cetic

Your Connection to ICT Research

Local search with OscaR.cbls explained to my neighbor

OscaR v3.0 (Sept 2015)

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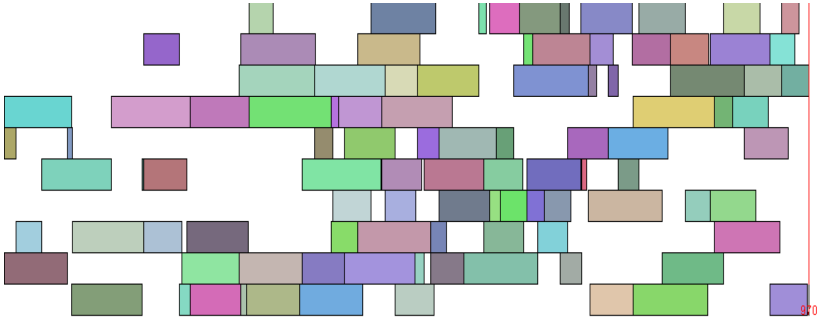
ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR.

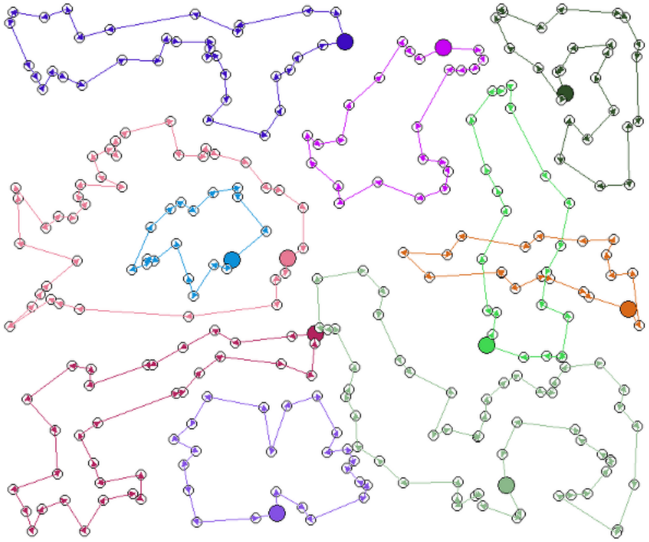
OscaR
OPERATIONAL RESEARCH IN SCALA

What are optimization problems?

- Scheduling
  - Tasks, precedence's
  - Shared resources
  - Deadlines



- Routing
  - Points, vehicles
  - Distance
  - Time windows
  - Minimize overall distance



- In general
  - Find values (possibly “structured values”)
  - Minimizing / optimizing objective (s)
  - Satisfying constraint (s)

OscaR
OPERATIONAL RESEARCH IN SCALA

- Oscar
  - Open source framework for combinatorial optimization
  - CP, CBLS, MIP, DFO engines
- Open source LGPL license
  - https://bitbucket.org/oscarlib/oscar
  - Implemented in Scala
- Consortium
  - CETIC, UCL, N-Side   Belgium
  - Contributions from UPPSALA, Sweden

Why open sourcing this code?

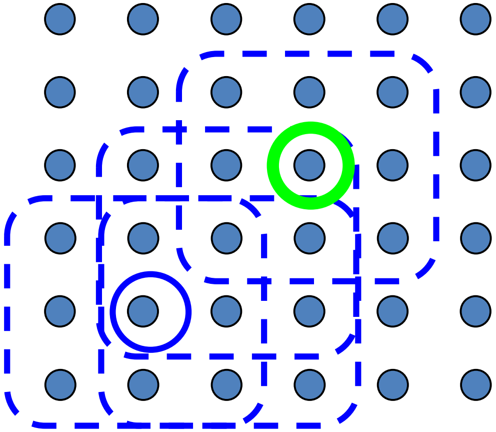
- Higher credibility
  - Since it is very intricate algorithms, customers can look at the quality of the work
  - Being able to look at the commit activity is also a plus for customers
- Easier transfer
- Mutualise extensions between customers
- Attract contributions
  - From external contributors
  - Find internships

Optimization by local search (LS)

- Perform a descend in the solution space; repeatedly move from one solution to a better one
- Next solution identified via neighborhood exploration

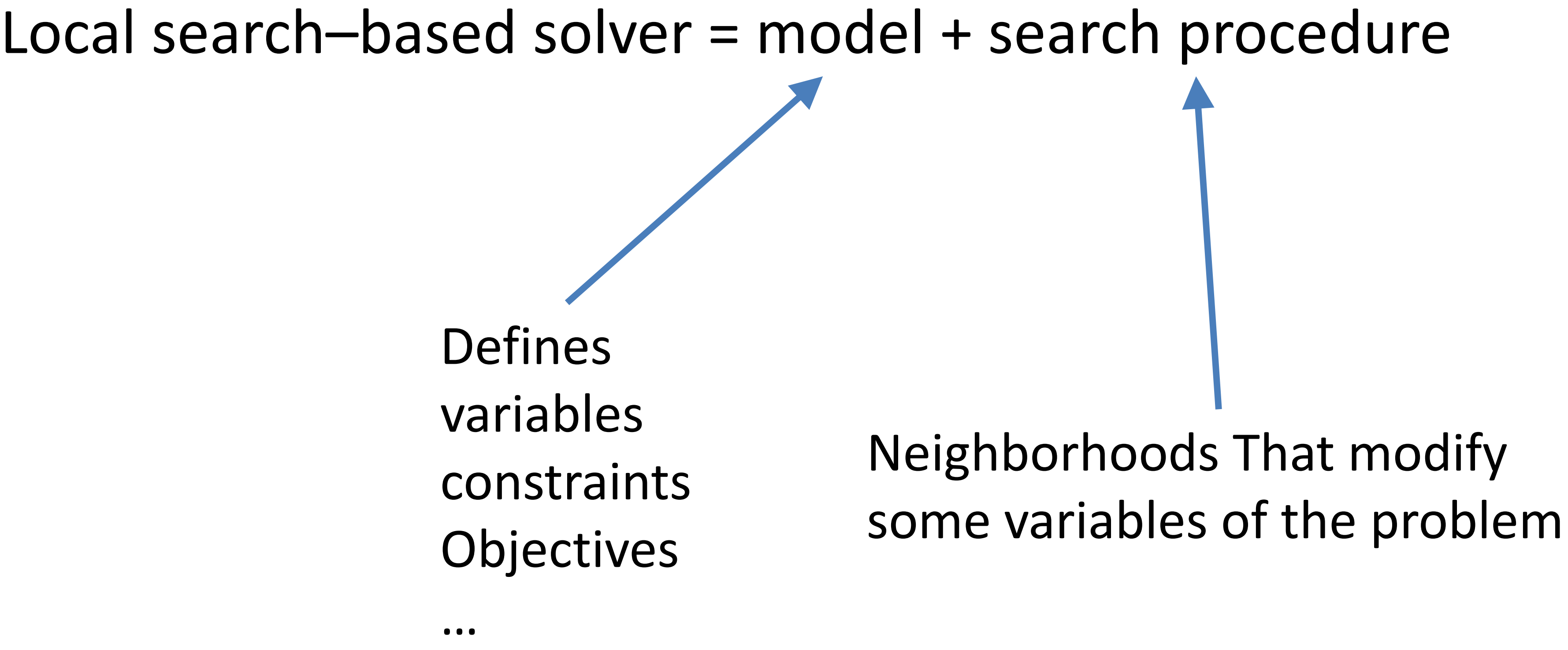
  TSP Example: moving a city to another position in the current circuit

  - Current state: a → b → **c** → d → e → a
  - Moving c gives three neighbors:
    - a → **c** → b → d → e → a
    - a → b → d → **c** → e → a
    - a → b → d → e → **c** → a
  - O(n²) neighbors in total



- Lots of black magic's, to escape from local minima

The basic equation of local search



Local search–based solver = model + search procedure

Defines
variables
constraints
Objectives
…

Neighborhoods That modify
some variables of the problem

Constraint-based local search

- Goal: make it easy to write optimization engine based on the principle of local search

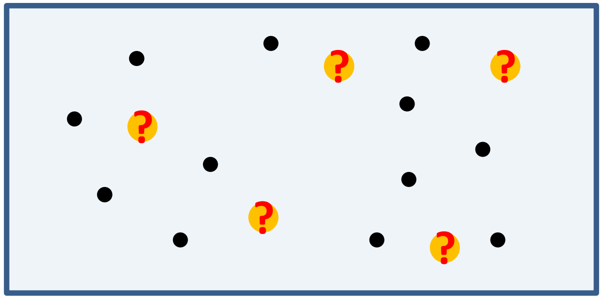
- Approach: Separate the modeling from the search in different component
  - Represent the problem as a large collection of mathematical formulas
  - Evaluate moves on this formula

- Technically:
  - Have an engine to evaluate the formula quickly
  - Based on the fact that very few decision variables are impacted by a move
  - So rely on incremental model updates

The uncapacitated warehouse location problem

- **Given**
  - S: set of stores that must be stocked by the warehouses
  - W: set of potential warehouses
    - Each warehouse has a fixed cost f_w
    - transportation cost from warehouse w to store s is c_{ws}
- **Find**
  - O: subset of warehouses to open
  - Minimizing the sum of the fixed and the transportation cost.

$$\sum_{w \in O} f_w + \sum_{s \in S} \min_{w \in O}(c_{ws})$$



- **Notice**
  - A store is assigned to its nearest open warehouse

A model of the WLP, written with OscaR.cbls

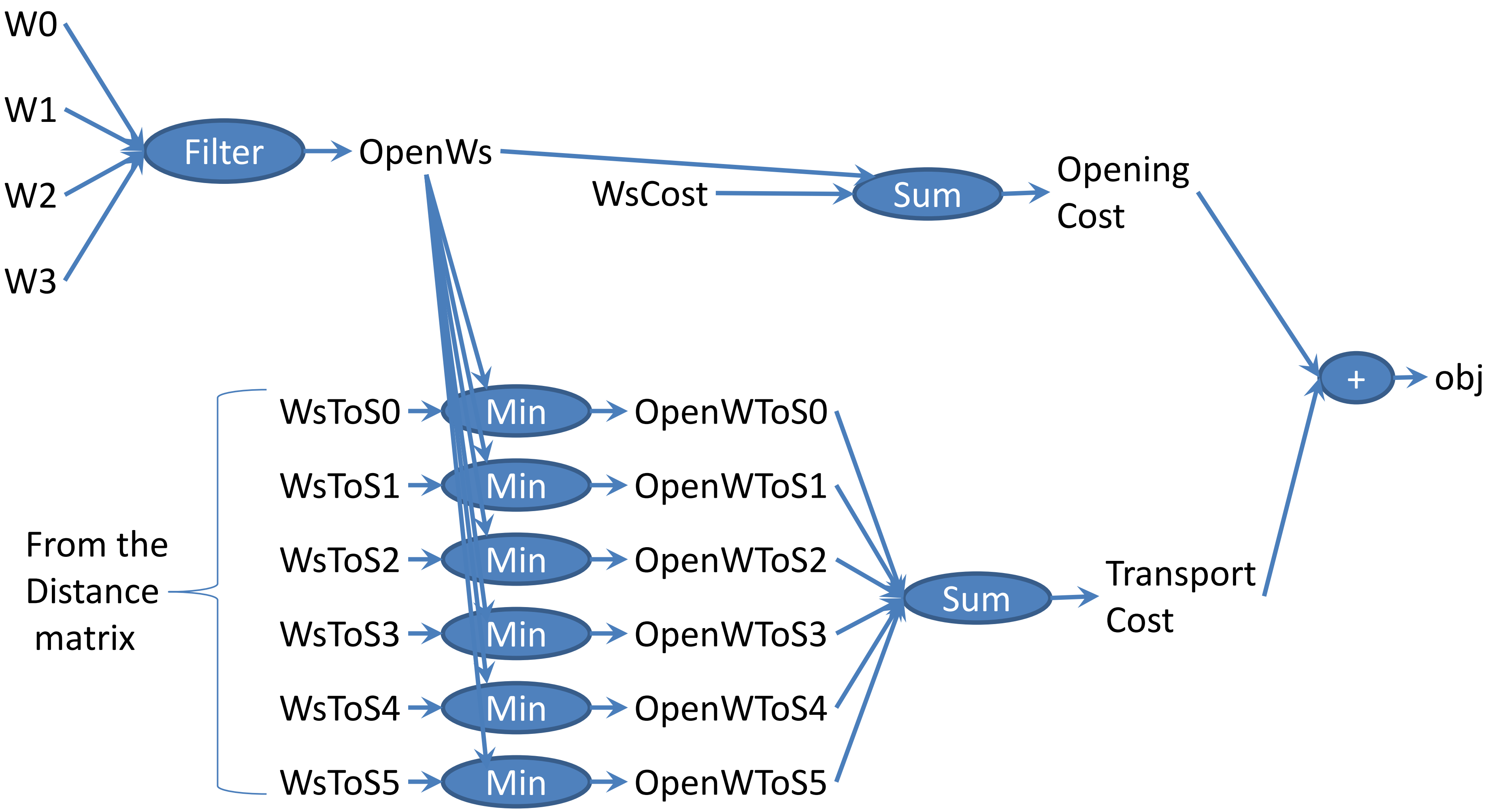
```
val m = new Store()

//An array of Boolean variables representing that the warehouse is open or not
val warehouseOpenArray = Array.tabulate(W)
           (w => CBLSIntVar(m, 0 to 1, 0, "warehouse_" + w + ""))

//The set of open warehouses
val openWarehouses = Filter(warehouseOpenArray)

//for each shop, the distance to the nearest open warehouse
val distanceToNearestOpenWarehouse = Array.tabulate(D)
           (d => Min(distanceCost(d), openWarehouses,
                     defaultCostForNoOpenWarehouse))

//summing up the distances and the warehouse opening costs
val obj = Objective(Sum(distanceToNearestOpenWarehouse)
                     + Sum(costForOpeningWarehouse, openWarehouses))
```

Modeling Support with OscaR

- Two types of variables
  - IntVar and SetVar
- Invariant library (they are functions, actually)
  - Logic, such as:
    - Acces on array of IntVar, SetVar
    - Sort
    - Filter, Cluster (indexes of element whose value is…)
  - MinMax, such as:
    - Min, Max
    - ArgMin, ArgMax
  - Numeric, such as:
    - Sum, Prod, Minus, Div, Abs
  - Set, such as:
    - Inter, Union, Diff, Cardinality

  Summing up to roughly 80 invariants in the library

Propagation graph for the WLP(4,6)



What we can do with a model

- Model has some input variables
  - *warehouseOpenArray*
- We can modify the value of these input variables
- The model is updated through a procedure called *propagation*.
  - *Propagation* is triggered when the value of an output variable is queried, so you always have coherent answers on the model
  - Propagation is very fast, thanks to adequate algorithms and data structures

Let’s play with the model in console

```
>println(openWarehouses)
openWarehouses:={}
>println(obj)
IntVarObjective(Sum2:=1500000)

> warehouseOpenArray(0) := 1
> println(openWarehouses)
openWarehouses:={0}
> println(obj)
IntVarObjective(Sum2:=7849)

> warehouseOpenArray(5) := 1
> println(openWarehouses)
openWarehouses:={0,5}
> println(obj)
IntVarObjective(Sum2:=6024)
```

How the model will help optimizing?

- Model is fit for local search, based on neighborhood exploration
  - Eg: switching one warehouse (open or close it)
- Does a move improve on the objective?
  - Perform the move Eg: switch the warehouse
  - Query the objective value
  - RollBack
  - Methods available in the Objective class perform this

```
//summing up the distances and the warehouse opening costs
val obj = Objective(Sum(distanceToNearestOpenWarehouse)
                           + Sum(costForOpeningWarehouse, openWarehouses))
```

- Neighborhood exploration is fast:
  - Propagation is incremental
  - Propagation is not performed after the rollback
  - Partial propagation: only involves what is needed to evaluate obj

Some Relevant Neighborhoods

- Switching a single warehouse
  - either closing an open warehouse,
    or opening a closed one
  - Size: O(#W)
  - Connected: all solutions are reachable

- Swapping two warehouses
  - close an open warehouse and open a closed one
  - Size: O(#W^2)
  - Not Connected

- Randomization at local minimum
  - Randomize a fraction of the warehouses

How can we assemble these bricks?

Searching the WLP: sample strategy

- Do all switch moves
- Then all the swap moves
- Iterate until no more moves

**We want to try also
the random neighborhood choice**

- Perform some randomization when minimum reached

- Stop criterion: only two randomizations authorized

- Save the best solution at all time,
  and restore it when search is finished

Note: the idea of combining neighborhood is not new (eg. [Glo84], [Ml97], and many papers at MIC)

A WLP solver written with neighborhood combinators

```
val m = new Store()
val warehouseOpenArray = Array.tabulate(W)
              (w => CBLSIntVar(m, 0 to 1, 0, "warehouse_" + w + ""))
val openWarehouses = Filter(warehouseOpenArray)

val distanceToNearestOpenWarehouse = Array.tabulate(D)
              (d => Min(distanceCost(d), openWarehouses,
                            defaultCostForNoOpenWarehouse))

val obj = Objective(Sum(distanceToNearestOpenWarehouse)
                            + Sum(costForOpeningWarehouse, openWarehouses))

m.close()

val neighborhood = (AssignNeighborhood(warehouseOpenArray, "SwitchWarehouse")
                exhaustBack SwapsNeighborhood(warehouseOpenArray, "SwapWarehouses")
                orElse (RandomizeNeighborhood(warehouseOpenArray, W/5) maxMoves 2)
                saveBestAndRestoreOnExhaust obj)

val it = neighborhood.doAllMoves(obj)
```

The console output

```
WarehouseLocation(W:15, D:150)
SwitchWarehouse(warehouse_0:=0 set to 1; objAfter:7052)            - #
SwitchWarehouse(warehouse_1:=0 set to 1; objAfter:5346)            - #
SwitchWarehouse(warehouse_2:=0 set to 1; objAfter:4961)            - #
SwitchWarehouse(warehouse_3:=0 set to 1; objAfter:4176)            - #
SwitchWarehouse(warehouse_4:=0 set to 1; objAfter:3862)            - #
SwitchWarehouse(warehouse_9:=0 set to 1; objAfter:3750)            - #
SwitchWarehouse(warehouse_12:=0 set to 1; objAfter:3620)           - #
SwitchWarehouse(warehouse_0:=1 set to 0; objAfter:3609)            - #
SwapWarehouses(warehouse_0:=0 and warehouse_4:=1; objAfter:3572)   - #
SwapWarehouses(warehouse_1:=1 and warehouse_6:=0; objAfter:3552)   - #
SwapWarehouses(warehouse_0:=1 and warehouse_1:=0; objAfter:3532)   - #
SwitchWarehouse(warehouse_7:=0 set to 1; objAfter:3528)            - #
RandomizeNeighborhood(warehouse_12:=1 set to 0, warehouse_
SwitchWarehouse(warehouse_7:=0 set to 1; objAfter:3656)            -
SwapWarehouses(warehouse_12:=0 and warehouse_13:=1; objAfter:3528) - °
RandomizeNeighborhood(warehouse_14:=0 set to 1, warehouse_
SwitchWarehouse(warehouse_7:=0 set to 1; objAfter:3907)            -
SwitchWarehouse(warehouse_12:=1 set to 0; objAfter:3882)           -
SwitchWarehouse(warehouse_13:=1 set to 0; objAfter:3862)           -
SwitchWarehouse(warehouse_14:=1 set to 0; objAfter:3658)           -
SwitchWarehouse(warehouse_12:=0 set to 1; objAfter:3528)           - °
MaxMoves: reached 2 moves
openWarehouses:={1,2,3,6,7,9,12}
```

Three shades of Warehouse Location

- The presented one:

```
val neighborhood = (AssignNeighborhood(warehouseOpenArray, "SwitchWarehouse")
                exhaustBack SwapsNeighborhood(warehouseOpenArray, "SwapWarehouses")
                orElse (RandomizeNeighborhood(warehouseOpenArray, W/5) maxMoves 2)
                saveBestAndRestoreOnExhaust obj)
```

- Chosing the neighborhood randomly

```
val neighborhood = (AssignNeighborhood(warehouseOpenArray, "SwitchWarehouse")
                random SwapsNeighborhood(warehouseOpenArray, "SwapWarehouses")
                orElse (RandomizeNeighborhood(warehouseOpenArray, W/5) maxMoves 2)
                saveBestAndRestoreOnExhaust obj)
```

- Learning about neighborhood efficiency

```
val neighborhood = (AssignNeighborhood(warehouseOpenArray, "SwitchWarehouse")
                learningRandom SwapsNeighborhood(warehouseOpenArray, "SwapWarehouses")
                orElse (RandomizeNeighborhood(warehouseOpenArray, W/5) maxMoves 2)
                saveBestAndRestoreOnExhaust obj)
```

Conclusion: Features of Oscar.cbls

- Modeling part: Rich modeling language
  - IntVar, SetVar
  - 80 invariants: Logic, numeric, set, min-max, etc.
  - 17 constraints: LE, GE, AllDiff, Sequence, etc.
  - Constraints can attribute a violation degree to any variable
  - Model can include cycles
  - Fast model evaluation mechanism
    - Efficient single wave model update mechanism
    - Partial and lazy model updating, to quickly explore neighborhoods
- Search part
  - Library of standard neighborhoods
  - Combinators to define your global strategy in a concise way
  - Handy verbose and statistics feature, to help you tuning your search
- Business packages: Routing, scheduling
  - Model and neighborhoods
- FlatZinc Front End [Bjö15]
- 27kLOC

To some extend, brain cycle is more valuable than CPU cycle (1/2)

- *Why don't you use C with templates, and compile with gcc –o3? You would be 2 times faster!*

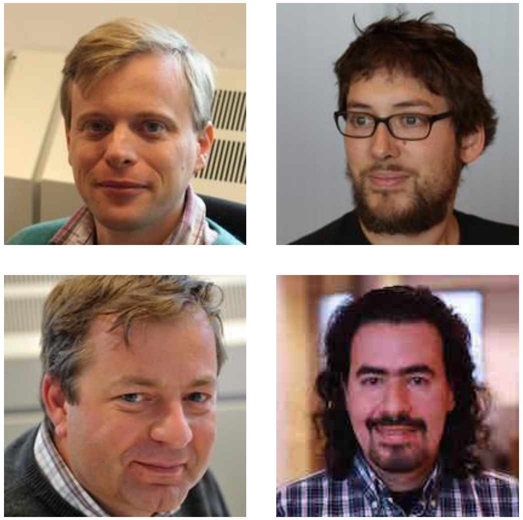
- *Why should I use your stuff? I can program a dedicated solver that will run 2 times faster because it will not need the data structures you need in OscaR*

To some extend, brain cycle is more valuable than CPU cycle (2/2)

- That is true, but
  - – Algorithmic tunings deliver more than 2 to 4!
    - Ex: We lately had a speedup 10 by tuning a search procedure
    - Using symmetry elimination on neighborhoods
    - Restricting your neighborhood to relevant search zones
  - – Our approach cuts down dev cost, so you have time to focus on these high-level tunings.
    - Since budget is always limited
  - – Next step: parallel propagation
    - So you will have the same “basic speed” than a dedicated implem, by using more cores
    - A core is cheaper than a single day of work for an engineer

Who is behind OscaR.cbls?

- CETIC team
  - Renaud De Landtsheer
  - Yoann Guyot
  - Christophe Ponsard
  - Gustavo Ospina
- Contributions from Uppsala
  - Jean-Noël Monette
    - Gustav Björdal



Where is OscaR?

- Repository / source code
  - https://bitbucket.org/oscarlib/oscar/wiki/Home
- Released code and documentation
  - https://oscarlib.bitbucket.org/
- Discussion group / mailing list
  - https://groups.google.com/forum/?fromgroups#!forum/oscar-user

Thank you
Merci

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