBs
Blocks 1 and 2 accepted, 1 PRB

Minimizing PRB utility loss would be a different market design choice

Sequential reinsertion of the PRBs

1. Compute the list of PRBs in the solution, and sort it by **decreasing δ_P** ("From the worst to the least PRB")
   - The size of the list is limited to 15 orders

2. Force the 1st block in this list to be accepted
   - If the **welfare** of the solution increased, continue to 3.
   - Otherwise, try reinserting the next order in the list

3. Check the **non-convex requirements**
   - If the prices are OK, go back to 1.
   - Otherwise, try reinserting the next order in the list

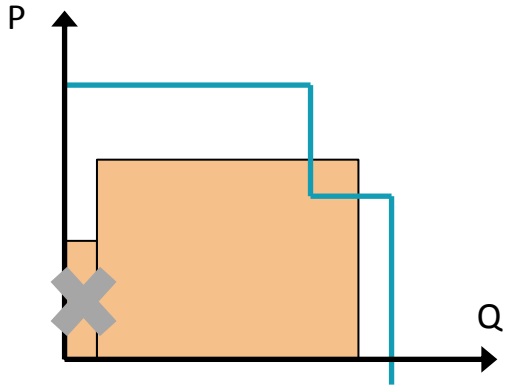
This is called local search. We apply small changes to the solution

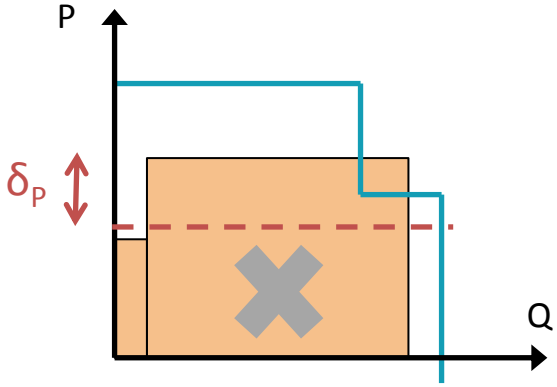
How does Euphemia deal with small blocks?

- **Is a small block more likely to become PRB?**
  YES, because we are optimizing the welfare, so even a deep in-the-money block may get rejected

- The delta P rule was added for this reason

- **Is a block submitted in a small bidding area more likely to become PRB?**
  - NO, Euphemia does not make any distinction
  - In practice, it may happen because of market circumstances (price, quantities, and other)





2. Performance

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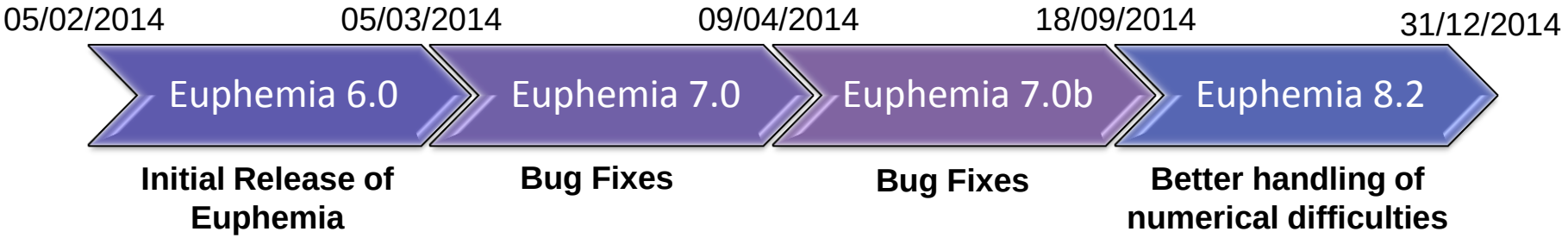
Euphemia – Main Releases since Go-Live

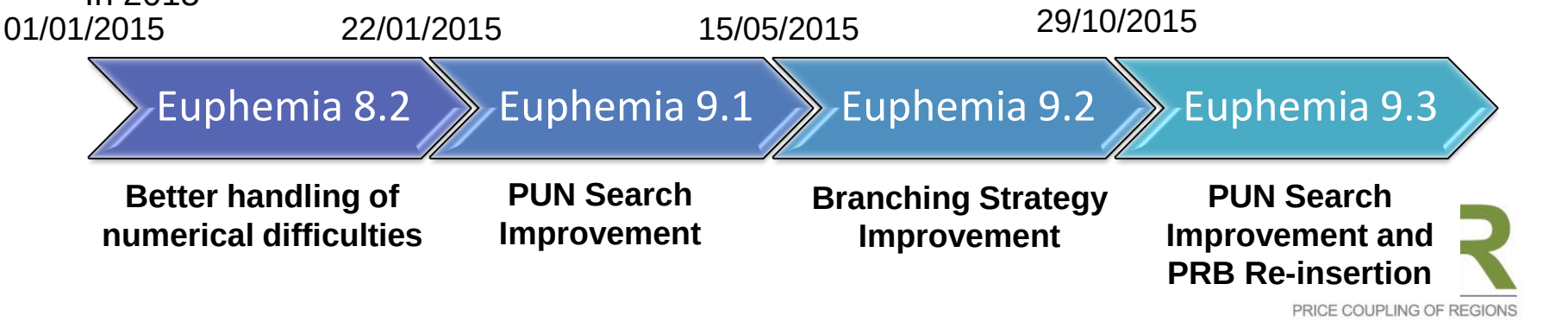
Euphemia Development

- In order to cope with the expending perimeter and the increasing number and complexities of the products that are used, significant performance improvements have been implemented within Euphemia.*

- In 2014, 4 releases of Euphemia have been put in production :



- In 2015



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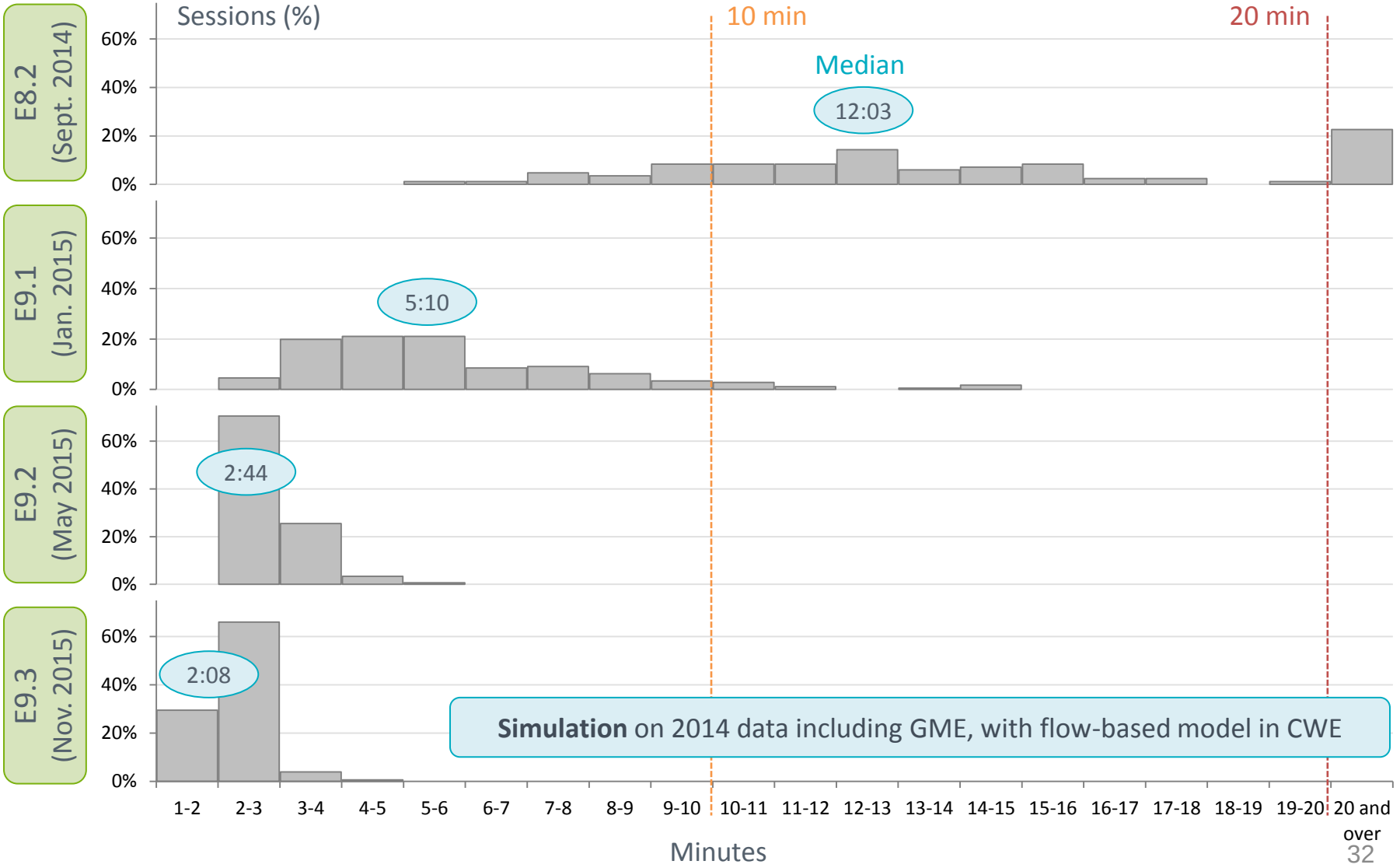
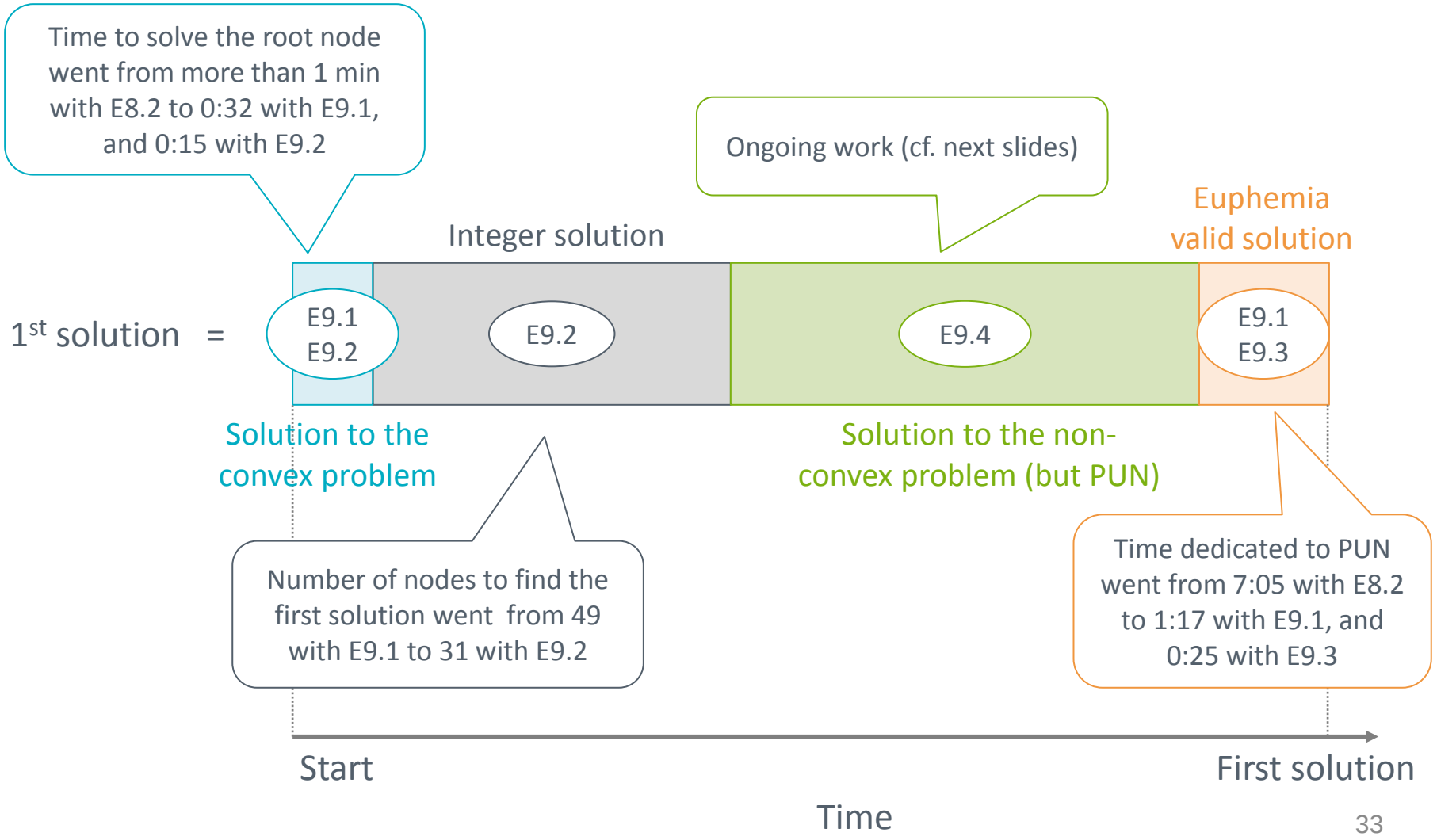
Time to the 1st solution: from 12 to 2 min in 1 year

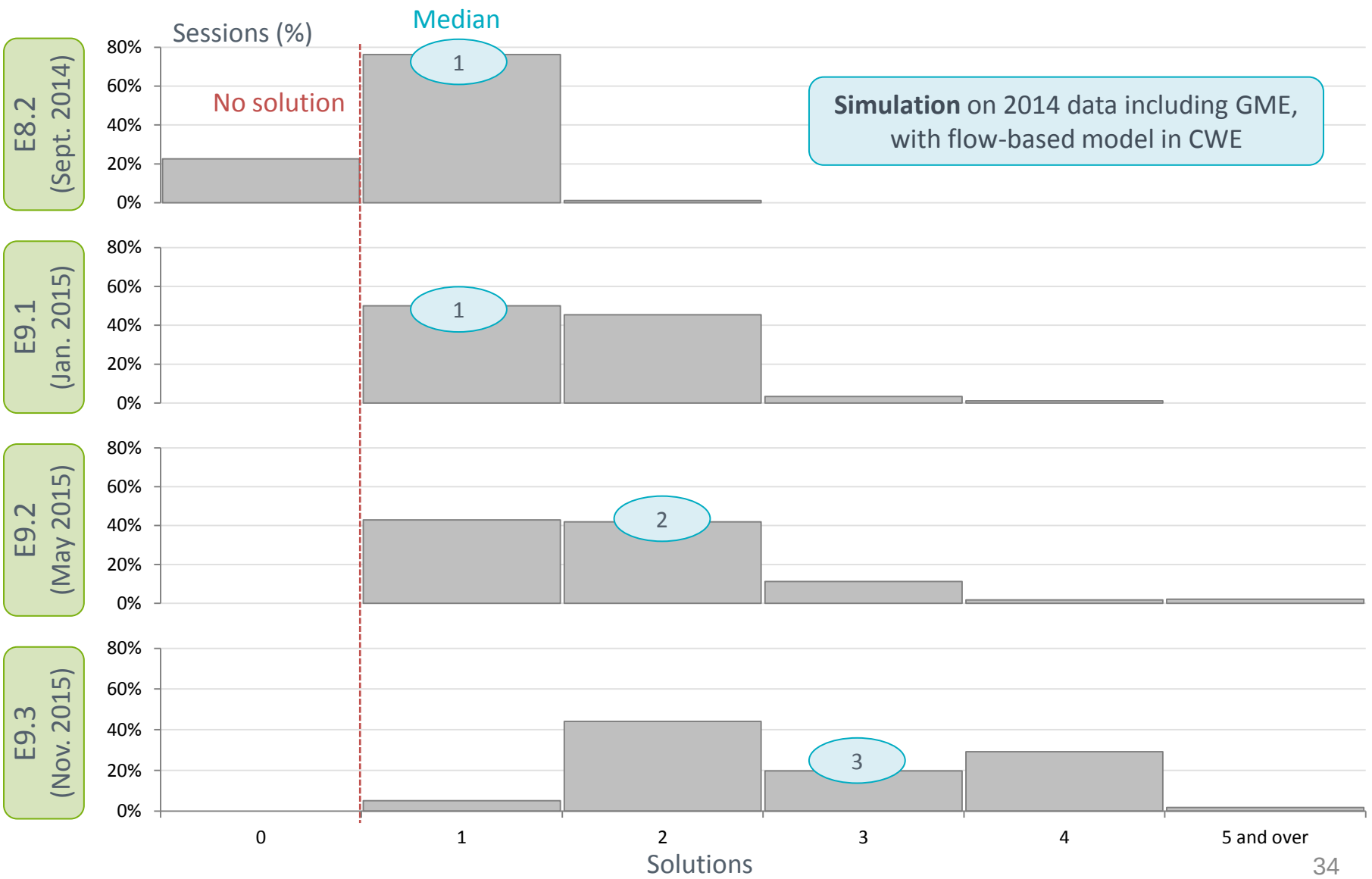


Number of analyzed sessions varies depending on the time frame.

All steps have been improved throughout the versions



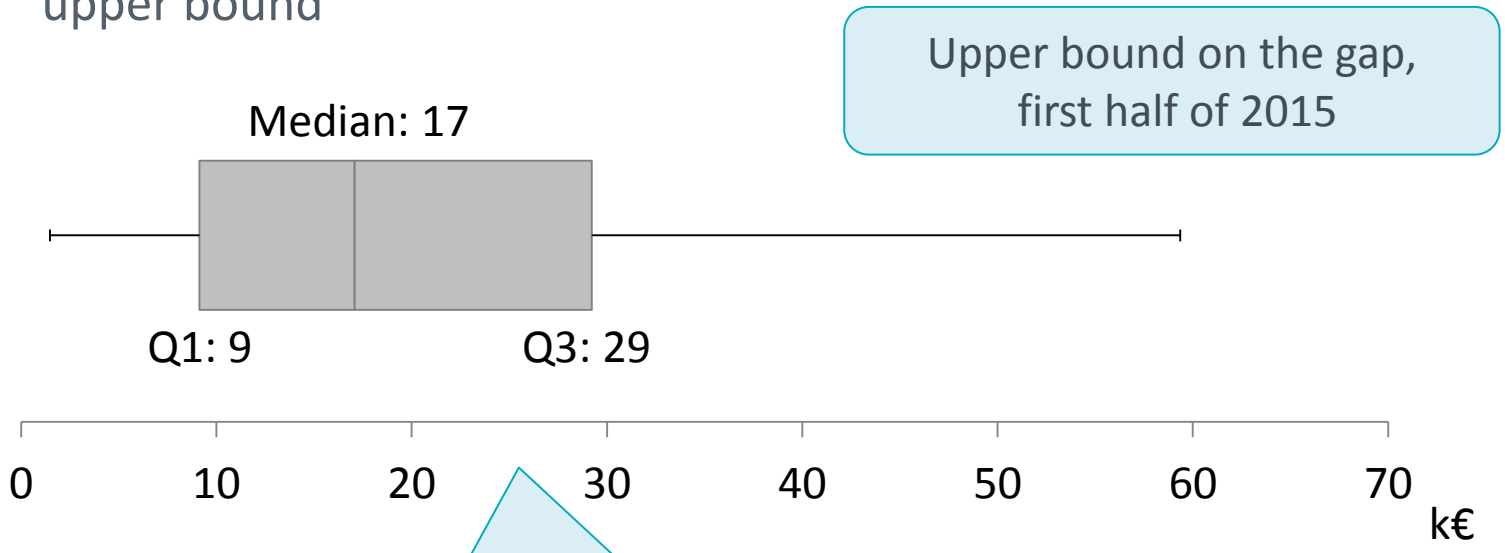
Number of solutions found: from 1 to 3 in 1 year



Number of analyzed sessions varies depending on the time frame

A posteriori evaluation of the gap

- The solutions returned by Euphemia (version 9.3) are very good
  - Based on our preliminary results, their welfare is about 17 k€ below the upper bound



3. Next development steps for the Euphemia algorithm

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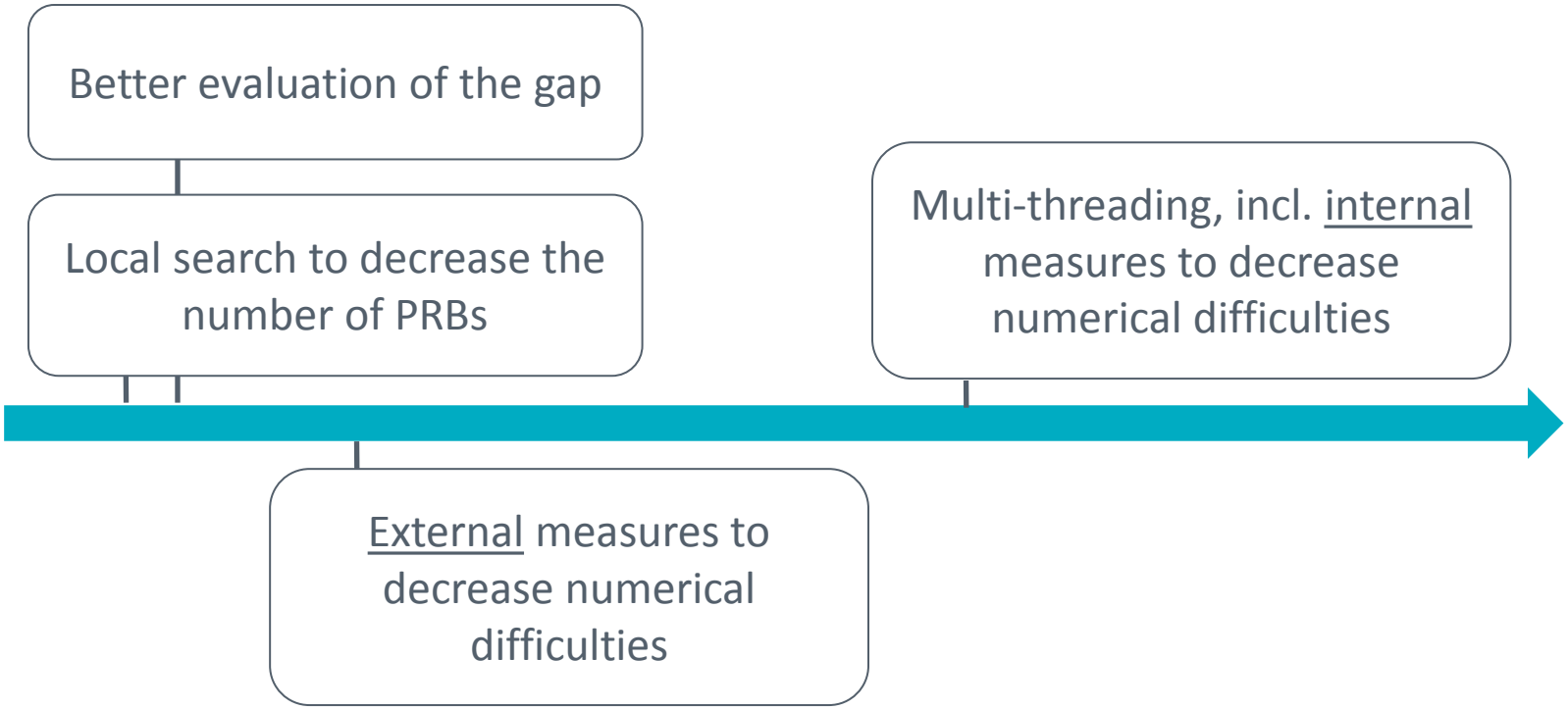
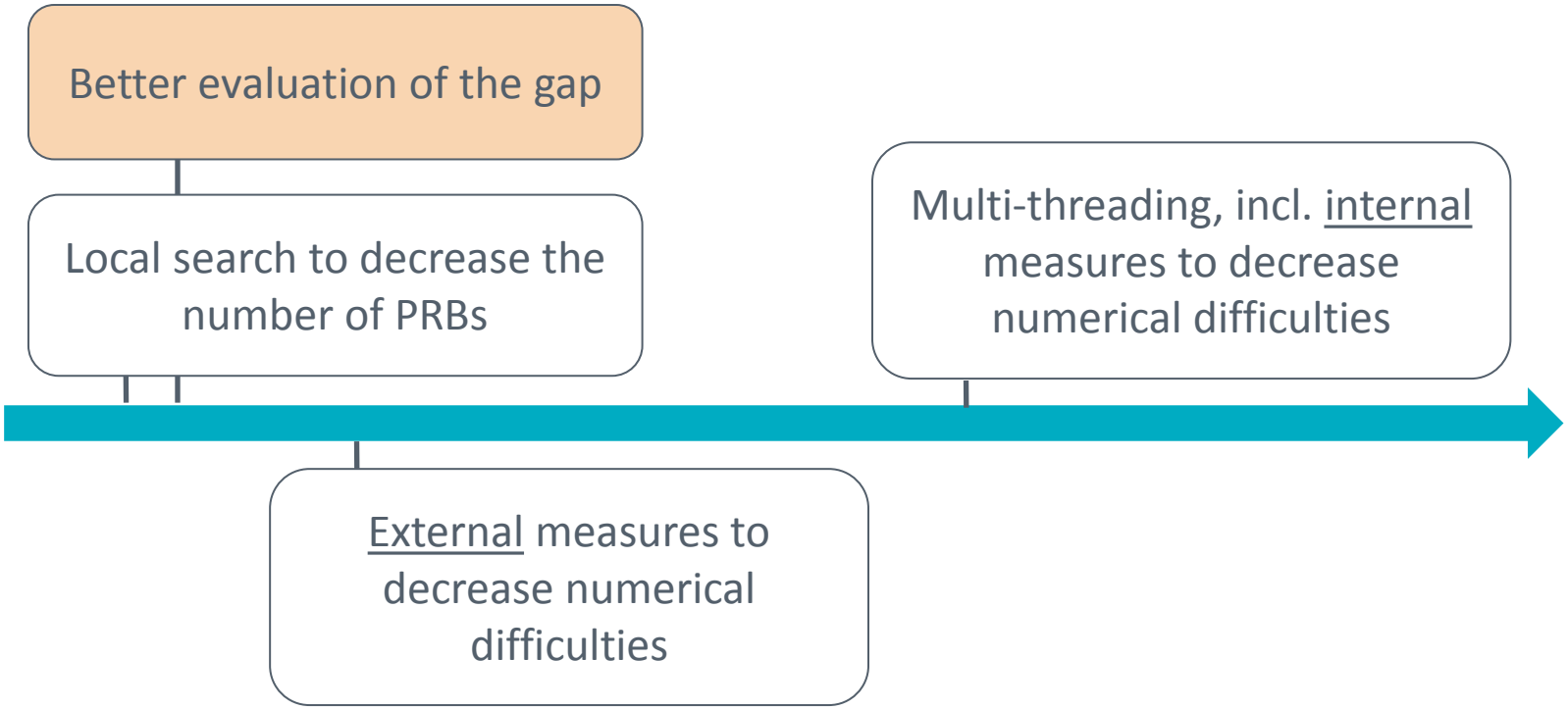
Next main steps to improve performance and quality of solutions



Next main steps to improve performance and quality of solutions



Complex orders cause the main overestimation of the gap

A complex order is defined as:

- A set of step supply curves, one per period
- Optionally
  - A MIC (minimum income condition) constraint for the complex order acceptance

    $$\text{Income} \geq \text{Fixed Term} + \text{Variable Term} \times \text{accepted quantity}$$

  - A Load Gradient condition, to set a maximum variation of the the accepted quantity between consecutive periods
  - A Scheduled Stop condition, to shut down a plant smoothly if not accepted

How does it compare to a block order?

- A block is defined as a set of quantities, a single price, and optionally a minimum acceptance ratio

- In a complex order,
  - the hourly orders must be rejected if out-of-the-money and accepted if in-the-money
  - the accepted ratio can vary from one period to the other
  - The variable term (VT) has a "**block effect**"
  - You can **recover a fixed cost (FT)**

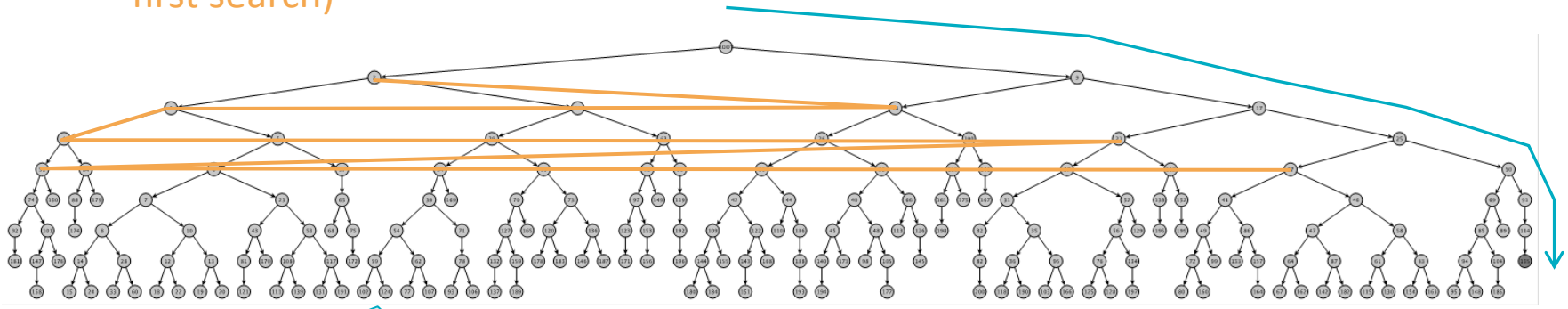
- A block
  - can lose money on some periods, as long as overall the block is not PAB
  - must have the same accepted ratio on all periods
  - A fixed cost can be implicitly integrated (as you know the minimum quantity that can be accepted)

Why do complex orders cause the main overestimation of the gap (1)?

To decrease the gap, we must:

2 Prove that the most promising nodes are not valid (breadth first search)

1 Find a good valid solution (Dive down in the tree)



Step 2 cannot be performed efficiently! We have to evaluate (almost) all combinations of complex orders with a MIC condition (and handle the blocks, the PUN, etc.)

Why do complex orders cause the main overestimation of the gap (2)?

The variable term makes the MIC constraint **non-convex**

The solution of the **convex** problem is based on the prices of the hourly orders, which can be very different from the VT

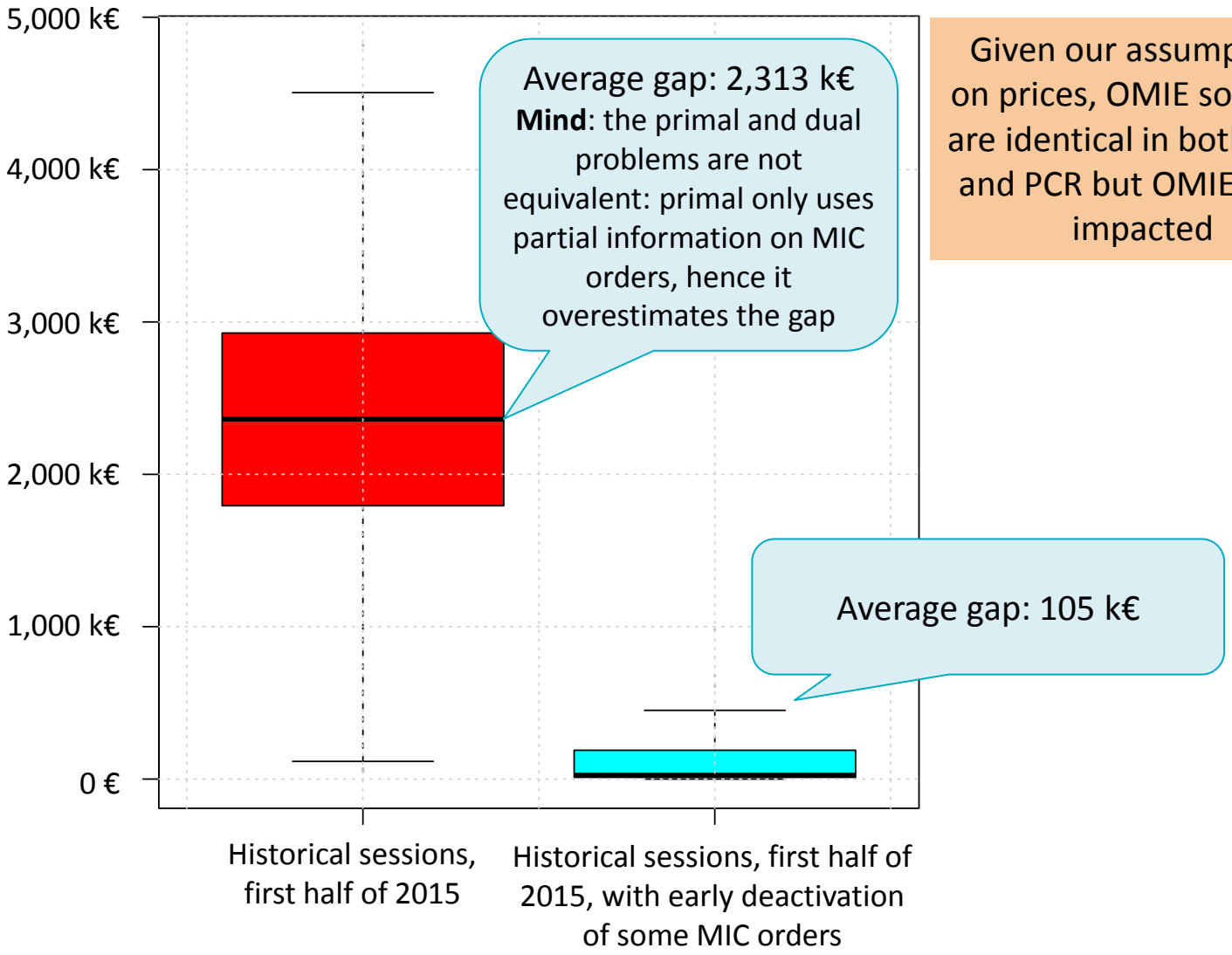
- Euphemia assumes first that the order has to be accepted at the hourly steps' price
- But the MIC constraint is not expressed in the initial relaxation of the problem; the MIC can actually request a different price

This discrepancy appears in Euphemia's optimality measure

To mitigate these effects, we propose to early deactivate some MIC orders

- Early deactivation of MICs that are unlikely to be satisfied
  - Reduces the number of nodes to explore
  - Improves the upper bound when there is not enough time to prove that these MICs should be deactivated
- An **assumption** on market prices is made, based on past results, with a safety margin
- Approach:
  - Compute tentative income and quantities of orders under these assumed market prices
  - Deactivate MIC order if tentative income violates the MIC
- Gap improves significantly

Early deactivation of MICs reduces the gap by 2,208 k€*



Given our assumptions on prices, OMIE solutions are identical in both cases and PCR but OMIE is not impacted

*Preliminary testing.

Limitations of early deactivation

- A few infeasible MIC orders with low difference between tentative costs and incomes cannot be rejected early
  - Deciding the acceptance of these orders remains hard and limits the ability to decrease the gap
- Hence the proposed approach is a speedup and reduces the gap, but it does not close the gap
- How did we reduce the gap further?
  - Geographical decomposition to obtain a good upper bound on the welfare

Motivation of the geographical decomposition

- If we can find **2 groups of variables** such that each constraint only contains variables from one group:

Z^*

Maximize $3x_1 + 2y_2 - 4x_2 + 10y_1$

Subject to
$x_1 + 9x_2 \leq 5$
$3y_1 + 2y_2 \leq 15$
$y_2 \geq 5$
$x_2 \geq 0$

- Then the problem can be solved by **decomposition**

$Z^* = Z_1 + Z_2$

Z_1

Maximize $2y_2 + 10y_1$

Subject to
$3y_1 + 2y_2 \leq 15$
$y_2 \geq 5$

Z_2

Maximize $3x_1 - 4x_2$

Subject to
$x_1 + 9x_2 \leq 5$
$x_2 \geq 0$

Motivation of the geographical decomposition

$$Z^* = Z_1 + Z_2$$

Z_1:

Maximize $2y_2 + 10y_1$

Subject to $3y_1 + 2y_2 \leq 15$

$y_2 \geq 5$

Z_2:

Maximize $3x_1 - 4x_2$

Subject to $x_1 + 9x_2 \leq 5$

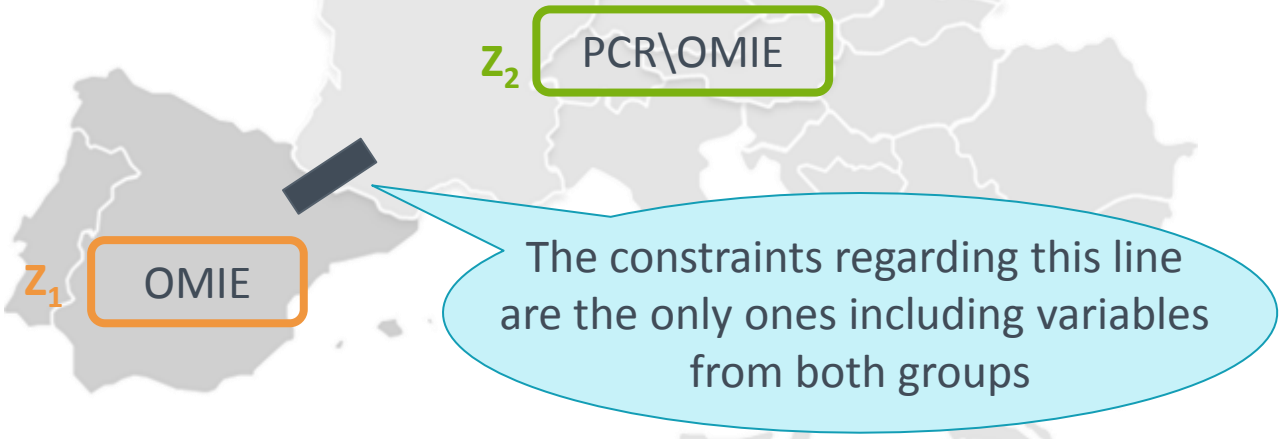
$x_2 \geq 0$

This is interesting if it is possible to solve very efficiently the resulting subproblems. In our case,

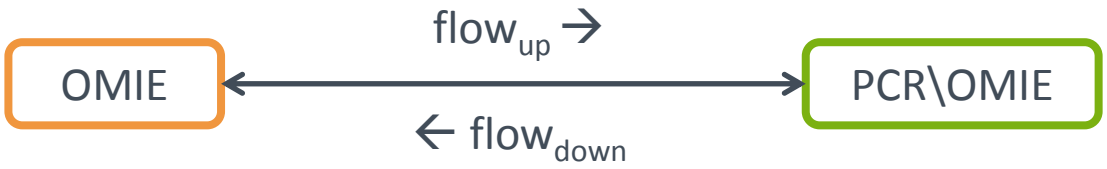
- OMIE alone is fairly easy to optimize
- PCR without OMIE remains challenging, but we can provably obtain solutions of good quality

How can we apply this idea to improve the upper bound on the welfare, and thus the gap?

- It is not so simple: we must find a way to decompose the problem
- PCR is nearly decomposable, there is only one line between OMIE and the other PXs

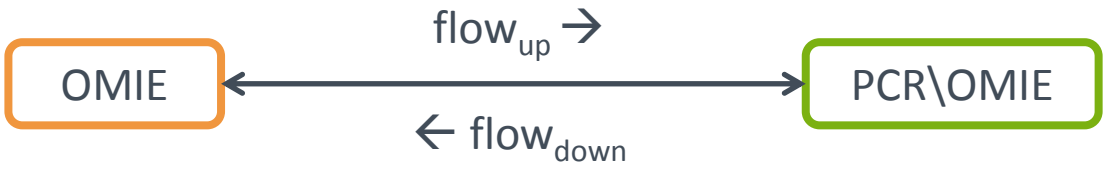


A valid upper bound on PCR welfare



The flow variables are used on both sides.

A valid upper bound on PCR welfare

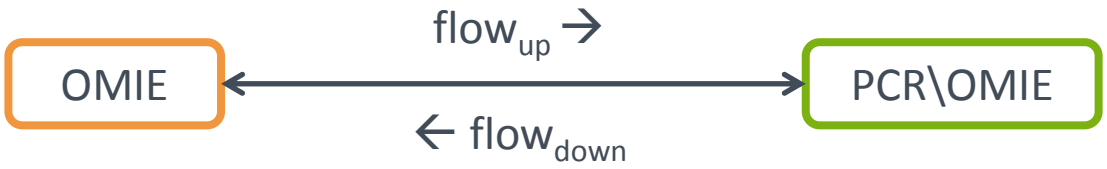


The flow variables are used on both sides. We decompose the problem as follows:

- S_{OMIE} is a supply order inserted in PCR\OMIE that represents the import from OMIE. Its quantity is defined as the ATC from Spain to France, and its price is set to the average of the prices in Spain and France in a valid Euphemia solution.

- $D_{PCR\OMIE}$, D_{OMIE}, and $S_{PCR\OMIE}$ are defined in a similar way.

A valid upper bound on PCR welfare



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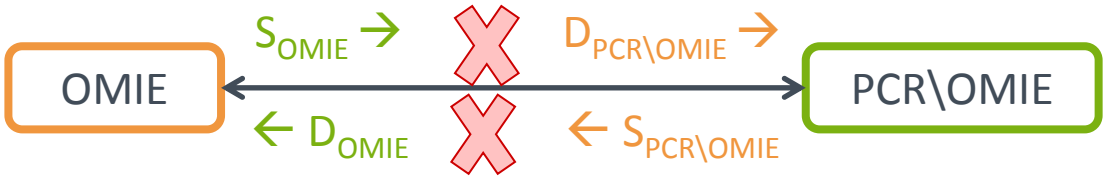
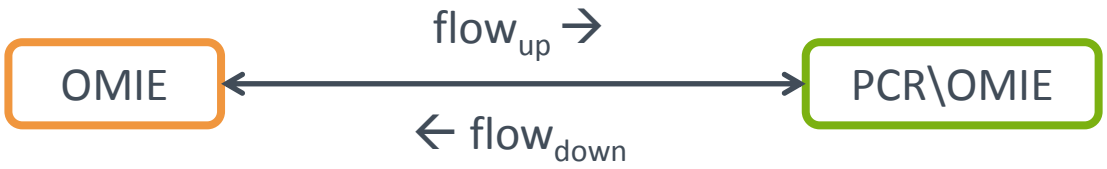


Removing some constraints from our maximization problem can only lead to solutions with a higher welfare.

A valid upper bound on PCR welfare



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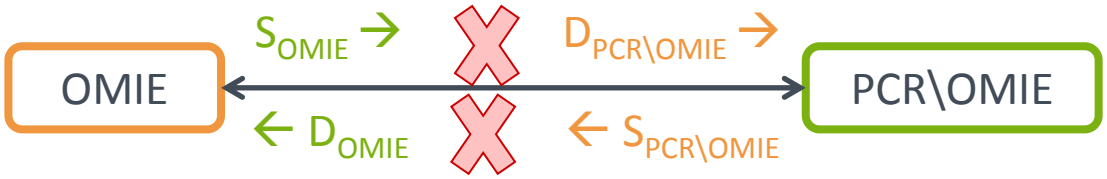
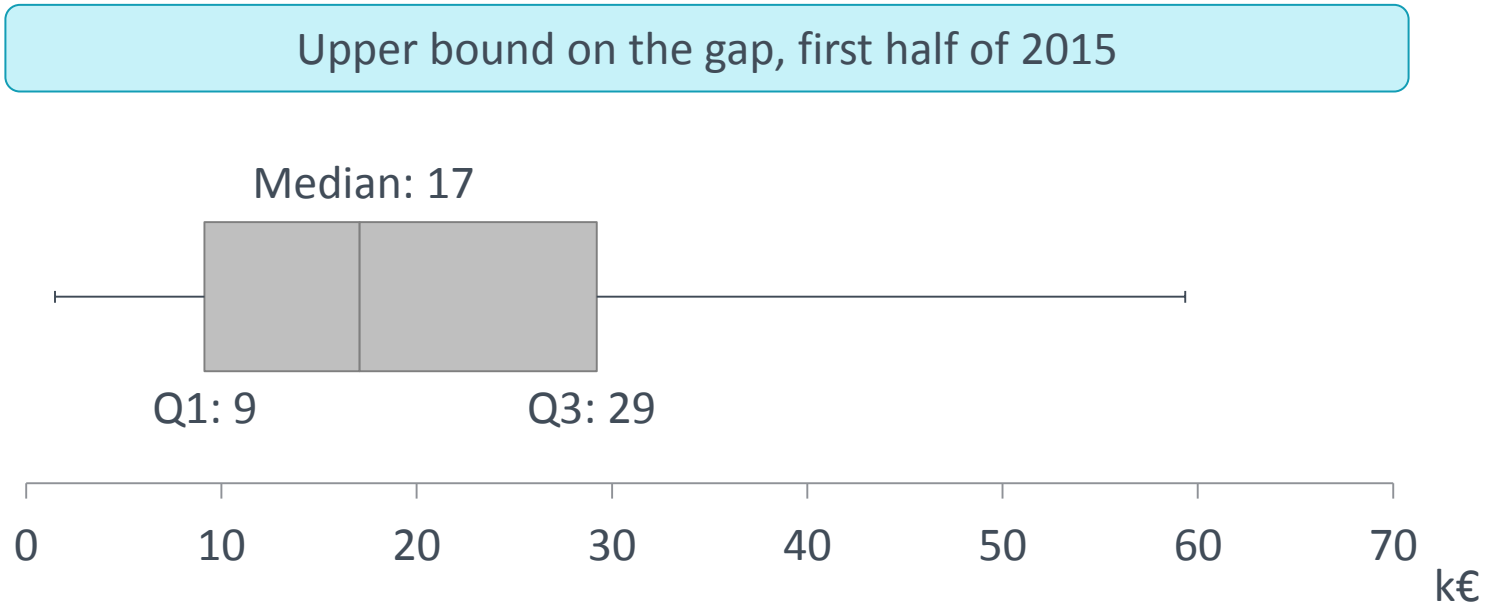


Removing some constraints from our maximization problem can only lead to solutions with a higher welfare. Hence we obtain a valid upper bound:

Conclusion of the gap evaluation

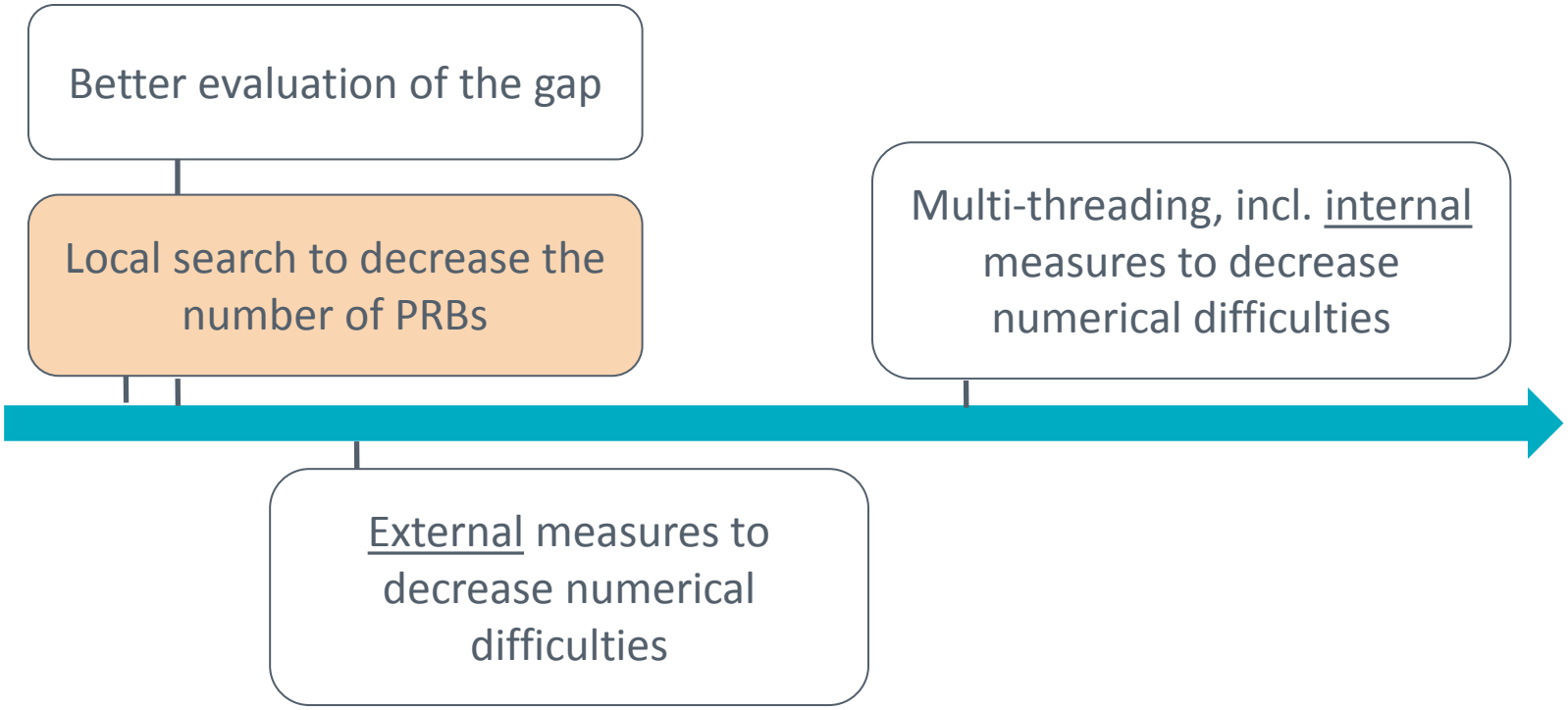
- The solutions returned by Euphemia are of high quality
- Based on our preliminary results, their welfare is about 17 k€ below the best achievable welfare



Conclusion of the gap evaluation

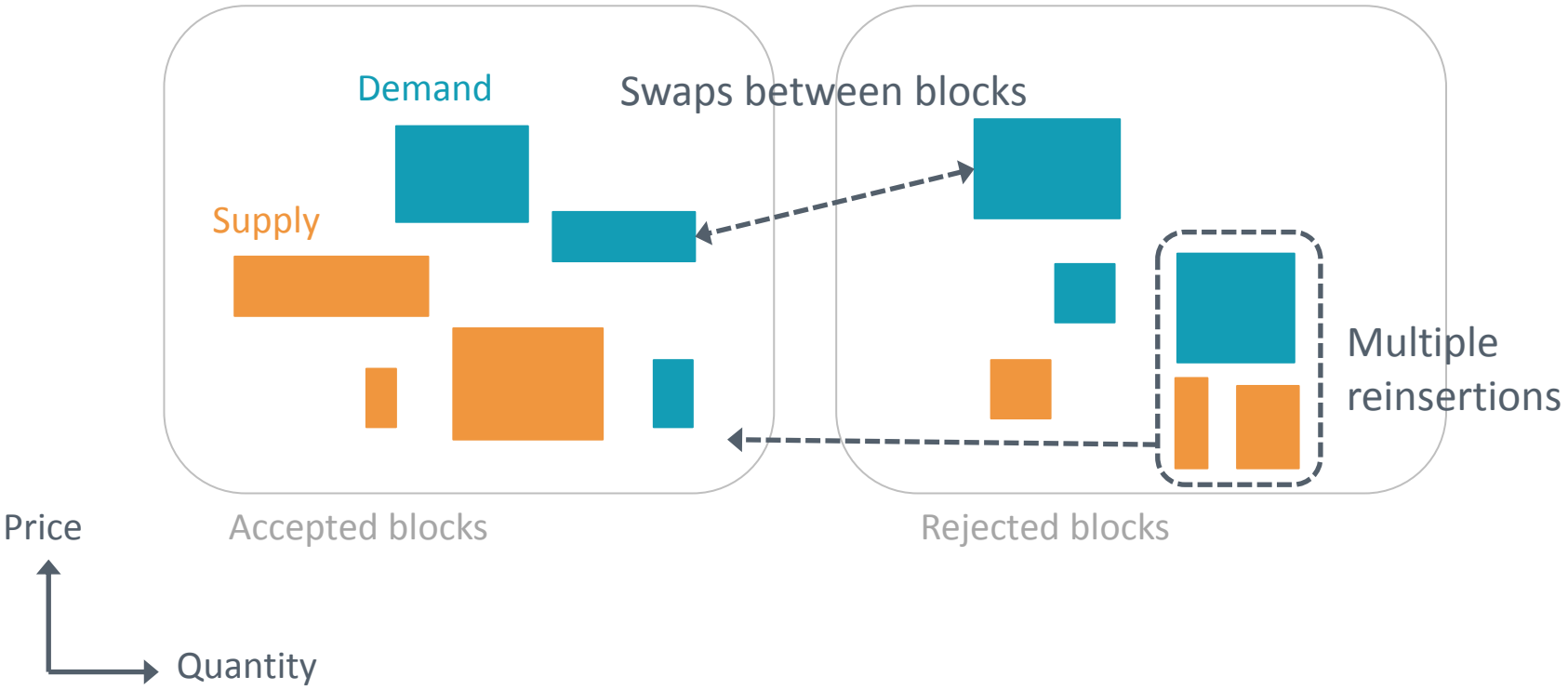
- Taking into account our assumptions on the prices (cf. slide on “Early deactivation of some MIC orders”), the achieved gap on OMIE is zero
- The residual gap is thus on PCR without OMIE
- Our developments will focus on decreasing this residual gap

Next main steps to improve performance and quality of solutions

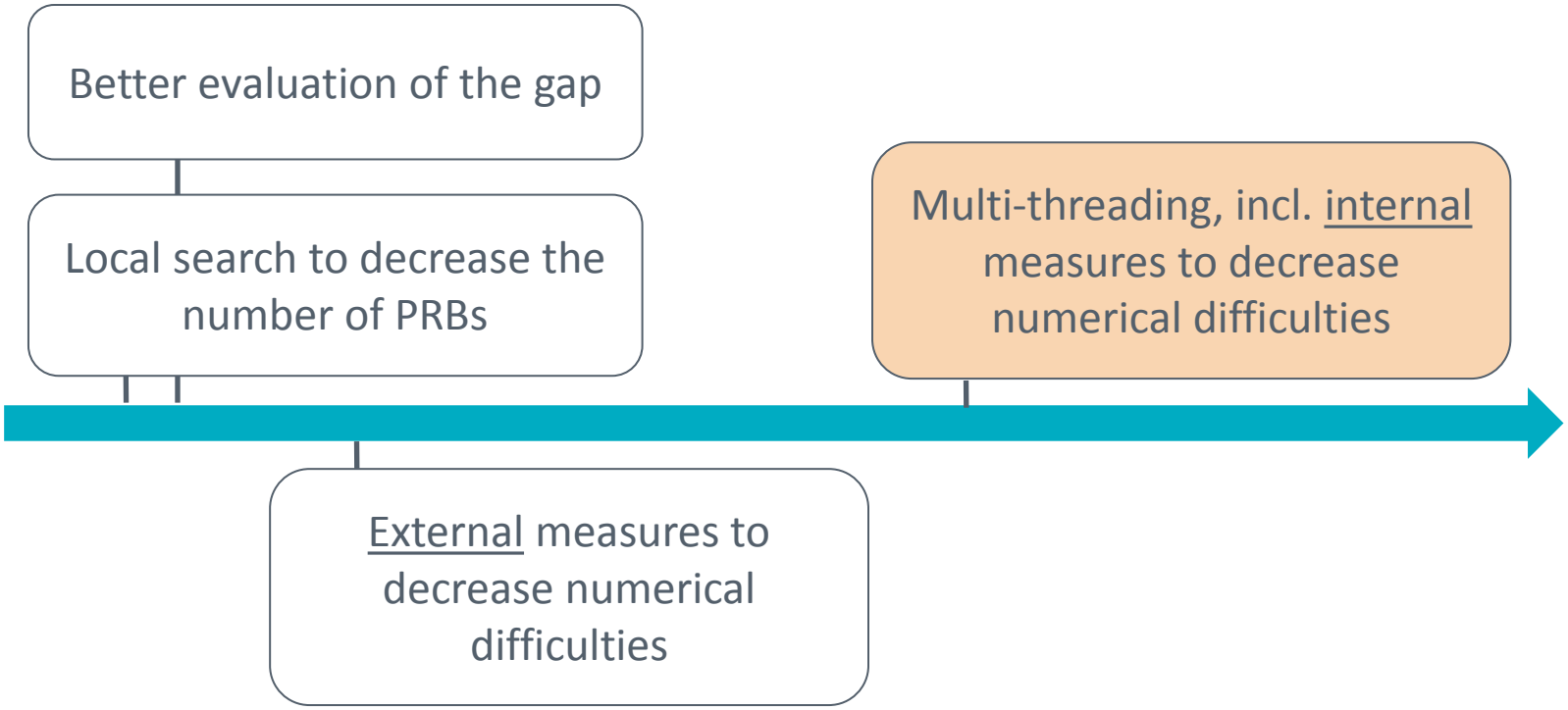


How can we improve the solution?

By improving the PRB reinsertion module (local search)



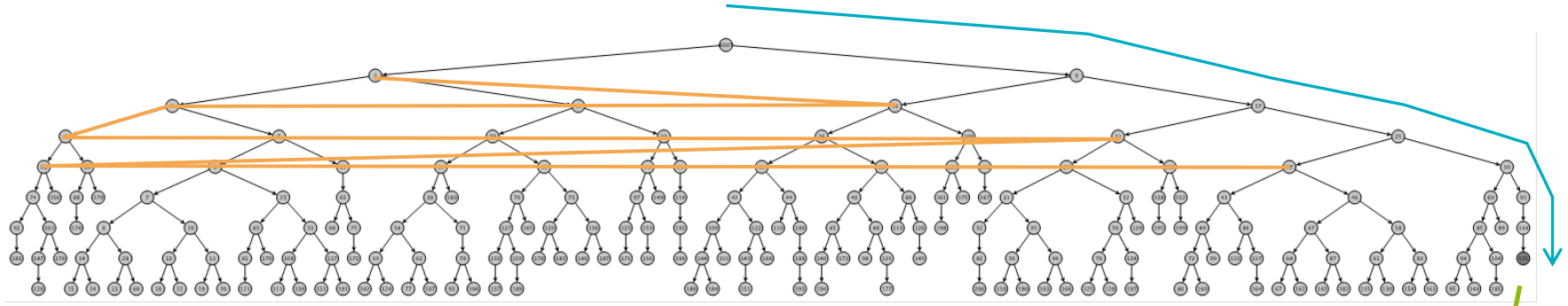
Next main steps to improve performance and quality of solutions



Work plan for Euphemia 10

3 Multi-threading to explore and close the gap

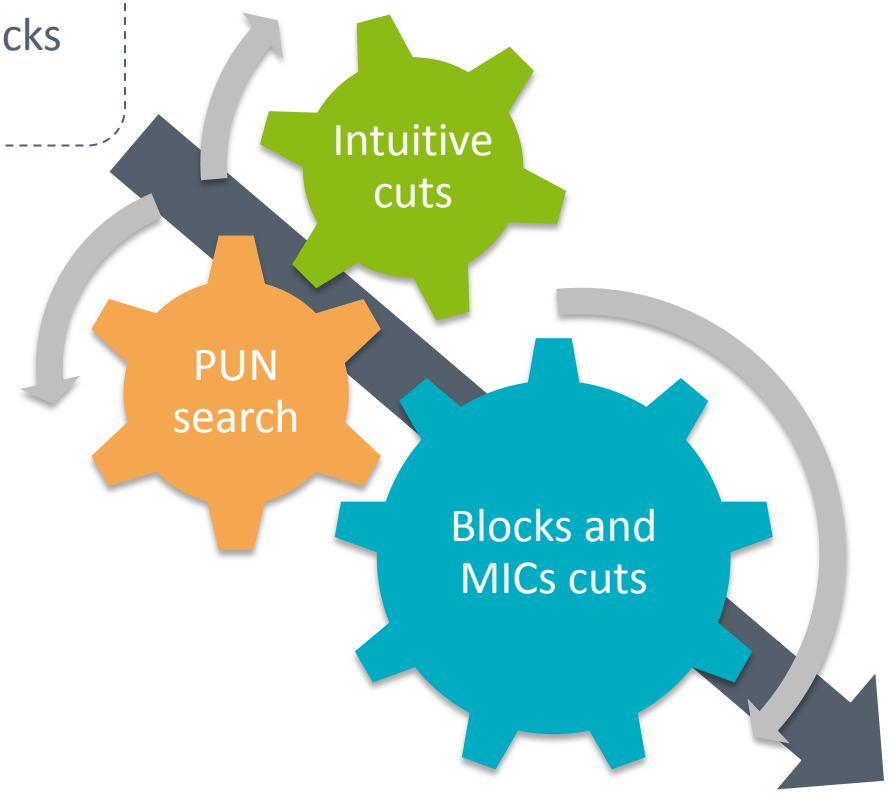
1 Find a valid solution



2 Look for a better solution by local search, attempt to remove PRBs

Feasible solution finder (FSF)

Candidate solution: Selection of blocks and MICs



Euphemia valid solution

N-SIDE
OPTIMIZING YOUR DECISIONS

Local search

The blocks and MICs selection is improved by **simple operations**: swaps, reinsertions, …

Euphemia valid solution

Improved Euphemia valid solution

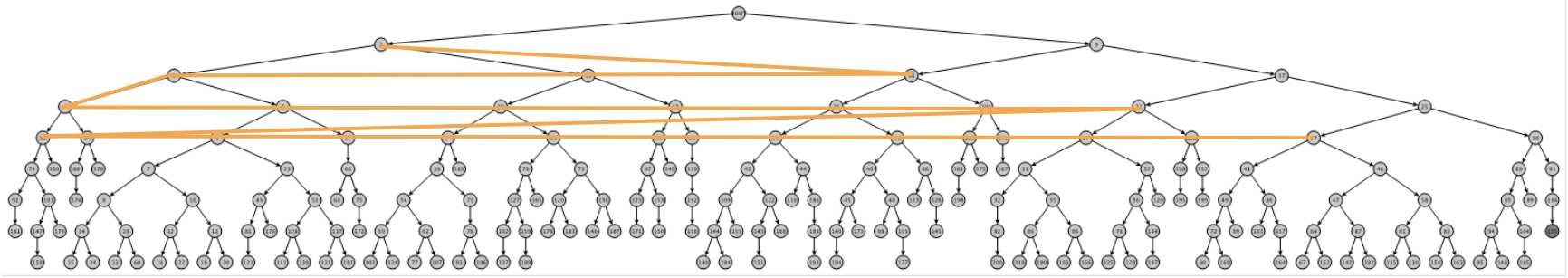
Local search will be applied on each solution returned by the FSF

N-SIDE
OPTIMIZING YOUR DECISIONS

Tree exploration

To reduce the gap, we have to work on the balance between depth and breadth exploration.

Upper bound



Lower bound

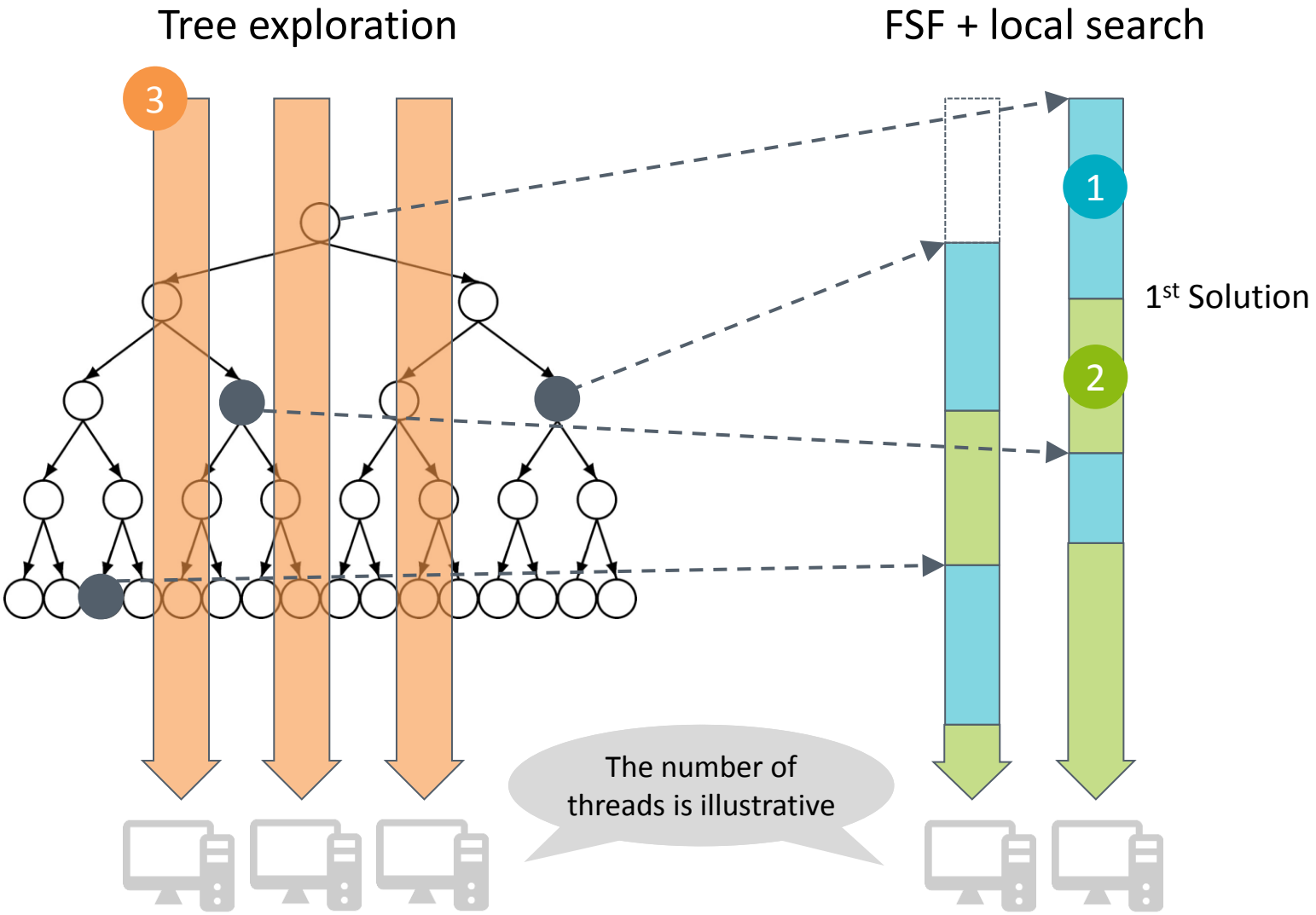
Other interesting candidate solutions will be discovered along the way, and fed to the FSF

N-SIDE
OPTIMIZING YOUR DECISIONS

Where can we benefit from multi-threading?

1. FSF and local search
2.
   - First, applied on the primal problem (root node) to find a first valid solution as soon as possible
   - Then, applied to improve “locally” solutions found in the tree
3. Tree exploration
   - Multiple threads simultaneously processing different nodes, and collaborating to decrease the gap

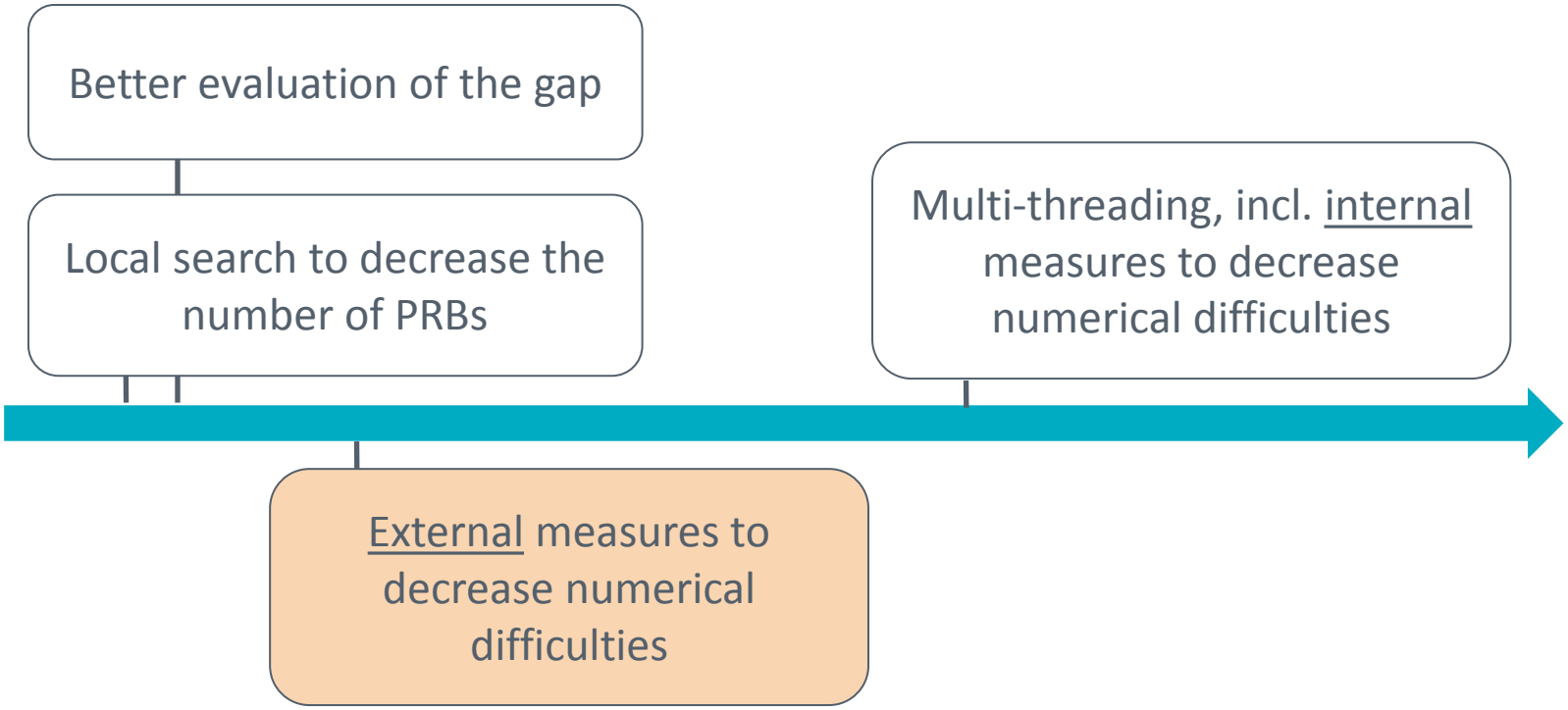
What Euphemia 10 will look like…



How does E10 address our current issues?

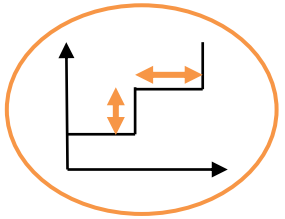
	FSF	Local search	Tree exploration
Solution quality (gap)		✔	✔
Number of PRBs		✔	✔
Numerical difficulties	✔		

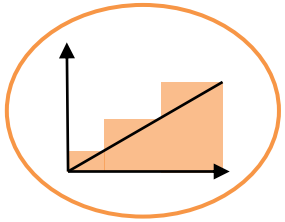
Next main steps to improve performance and quality of solutions

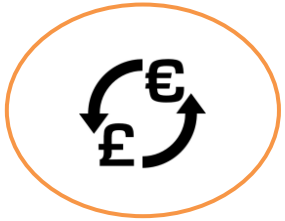


Numerical issues impact the algorithm performances, and its robustness

- Small orders
  - Quantity and /or price difference
- Small slopes for interpolated orders
  - Curve aggregation can increase this issue
  - Hybrid curves with steps and interpolated orders could be a solution
- Lots of decimals
  - Currency conversion







Plan

- For mid 2016:
  - Euphemia 9.4 with Local search to decrease number of PRBs, and other change requests
  - Gap re-evaluation module
- For end 2016:
  - Euphemia 10 with multithreading for more scalability, and yet more provably optimal solutions

Thank you !

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Thank you - Q&A

PCR
PRICE COUPLING OF REGIONS

Supplementary slides

PRICE COUPLING OF REGIONS

Long term improvements

More radical solutions could involve to alter the market design to ease the complexity of the problem.

This could imply at least three possible approaches:

1. Reduce the amount of blocks types and other complex products allowed per participant and market (bidding zones).
2. Reducing the range of products treated in Euphemia
3. Relaxing the linear pricing rule (accept that the result has more than one price per bidding zone and time period)

Following slides gives some more insight in to 2 and 3

PCR
PRICE COUPLING OF REGIONS

Harmonization of products

- **One such product could possibly be the new Thermal Order, modelling a thermal unit**
  - Minimum stable generation (similar to minimum acceptance ratio)
  - Load gradient (similar to complex orders)
  - Start up profile and cost (similar to MIC fixed term)
  - Minimum running time when started, minimum down time
  - Shut down profile (similar to scheduled stop)
  - Must run conditions (capacity not available to the market)
  - Flexible in time (similar to exclusive groups)
  - Variable cost expressed in €/MWh
  - Etc.

- **Caveat**
  - This product may actually bring additional complexity compared to (smart) blocks or MICs.
  - This product would work **only** if 1 Thermal Order would replace multiple blocks.
  - According to our provider the Thermal Order would also need us to consider a more radical market design and pricing regime change (next slide)

Van Vyve model

- An alternate market design is discussed in [2011] *Linear prices for non-convex electricity markets: models and algorithms, M. Van Vyve;*
- It builds on experiences from electricity markets in both US and Europe
- The model drops some of the current requirements in the current market design, and becomes more computationally tractable;
  - The proposal does not respect the CACM one price per bidding zone and time unit requirement
- Preliminary thoughts of our algorithm provider (N-Side) are that such a model could be solved to (near) optimality with a proven optimality gap.
  - If confirmed after extensive modelling and testing in pan-Europe or MRC production like scenarios, this solution could possibly would address the main concerns expressed by Market Parties Platform

Van Vyve model - Caveats

- The proposed model however does introduce a series of significant changes to the current European market design:
  - Out-of-the-money orders can be accepted, i.e. paradoxically accepted orders;
  - These orders could be compensated via “uplifts”: some of the surplus generated by in-the-money orders would be funneled to these loss giving orders.
  - Effectively this is a deviation from the single price per bidding zone and time period requirement of CACM: some orders receive uplifts on top of the clearing price, others pay uplifts on top of the clearing price. The net effect is that different orders pay/receive a different price even when they are in the same Bidding Zone;

PCR
PRICE COUPLING OF REGIONS