Parallel Cooperative Optimization ***Research Group***

Reusable design of single solution-based metaheuristics

Laboratoire d'Informatique Fondamentale de Lille

The main steps to build a Solution-based metaheuristic

- Always:
  - The neighborhood/the moves and some operators to manages it/them,
  - The way to initialize the starting condition.
- Specialist:
  - Neighborhood selection strategy,
  - Cooling schedule,
  - Tabu list, …
  - The continuation criterion.

Framework and tutorial application

- A framework for the design of Local Searches (Hill Climbing, Simulated Annealing and Tabu Search):
  → Moving Objects (MO).

- Tutorial application:
  → The Traveling Salesman Problem (TSP).

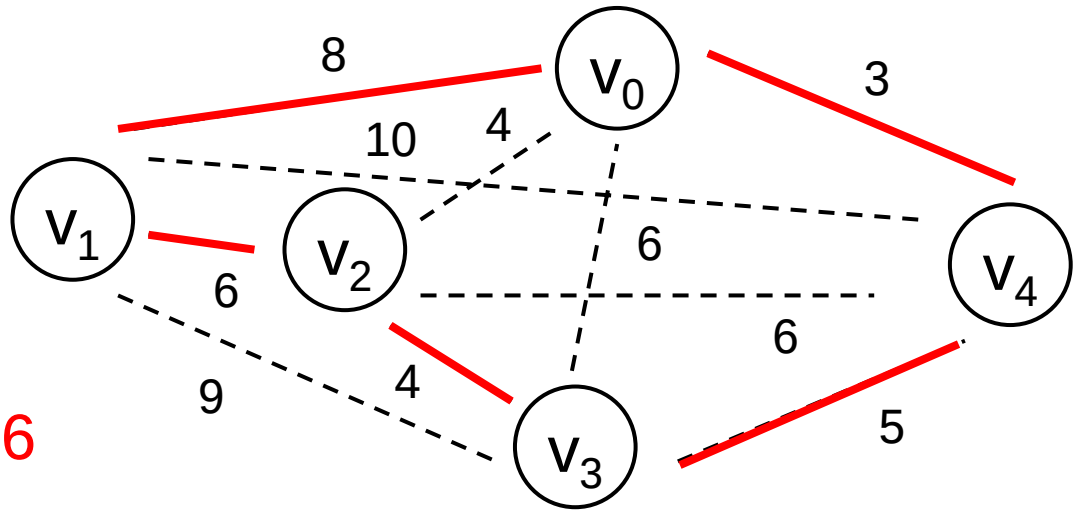
Moving Objects (MO)

- A framework that extends the EO library in order to design solution-based meta-heuristics.

- Design/development team:
  - S. Cahon, N. Melab and E-G Talbi (OPAC-LIFL).

Application to the Traveling Salesman Problem (TSP)

- "Given a collection of N cities and the distance between each pair of them, the **TSP** aims at finding the shortest route visiting all of the cities".
- Symmetric TSP.
- Example:



Length: 26

Common features

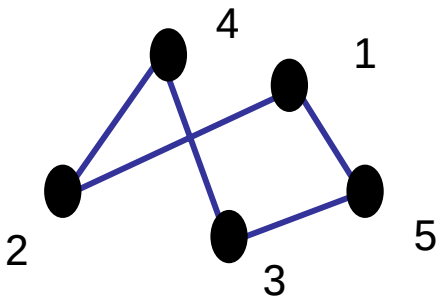
Designing the neighborhood

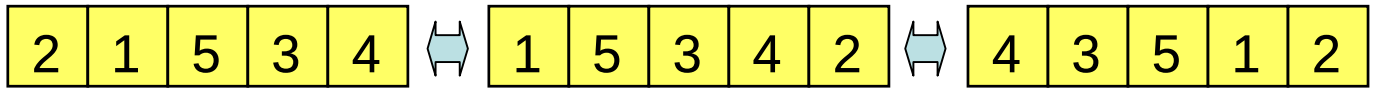
- It is strongly dependant of the representation of the solution !
- The nature of the landscape depends on it.
- Issues:
  - Moves that imply minor changes are preferred,
  - Fitness delta should be easily and efficiently computed,
  - Analysis of complexity (i.e. size of the neighborhood).

Application to the TSP

- Reminding the chosen coding.

→ Ordered sequence of visited vertices.





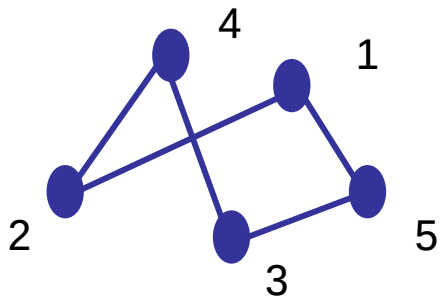
- Some relevant moves:
  - Two-opt, City-swap, LK, etc…

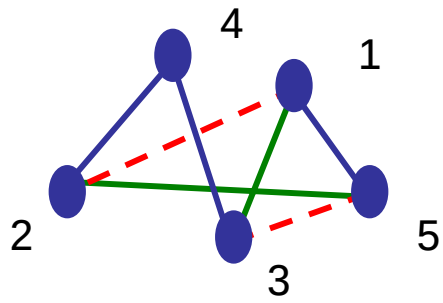
Two-Opt

- Two points within the string are selected and the segment between them is inverted. This operator put in two new edges in the tour.

2	1	5	3	4

2	5	1	3	4





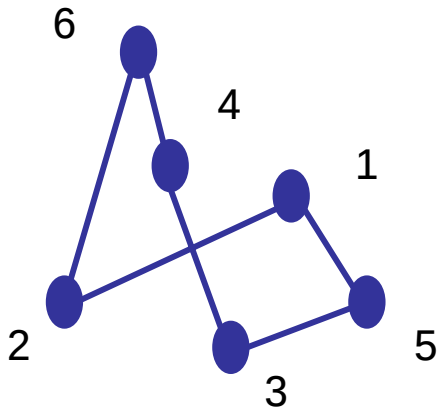
$$\text{Delta} = -d(2,1) - d(5,3) + d(2,5) + d(1,3)$$

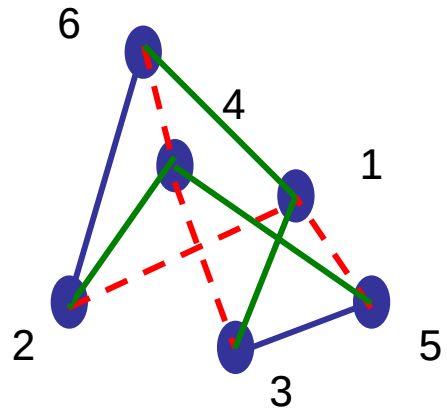
City-Swap

- The values contained in two positions are exchanged, thus introducing four new edges in the string.

2	1	5	3	4	6

2	4	5	3	1	6





Delta = - d(2,1) – d(1,5) - d(3, 4) - d(4, 6)
+ d(2,4) + d(4,5) + d(3,1) + d(1,6)

It is known less efficient than City-swap for many instances !

Strategies for the starting solution (to improve)

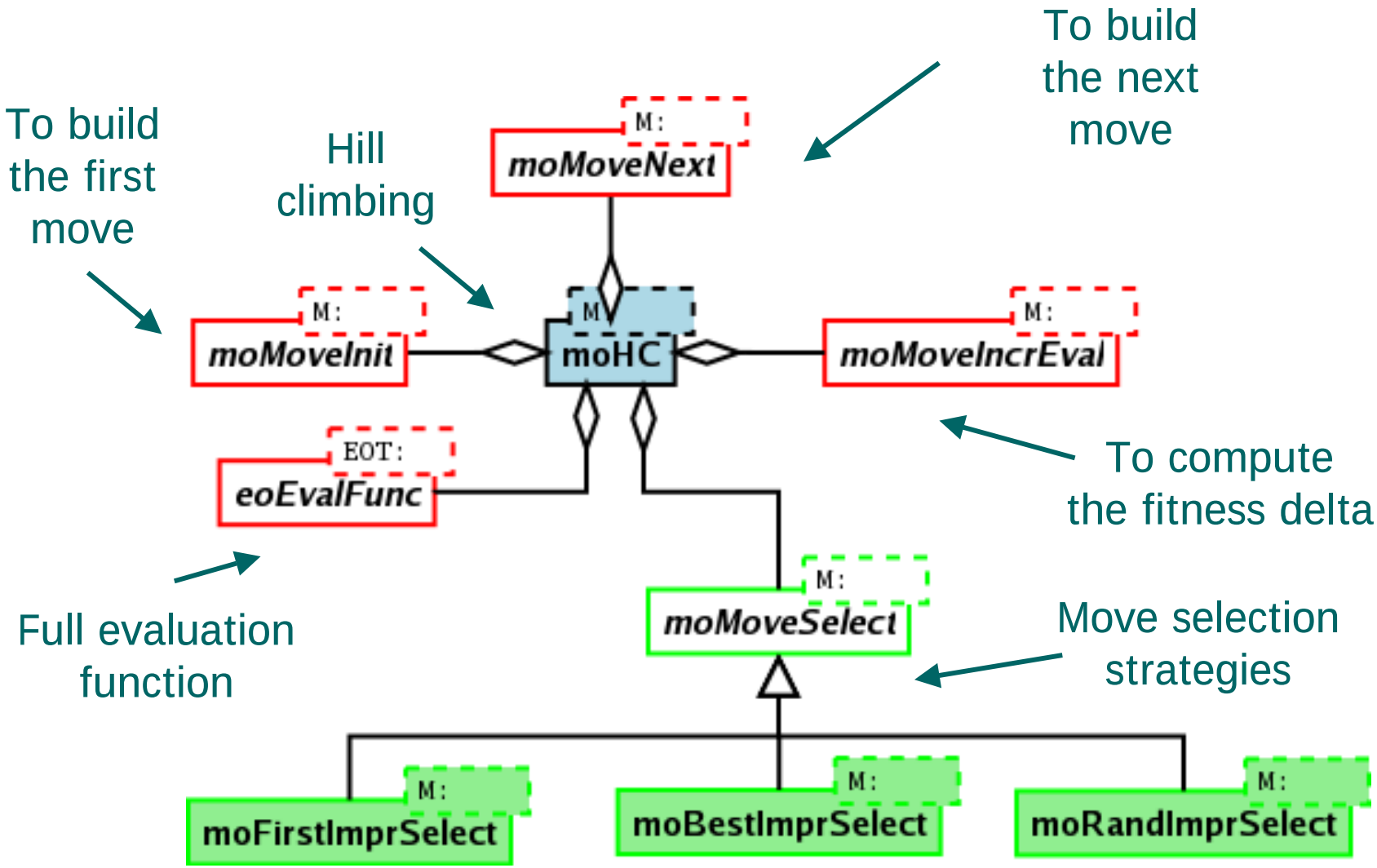
- Two main used cases in practice:
  - A randomly generated initial solution,
  - A solution built by another metaheuristic (greedy algorithm, genetic algorithm, …).

Hill Climbing

How to build a Hill Climbing ?

- Design a move operator, its features.
- Design/implement the operator to build the first move (and implicitly the first neighboring candidate).
- Design/implement the operator to update a given move to its successor.
- Design/implement the incremental evaluation function.
- Chose the neighbour selection strategy.
- No continuation criterion (stopping as a local optima is reached).

Core classes

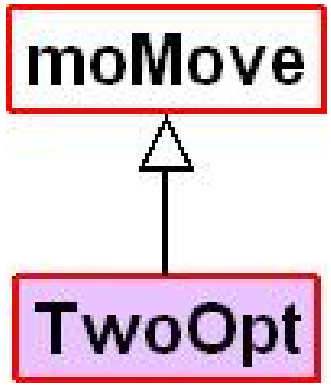


The Two-Opt move

- A Two-opt move is a couple of positions in the sequence of visited nodes.

```
class TwoOpt : public moMove <Route>, public std :: pair <unsigned, unsigned> {

public :

  void operator () (Route & __route);

} ;
```

To be implemented

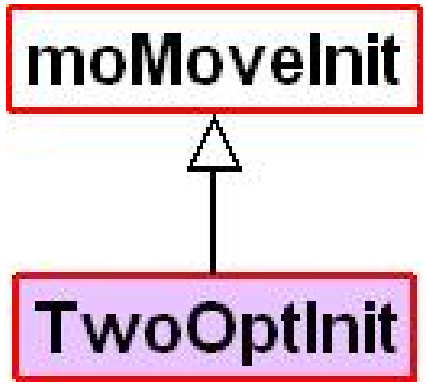


The Two-Opt move initializer

- It initializes both positions to zero !

```
class TwoOptInit : public moMoveInit <TwoOpt> {

public :

  void operator () (TwoOpt & __move, const Route & __route) ;
} ;
```

To be implemented



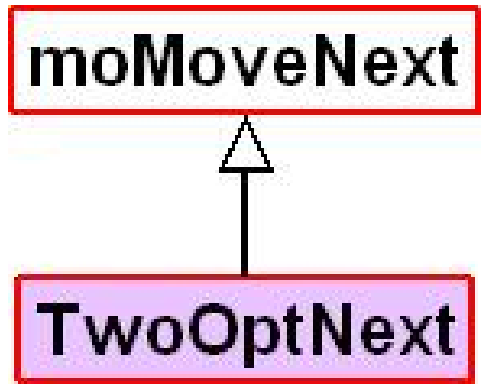
The Two-Opt move updater

- It increments the second position if possible. Else, it increments the first position, and reinitializes the second position.

```
class TwoOptNext : public moMoveNext <TwoOpt> {

public :

  bool operator () (TwoOpt & __move, const Route & __route) ;
} ;
```

To be implemented

Succeeding in building the next move



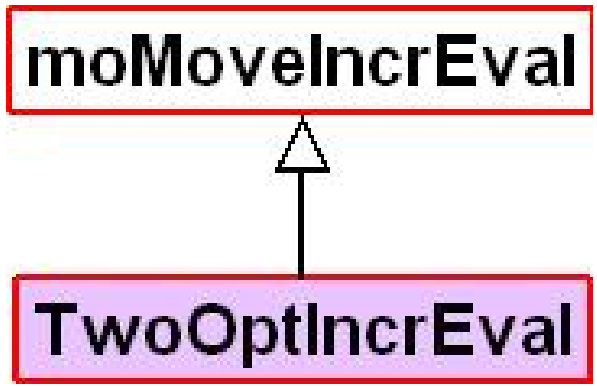
The Two-Opt move incremental evaluation function

- It computes the new length from the costs of the added/removed edges.

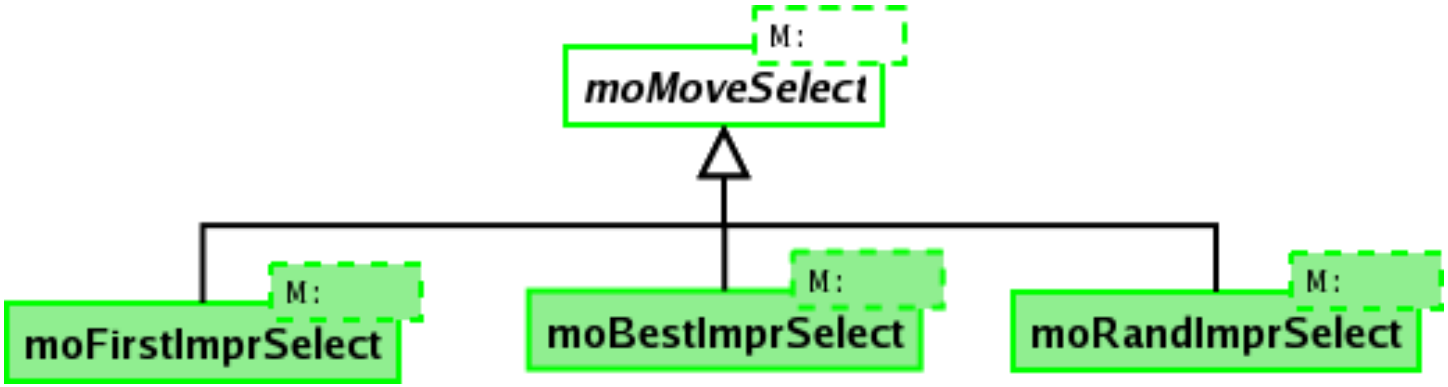
```
class TwoOptIncrEval : public moMoveIncrEval <TwoOpt> {

public :

  int operator () (const TwoOpt & __move, const Route & __route) ;
} ;
```

New length

To be implemented



Neighbour selection strategy



- Deterministic/full: choosing the best neighbor (i.e. that improves the most the cost function).
- Deterministic/partial: choosing the first processed neighbour that is better than the current solution.
- Stochastic/full: processing the whole neighborhood and applying a random better one.

Implementation of a Hill Climbing

```
Route route; /* One solution */
RouteInit route_init; /* Its builds random routes */
route_init (route); /* Building a random starting solution */

RouteEval full_route_eval; /* Full route evaluator */

TwoOptInit two_opt_init; /* Initializing the first couple of edges to swap */
TwoOptNext two_opt_next; /* Updating a movement */
TwoOptIncrEval two_opt_incr_eval; /* Efficiently evaluating a given neighbor */

moBestImprSelect <TwoOpt> two_opt_move_select; /* Movement selection
                                                  strategy (elitist) */

/* Building the Hill Climbing from those components */
moHC <TwoOpt> hill_climbing (two_opt_init, two_opt_next, two_opt_incr_eval,
two_opt_move_select, full_route_eval);

/* It applies the HC to the solution */
 hill_climbing (route);
```

Simulated Annealing

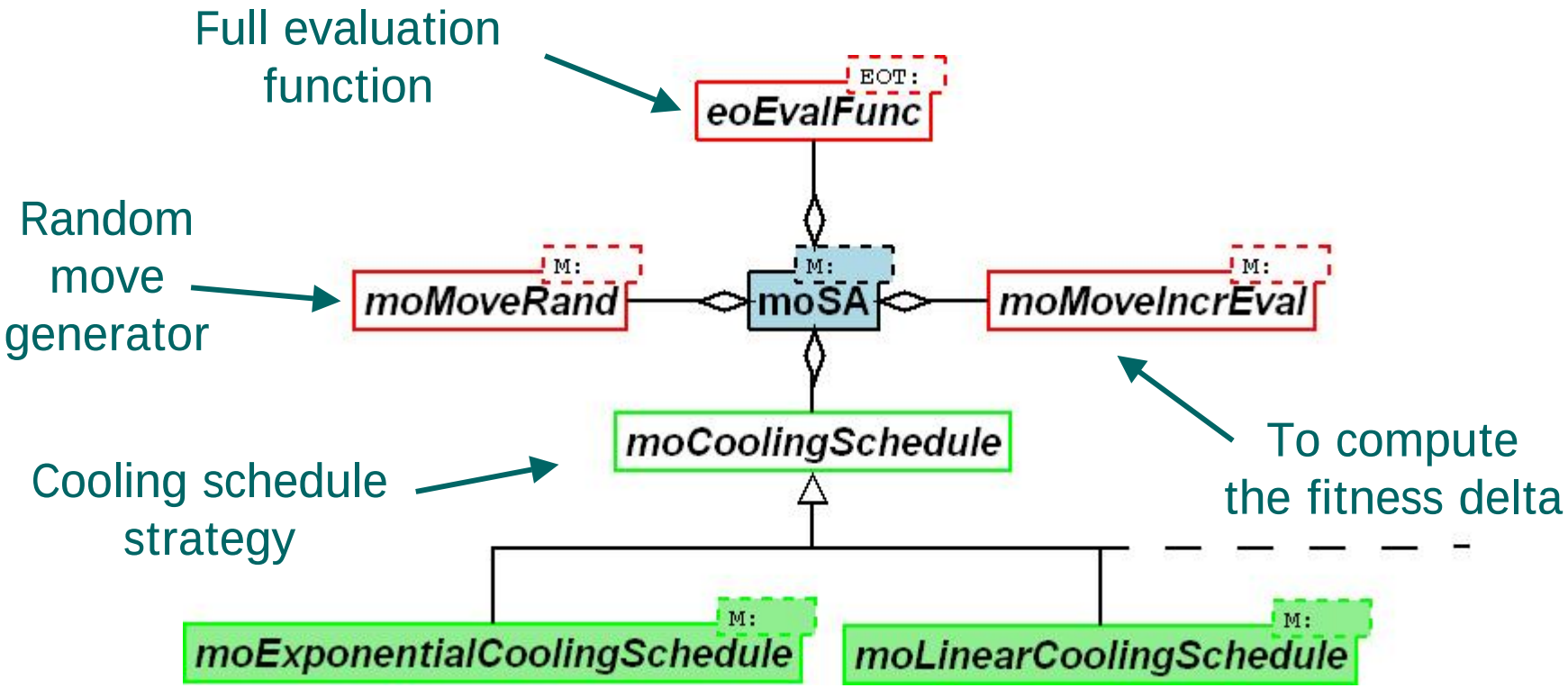
How to build a Simulated Annealing ?

Could be reused from Hill Climbing

- Design a move operator, its features
- Design/implement the operator to build a random candidate move
- Design/implement the incremental evaluation function
- Chose the cooling schedule strategy

Independent of the tackled problem

Core classes

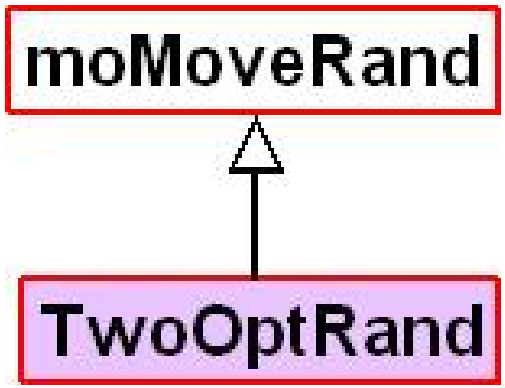


The Two-Opt random move generator

- It randomly determines a couple of random positions !

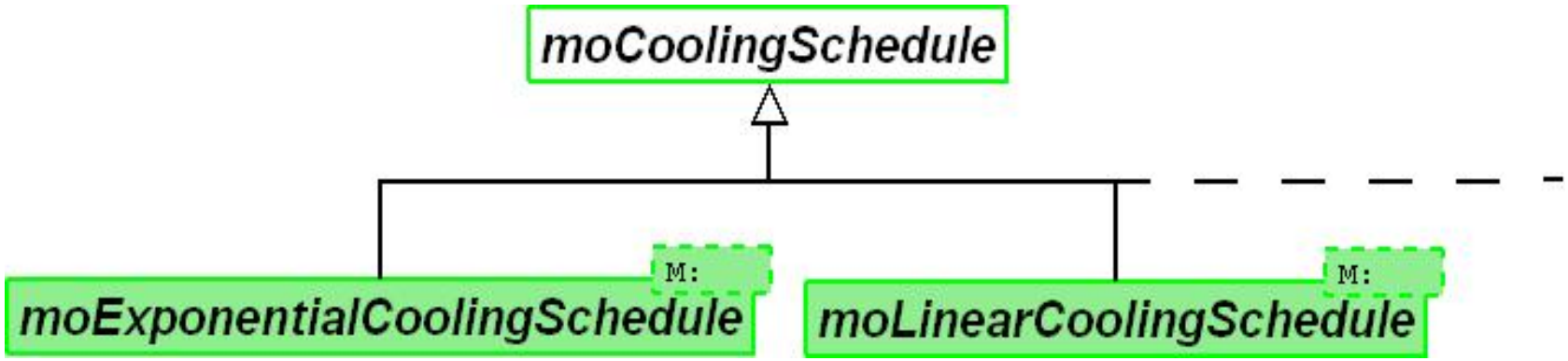
```
class TwoOptRand : public moMoveRand<TwoOpt> {

public :

  void operator () (TwoOpt & __move, const Route & __route) ;
} ;
```

To be implemented



Cooling Schedule

- Two (basic) strategies are already implemented: linear and exponential:
  - Linear ⇔ *temp=temp – x.*
  - Exponential ⇔ t*emp=temp * x.*



Implementation of Simulated Annealing

```
RouteInit route_init; /* Its builds random routes */
route_init (route); /* Building a random starting solution */

RouteEval full_route_eval; /* Full route evaluator */

TwoOptRand two_opt_rand; /* It builds random candidate movements */
TwoOptIncrEval two_opt_incr_eval; /* Efficiently evaluating a given neighbor */

moExponentialCoolingSchedule cool_scheme (0.99, 1); /*Cooling schedule and
                                                      associated parameters */
```

Factor and threshold

```
/* Building the Simulated Annealing from those components */
moSA <TwoOpt> simulated_annealing (two_opt_init, two_opt_incr_eval, 100,
100, cool_scheme, full_route_eval);

/* It applies the SA to the solution */
 simulated_annealing (route);
```

Init. Temp and number of iter. At any step

Tabu Search

How to design a Tabu Search

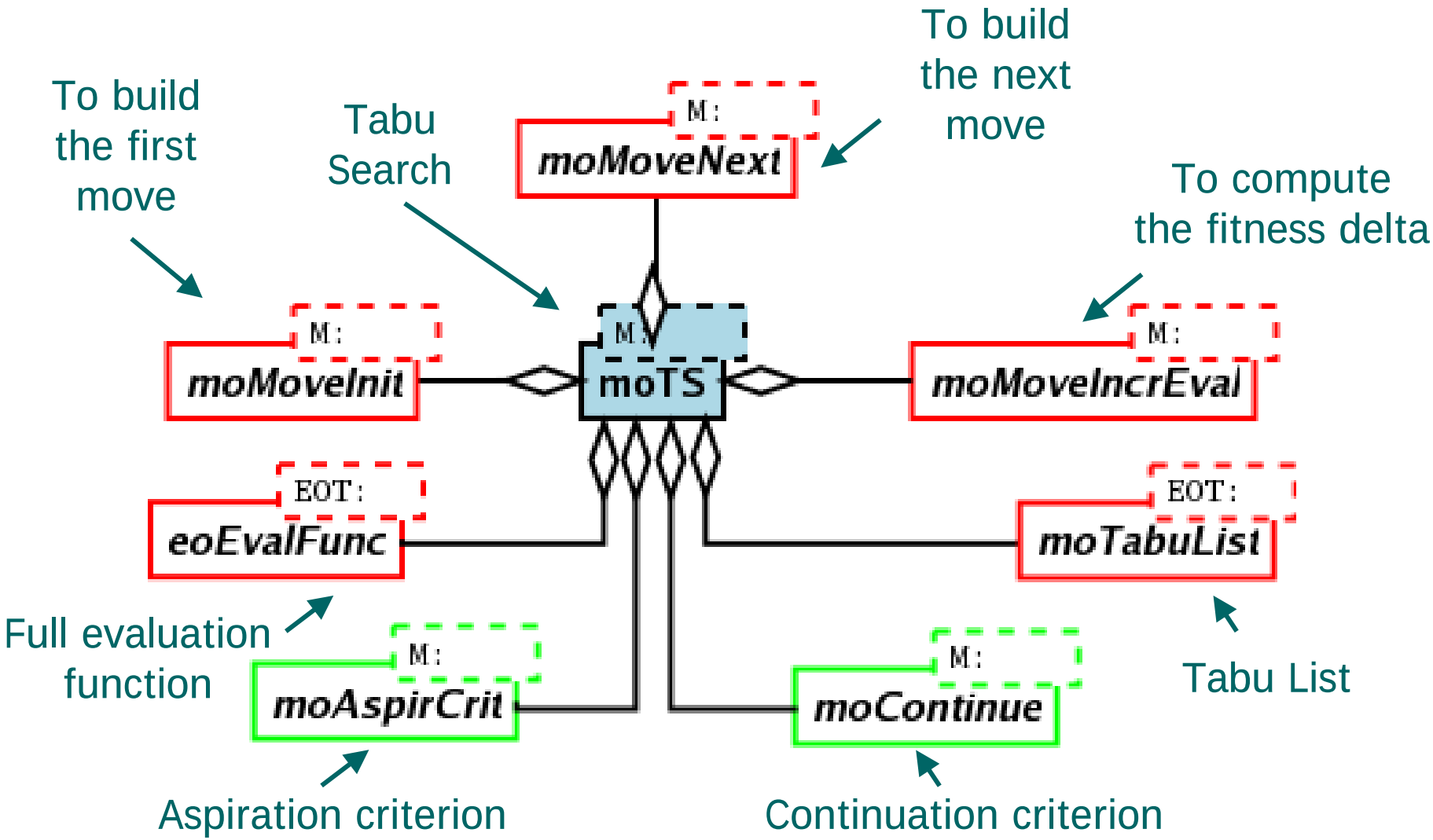
- Design a move operator, its features
- Design/implement the operator to build the first move (and implicitly the first neighboring candidate)
- Design/implement the operator to update a given move to its successor
- Design/implement the incremental evaluation function

Could be reused from Hill Climbing

- Design/implement the Tabu List
- Choose the aspiration criterion
- Choose the continuation criterion

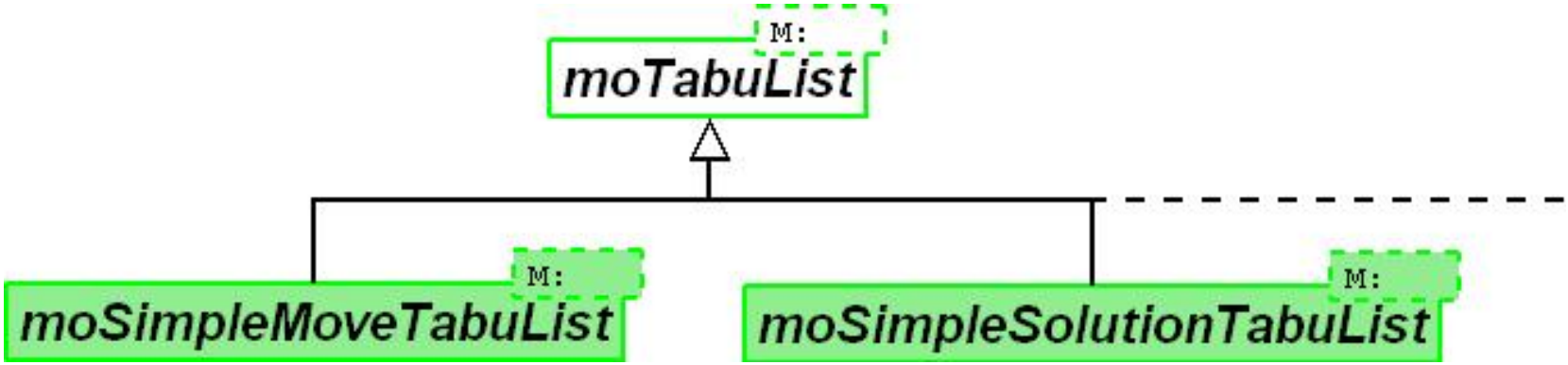
Independent of the tackled problem

Core classes



Designing/implementing the Tabu List (1/2)

- Predefined structures:
  - List of tabu solutions or tabu moves storing the tenure (short term memory).



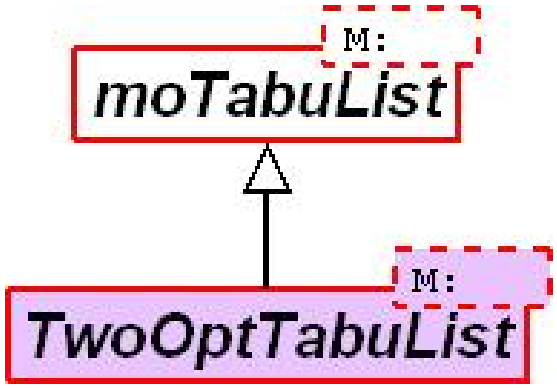
Designing/implementing the Tabu List (2/2)

- Regards the two-opt in TSP, it is preferred to build another efficient and more adapted structure.

```
class TwoOptTabuList : public moTabuList <TwoOpt> {

public :

  int operator () (const TwoOpt & __move, const Route & __route) ;
} ;
```

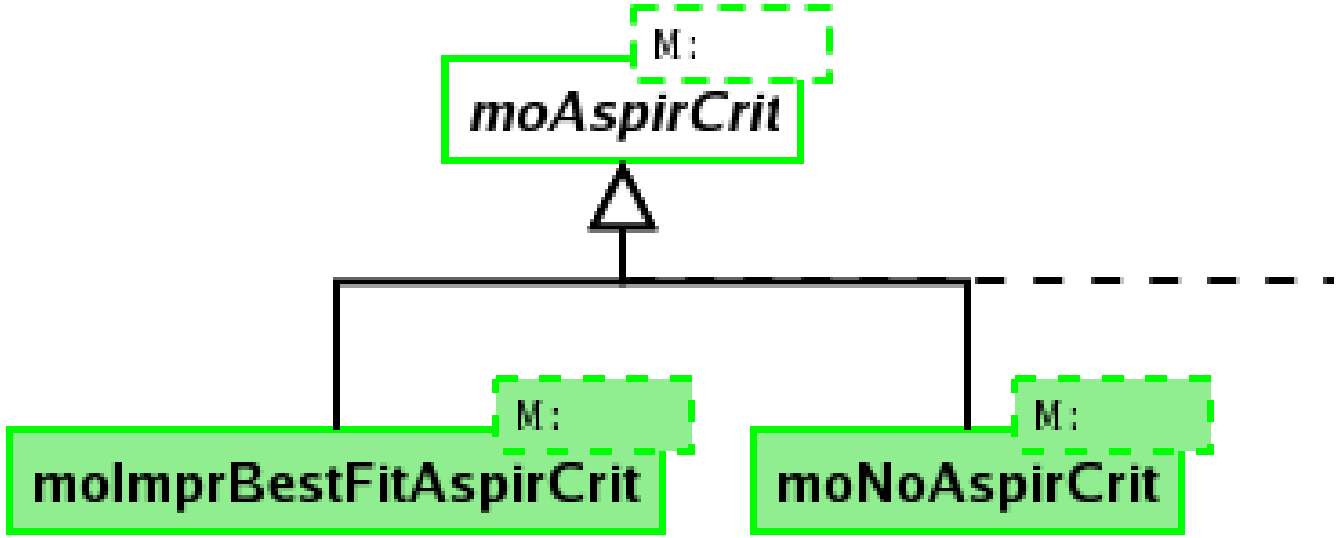
New length

To be implemented

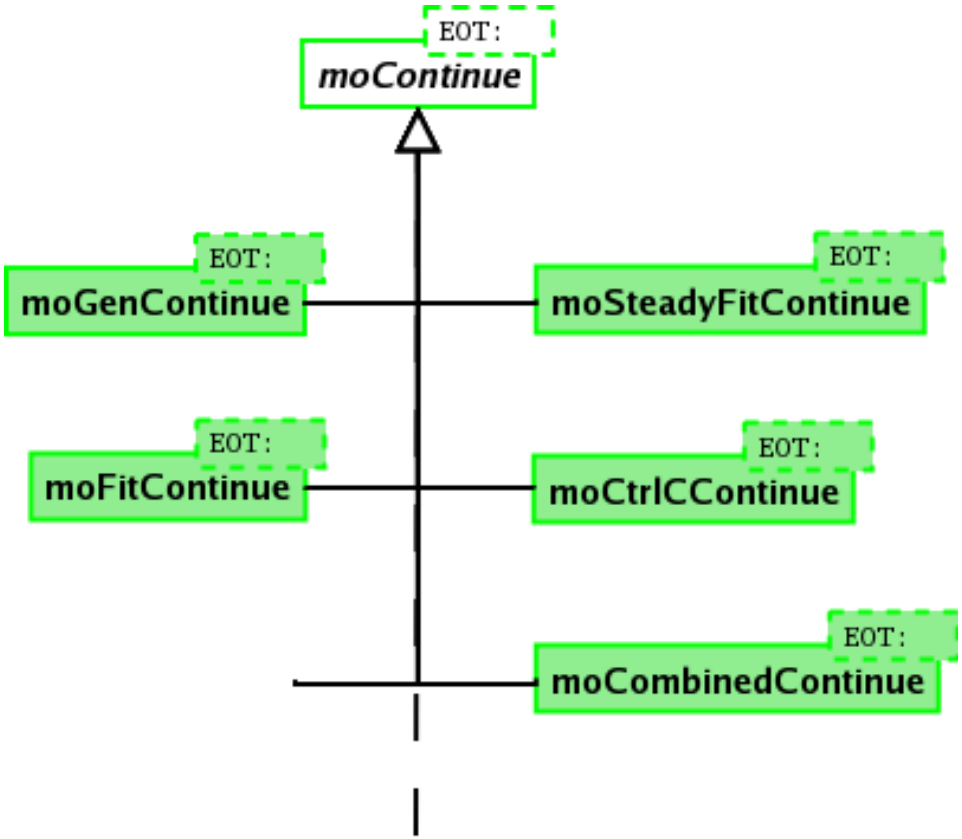


Choosing an aspiration criterion (1/2)

- (Basic) implemented strategies
  - No aspiration criterion,
  - A tabu move builds a new solution that updates the best solution found during the search.



Choosing a continuation criterion (2/2)



- Same strategies as those provided in the design of an Evolutionary Algorithm
  - An optimum is reached,
  - A given total number of iterations,
  - A given number of gen. without improvement,
  - …

Implementing a Tabu Search

```
Route route; /* One solution */
RouteInit route_init; /* Its builds random routes */
route_init (route); /* Building a random starting solution */

RouteEval full_route_eval; /* Full route evaluator */

TwoOptInit two_opt_init; /* Initializing the first couple of edges to swap */
TwoOptNext two_opt_next; /* Updating a movement */
TwoOptIncrEval two_opt_incr_eval; /* Efficiently evaluating a given neighbor */

moNoAspirCrit <TwoOpt> two_opt_aspir_crit; /* Aspiration criterion */
TwoOptTabuList <TwoOpt> two_opt_tabu_list; /* Tabu List */

moGenContinue <TwoOpt> cont (10000); /* A fixed number of iter. */

/* Building the Tabu Search from those components */
moTS <TwoOpt> tabu_search (two_opt_init, two_opt_next, two_opt_incr_eval,
two_opt_aspir_crit, two_opt_tabu_list, cont, full_route_eval);

/* It applies the TS to the solution */
 tabu_search (route);
```