

# **A Reactive Agent Based Approach to Facility Location: Application to Transport**



**By: Arman Didandeh**

# Facility Location Problem

- Concerns the positioning of facilities
  - train station
  - bus stop
  - fire station
  - school
  - hospitals
- , so as to optimize one or several **objectives**:
  - » distance
  - » travel time
  - » travel cost
  - » demand satisfaction



# Facility Location Problem (cont'd)

- 4 key components to characterize:
  - a metric to indicate distance/time/etc. between demands and facilities
  - facilities to be located
  - demands to be assigned to facilities
  - a space in which demands and facilities are located
    - discrete vs. continuous space → discrete vs. continuous problems



# Facility Location Models

- Set Covering Location Problem (SCLP)
- Maximal Covering Location Problem (MCLP)
- $p$ -Median
- $p$ -Center



# Facility Location Models(cont'd)

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- **Set Covering Location Problem (SCLP):**

- to locate the minimum number of facilities required to cover all demand nodes



# Facility Location Models(cont'd)

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## – Maximal Covering Location Problem (MCLP):

- to locate a pre-determined number of facilities such that the covered demand is maximized
- no enough facilities to cover all demands



# Facility Location Models(cont'd)

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## – **p-Median:**

- **locate  $p$  facilities to serve  $n$  demand points in some space**
  - **Euclidian plane or a road network**
- **to minimize the weighted distance between demand points and facilities**



# Facility Location Models(cont'd)

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## – p-Center:

- minimizing the maximum distance between a demand and its closest facility
- we are sitting a pre-determined number of facilities



# Facility Location Models(cont'd)

- Other classes can be defined, i.e.:
  - dynamic location problems:
    - time dimension is introduced
    - parameters (e.g. demands) may vary over time
  - stochastic location problems:
    - problem parameters are not known with certainty
  - multi-objective location problems:
    - consider multiple, often conflicting, objectives



# Facility Location Problem (cont'd)

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- Facility Location problems:
  - often extremely difficult to solve
    - optimally or even comparison-based
  - classified as NP-Hard
  - no generic solution appropriate for all potential/existing applications



# Facility Location Problem (cont'd)

- Facility Location solutions:
  - known approaches:
    - Genetic algorithms
    - Branch & Bound
    - Greedy heuristics
    - etc.
  - not easily adapted for dynamic systems
    - system constraints change or data change



# Solving Approaches

- A wide range of facility location variants as seen in previous slides
- Well-known mathematical formulations
- But:
  - formulation is only one step of analyzing a location problem
  - other is more challenging: **to find optimal solutions**



# Solving Approaches (cont'd)

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- Typical solutions:
  - B&B: are quickly inefficient for very complex problems:
    - i.e. with hundreds of constraints and variables
  - obtaining optimal solutions requires colossal computational resources
    - a justification for NP-Hardness of p-median problem



# Solving Approaches (cont'd)

- Typical solutions:
  - Heuristics:
    - allow finding good solutions
    - but do not guarantee finding optimal ones
    - i.e.:
      - Greedy heuristics
      - Genetic algorithms
      - Improvement heuristics
      - Lagrangean relaxation



# Solving Approaches (cont'd)

- Typical solutions have several drawbacks:
  - computational cost
    - huge population size and long convergence time, for example in genetic algorithms
  - rigidity & hardness of implementation
  - lack of robustness
  - lack of flexibility



# A Multi-Agent Approach

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- Reactive agent-based models
- Advantages:
  - well-suited for dynamical problems
  - well-suited for model **distributed** problems:
    - several entities evolving/moving in a common environment have to cooperate to perform collective and local goals



# A Multi-Agent Approach (cont'd)

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- Advantages:
  - able to find a satisfying (even if not optimal) solutions without much computational cost
  - flexibility, modularity and adaptability to open systems



# A Multi-Agent Approach (cont'd)

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- Approach:
  - agent behavior based on combination of attractive & repulsive forces
- Key idea:
  - agents are attracted to demands
  - agents are repulsed by other agents



# A Reactive Approach for the Continuous $p$ -median Problem

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- Model relies on the Artificial Potential Fields (APF) technique
  - has been used extensively in many different varieties for robotic path planning because of its simplicity
  - generally used for decentralized coordination of situated agents



# Problem Statement

- Continuous stations positioning
- To locate a fixed number of stations such that the whole environment space may be used for locating stations
- Objective is to minimize the distance between users demand and the stations



# Problem Statement(cont'd)

- The problem is expressed as below:
  - $\mathcal{D}$ : the set of demand points in  $\mathbb{R}^2$  indexed by  $a$
  - $W_a$  : a positive weight assigned to each demand
  - $P$ : maximum number of facilities to locate
- Problem: find a subset  $X$  of  $P$  within a feasible region  $S \subset \mathbb{R}^2$  such that:



$$\min_{X \subset S} F_A(X)$$

$$F_A(X) = \sum_{a \in A} W_a \cdot \min_{x \in X} d(x, a)$$

Subject to:

$$\sum_{x \in X} x \leq p$$

# Reactive Agent Model

- Agent: an entity that is able
  - to perceive its environment
  - to act according to its own decisions
- Decision making process:
  - simple as in reactive agents
  - complex as in cognitive architectures



# Reactive Agent Model (cont'd)

- Potential Fields based approach:
  - Reactive agents have simple behaviors based on reaction to stimuli coming from the environment
  - Agents have numerous interactions between them and their environment in a stimulus-response way to collectively organize the whole system
  - Key idea is that:
    - the human behavior is controlled by a force field generated by objects or situations with positive or negative values



**AFP is limited by a well-known drawback:  
Local Minima**

# A Reactive Approach for the Continuous $p$ -median Problem (cont'd)

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- Consider facilities as reactive agents
- Environment is defined by a finite and continuous space
- Demands are static data of problem and defined as environment characteristic



# A Reactive Approach for the Continuous p-median Problem (cont'd)

- A demand is covered if next facility is within a covering radius
  - ▶ **Attractive Behavior**
- Agents should not be too far from or too close to each other (inter-agent distance constraint)
  - ▶ **Repulsion Behavior**



# A Reactive Approach for the Continuous p-median Problem (cont'd)

- Each agent has a local perception of the environment and of other agents
- As attraction and repulsion influences are considered separately, two perception radius are defined:
  - attractive radius
  - repulsive radius

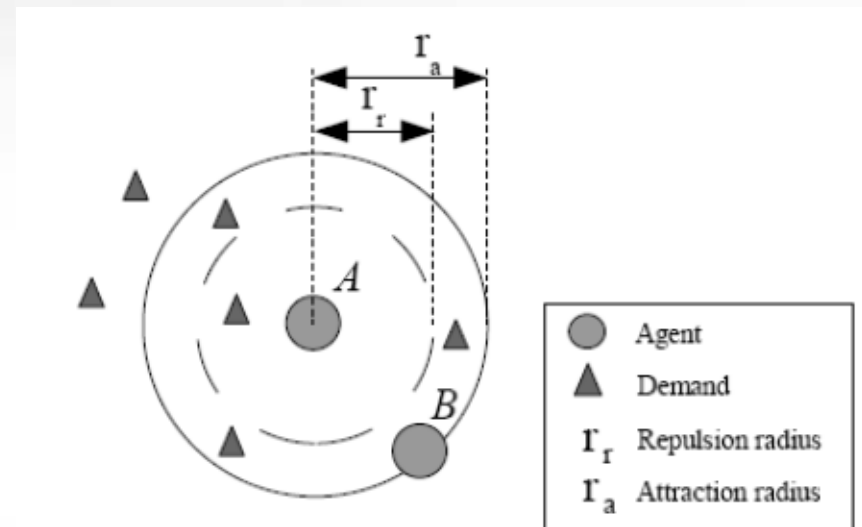


Figure 1: Perception radius of an agent

# A Reactive Approach for the Continuous p-median Problem (cont'd)

- Attraction:
  - an interaction between agents and their environment
  - each agent perceives the demand within its attraction radius
  - an attractive force is defined from the agent towards the demand point as a vector proportional to the demand weight and the distance between them:



$$\vec{F}_{D/A} = W_D \cdot \vec{AD}$$

# A Reactive Approach for the Continuous p-median Problem (cont'd)

- Attraction:
  - the influence of the attraction decreases as the agent moves towards the demand
  - so agents move towards a balance point when subject to several demands
  - global attraction force is:



$$\vec{F}_{demands/A} = \frac{\sum_{i=1}^n \vec{F}_{i/A}}{n}$$

# of demands for agent  $A$   
in its attraction radius

# A Reactive Approach for the Continuous p-median Problem (cont'd)

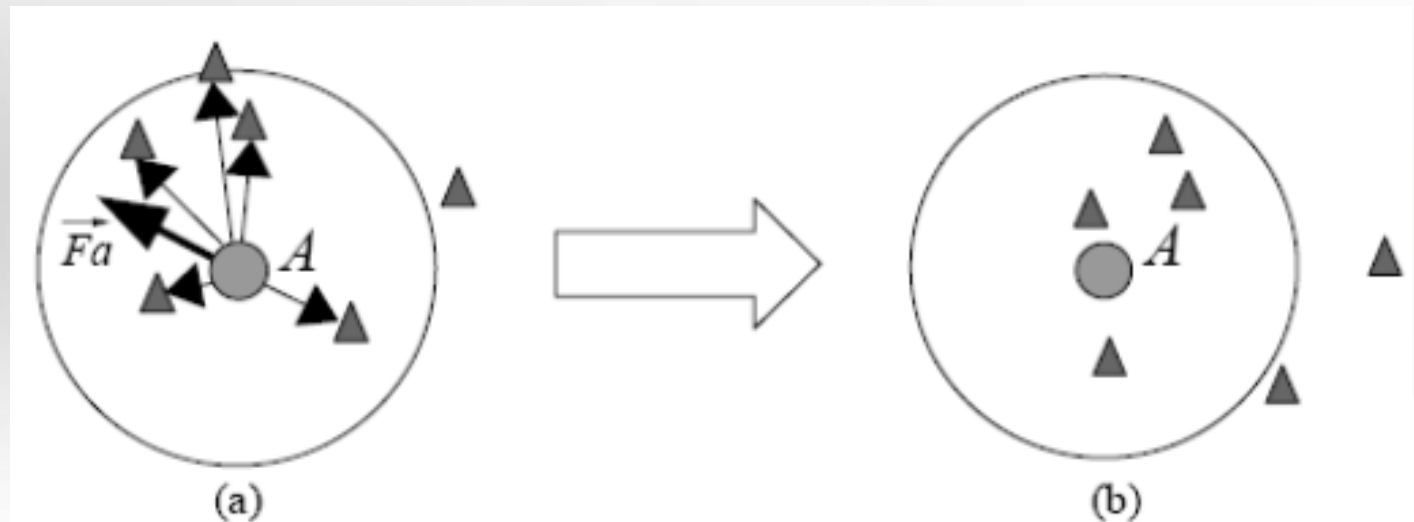


Figure 2: (a) Attraction to demands (b) The agent moves to the balance point



# A Reactive Approach for the Continuous p-median Problem (cont'd)

- Repulsion:
  - if only attraction  $\rightarrow$  agents move to common locations, which is a sub-optimal process
  - to ensure efficient agent repartition, we define repulsive forces between agents inversely proportional to inter-agent distances:
  - so the global repulsive force for agent  $A$  is:

$$\vec{R}_{B/A} = \frac{\vec{BA}}{\|\vec{AB}\|^2}$$

$$\vec{R}_{agents/A} = \frac{\sum_{j=1}^m \vec{R}_{j/A}}{m}$$



# A Reactive Approach for the Continuous p-median Problem (cont'd)

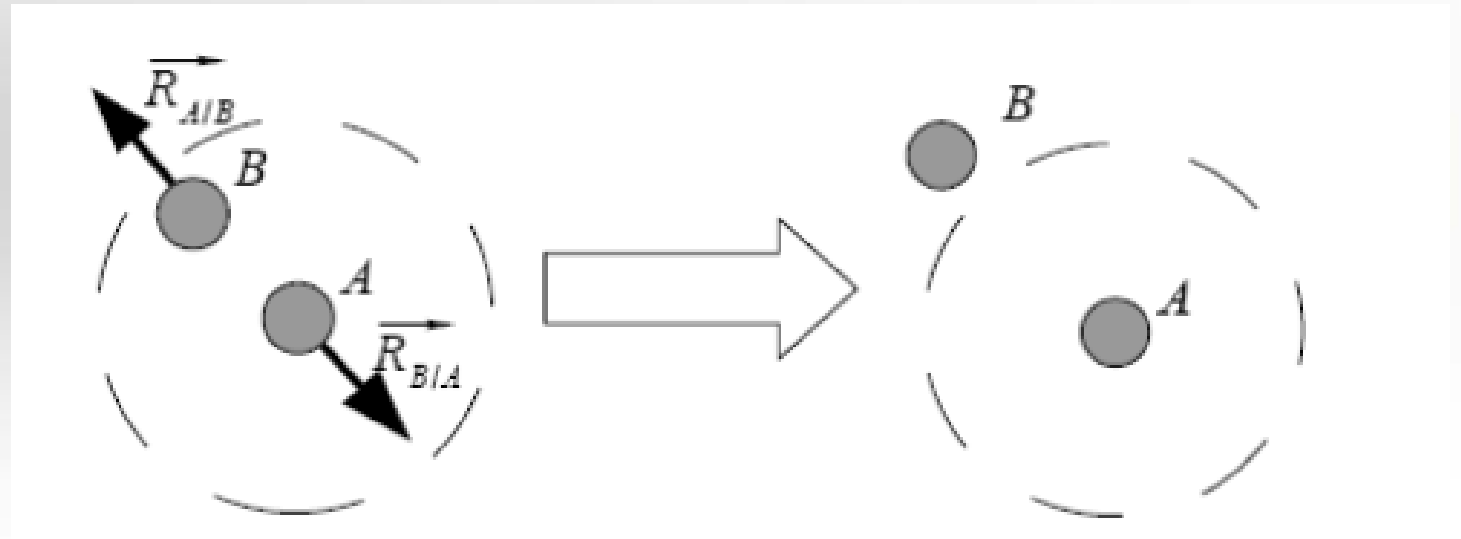


Figure 3: Repulsion between two agents A and B



# A Reactive Approach for the Continuous p-median Problem (cont'd)

- Agent behavior is defined the weighted sum of both global attraction and repulsion forces:

$$\overrightarrow{Move} = \alpha \overrightarrow{F}_{demands/A} + (1 - \alpha) \overrightarrow{R}_{agents/A}$$



# A Reactive Approach for the Continuous p-median Problem (cont'd)

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## Algorithm 1 The system behavior

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```
1: Initialization of Agent positions
2: while Fitness in progress do
3:   for all Agents do
4:     Attraction computation
5:     Repulsion computation
6:     Move computation
7:     Move execution
8:   end for
9:   Fitness computation
10: end while
```

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Will be explained

# Experimentations

- Application to Stations Location
- Application to Bus-Stop Location

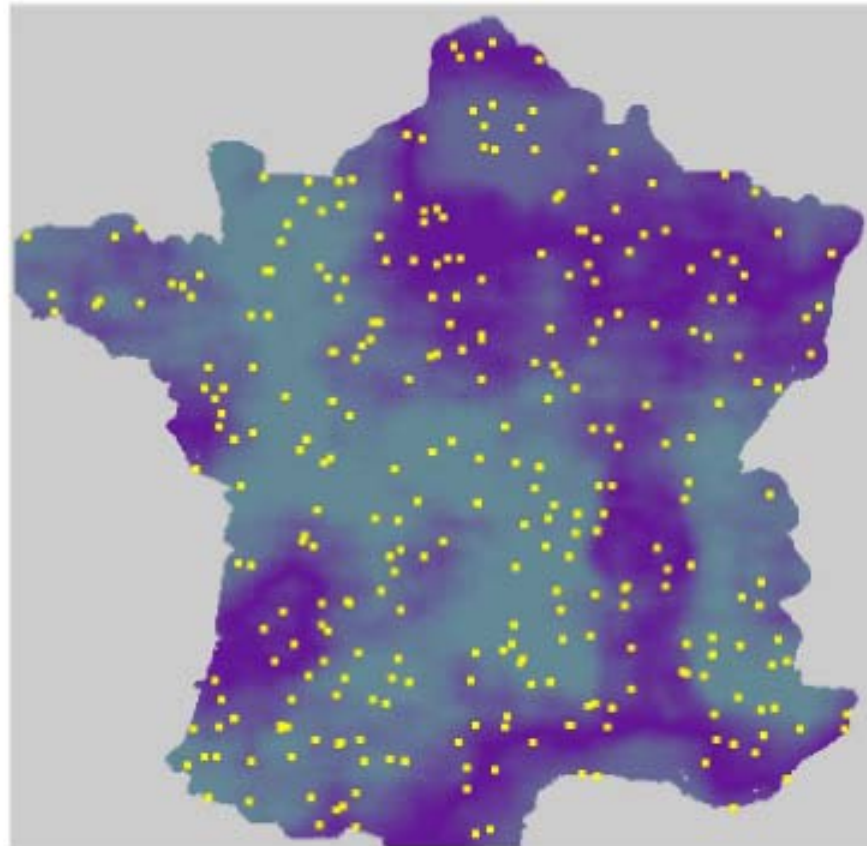


# Application to Stations Location

- Stations Location:
  - a continuous environment corresponding to France map
  - demand weights are randomly chosen values between 0 and 255, and represented as a gradation from black color (255) to white color (0)
  - $\alpha = 0.5$ ,  $r = 25$ ,  $r = 20$ ;

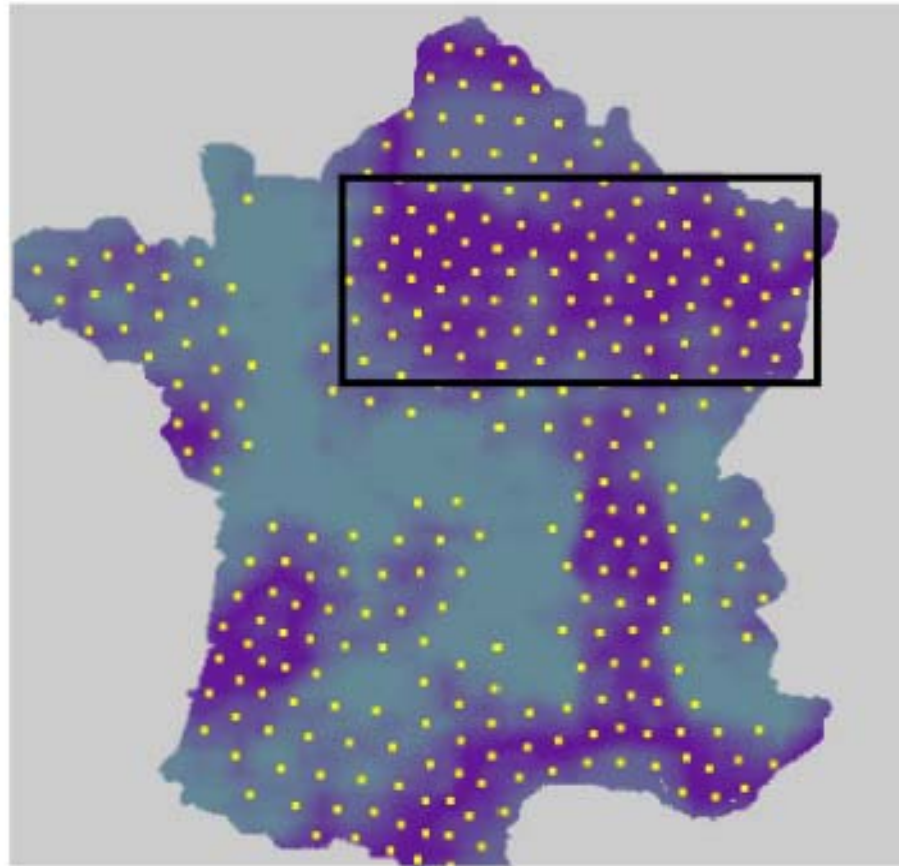


# Application to Stations Location (cont'd)



**Figure 4: Demand representation (dark areas) and random initialization of station locations**

# Application to Stations Location (cont'd)



**Figure 5: Final result (since the iteration 41)**

# Application to Stations Location (cont'd)

- Results performance is compared to k-means clustering, using a global fitness index:

$$Fitness = \frac{\sum_{ij} V_{ij} \cdot d(C_{ij}, x_{ij})}{\sum_{ij} V_{ij}}$$

demand at point  $x_{ij}$

distance between the point  $x_{ij}$   
and the nearest station  $C_{ij}$



# Application to Stations Location (cont'd)

<b>Fitness: minimal values</b>					
Stations	50	80	100	150	200
Multi-Agent	16,592	12,501	11,187	9,164	7,945
K-means	15,556	12,253	10,956	9,010	7,820
Deviation	6.65%	2.02%	2.02%	1.7%	1.5&%



# Application to Stations Location (cont'd)

Reactive approach is an interesting heuristic to deal with optimization problems

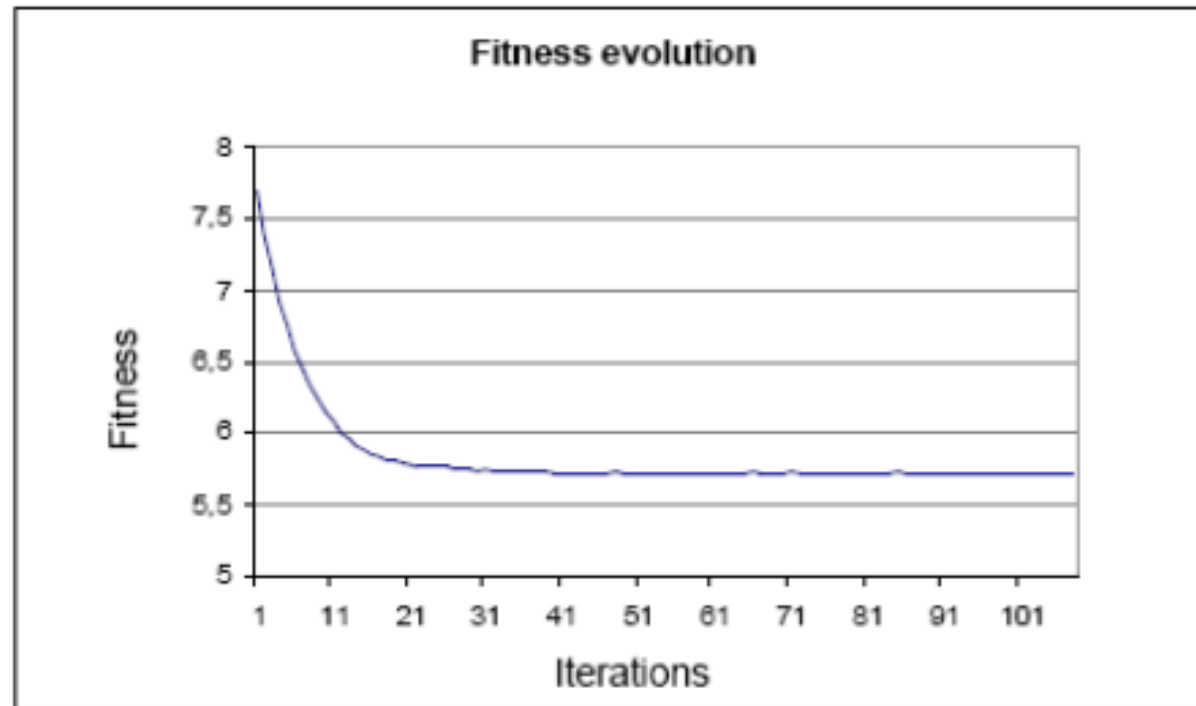


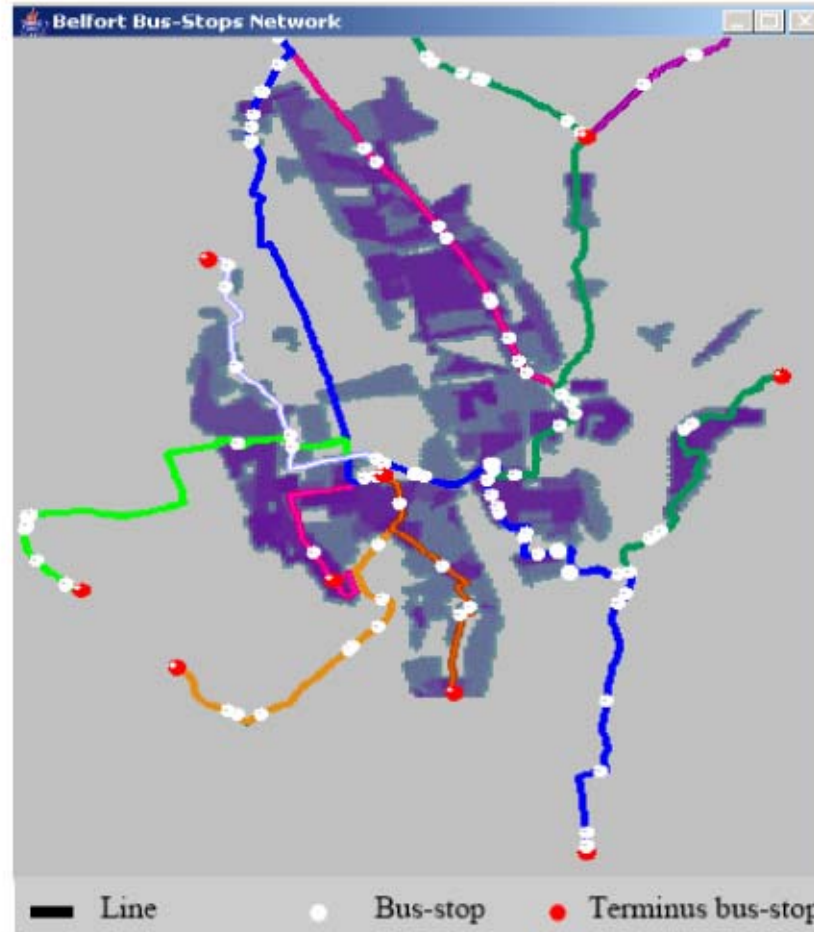
Figure 6: The fitness evolution for the case study with 400 station agents

# Application to Bus-Stop Location

- Bus-Stop Location:
  - a discrete environment corresponding to Belfort city
  - real values of demands corresponds to inhabitants density per quarter
  - an important constraint: bus-stops should move but remain on lines
  - terminus agents are fixed and not subject to forces



# Application to Bus-Stop Location(cont'd)



**Figure 7: Belfort bus-network; random initialization of the bus-stop agents**

# Application to Bus-Stop Location(cont'd)

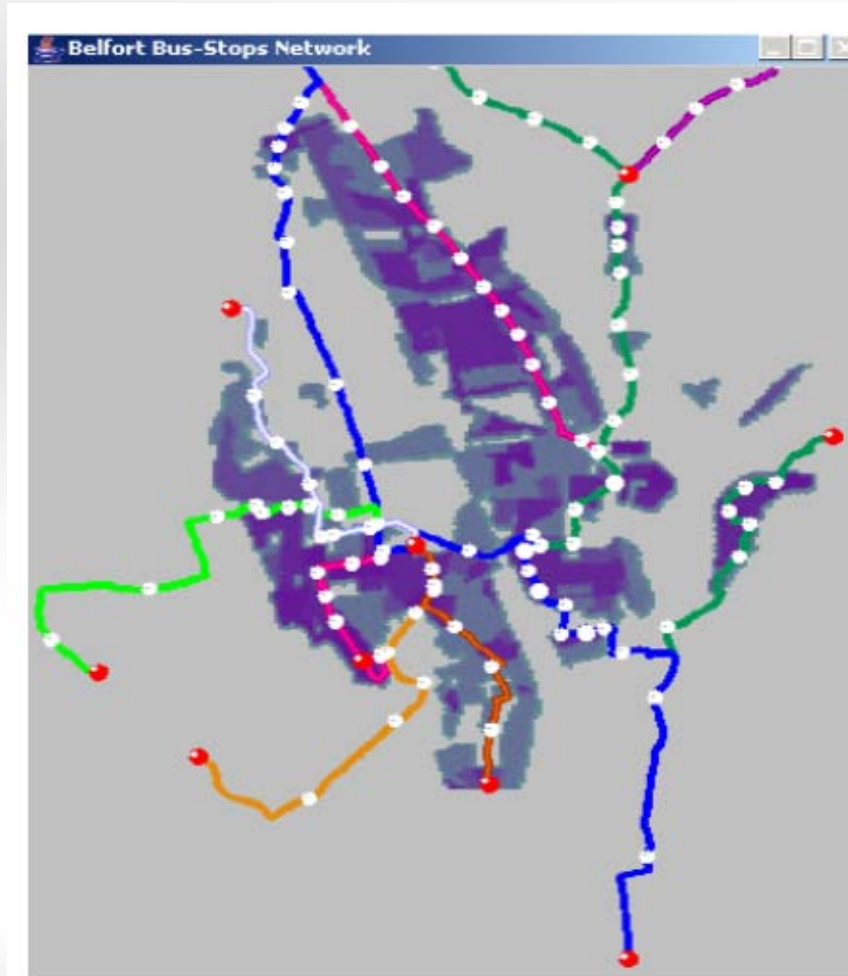
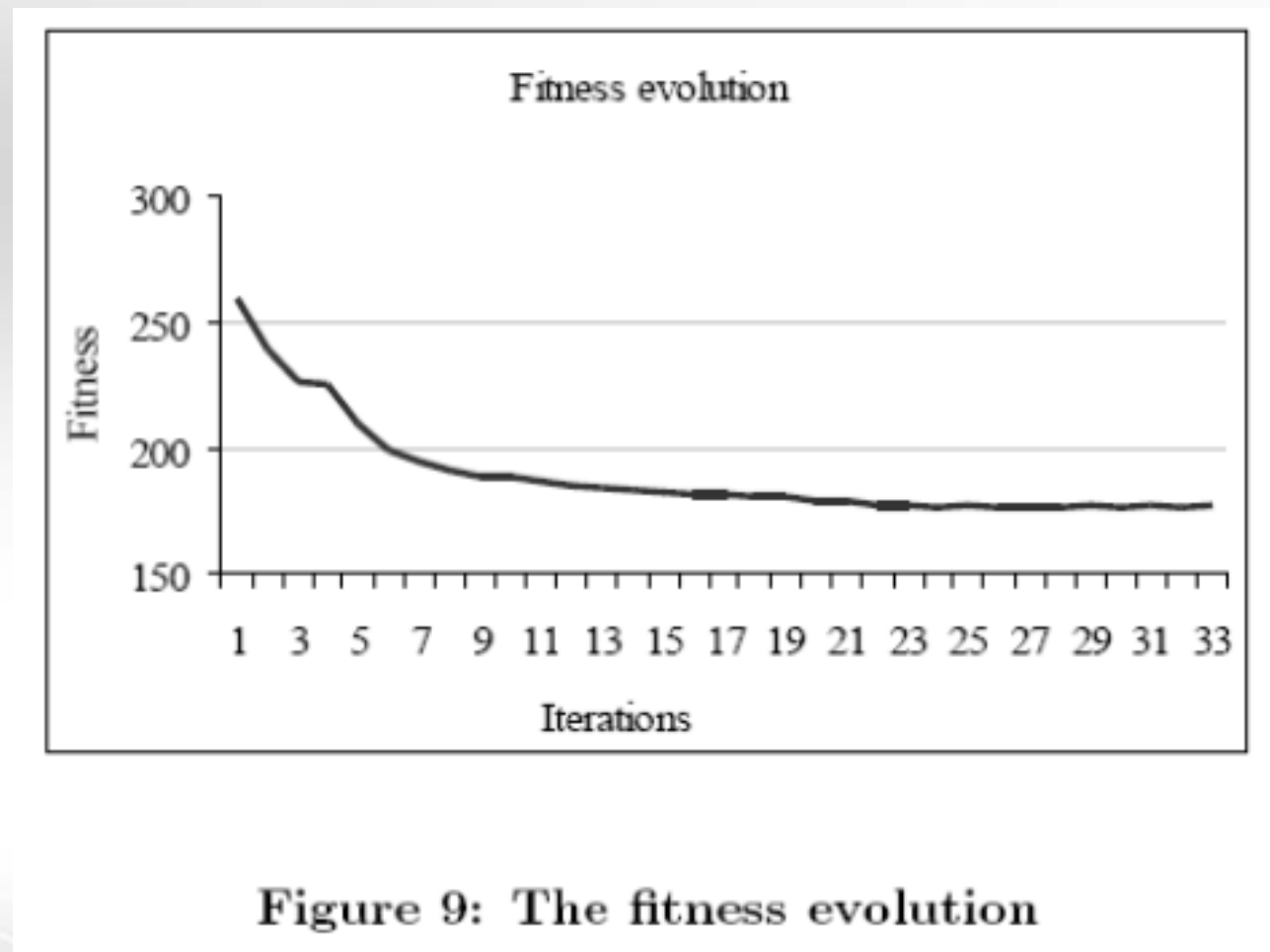


Figure 8: Execution final result

# Application to Bus-Stop Location(cont'd)



**Figure 9: The fitness evolution**



# Discussion & Conclusion

- The obtained solutions are globally satisfying considering the fitness value
- They are quickly obtained, i.e. few iterations are necessary to reach a stable state
- Attraction radius is defined by coverage distance
- Repulsion radius is defined by maximal distance between two facilities



## Discussion & Conclusion (cont'd)

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- The existing solutions for facility location are not easily adaptable when the problem changes, particularly, for dynamic systems characterized by a variation of the problem constraints or data
- The proposed model is not limited to a specific facility location variant and can be adapted through changes of the agent behaviors



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to Facility Location:  
Application to Transport**



**Questions Are  
Welcome**