Evolutionary Algorithms for Arc Routing Problems

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Invited paper.

Outline

1. Overview of our research in arc routing / node routing

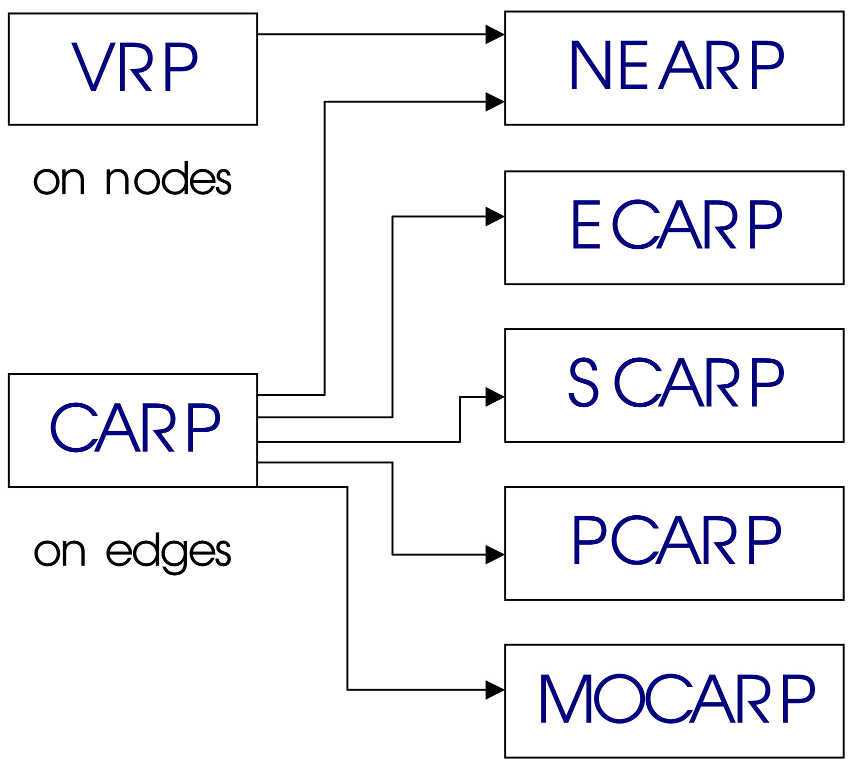
Then zoom on some of these selected topics:

2. The CARP
3. The ECARP (Extended CARP)
4. The SCARP (Stochastic CARP)
5. The PCARP (Periodic CARP)
6. The MOCARP (Multi-Objective CARP)
7. The NEARP (Node, Edge and Arc Routing Problem)

Overview of Research

Academic pbs

5 new problems motivated by waste collection



Node, Edge and Arc Routing Problem

Extended CARP (complex networks)

Stochastic CARP (random quantities)

Periodic CARP (long-term planning)

Multi-Objective CARP

The Capacitated Arc Routing Problem

CARP Data:

- ♣ undirected network *G*
- ♣ *n* nodes including a depot with vehicles of capacity *W*
- ♣ *m* edges including a set of *t* tasks (required edges)
- ♣ each edge has a demand and a traversal cost

Goal: process all tasks with a min-cost set of trips

Applications: urban waste collection, winter gritting etc.

NP-hard. Solved by TS (Eglese, 1996; Hertz et al. 2000), GLS (Beullens et al. 2001) or GA (Lacomme et al., 2001). Excellent lower bounds (Belenguer & Benavent, 1997).

A Hybrid GA for the CARP

Memetic: hybridized with local search (Moscato, 1999)
Template below tested on the open-shop (Prins, 2000):

build initial population Pop (small one, e.g. 30 distinct solutions)
include a few good heuristic solutions (1 to 3)
repeat
  select parents P1,P2 by binary tournament
  apply a crossover to P1,P2 and keep one child C
  if random < given_probability then LocalSearch(C)
endif
  select Pop(k) to be killed, with a cost > median cost of Pop

```
   if C not in Pop\{Pop(k)} then replace Pop(k) by C
endif
until (stopping criterion)
if LB not reached then perform a few intensive restarts
endif
```

CARP GA: chromosome & Xover

1. Chromosome

- ♣ *G* coded as a symmetric digraph with 2*m* arcs (2 per edge)
- ♣ a chromosome is a sequence *S* of *t* arc indexes (1 per task)
- ♣ each task appears in *S* as one of its 2 opposite arcs
- ♣ implicit shortest paths between consecutive tasks
- ♣ no trip delimiter: giant tour or priority order for 1 vehicle

2. Crossovers OX & LOX for sequencing pbs can be used

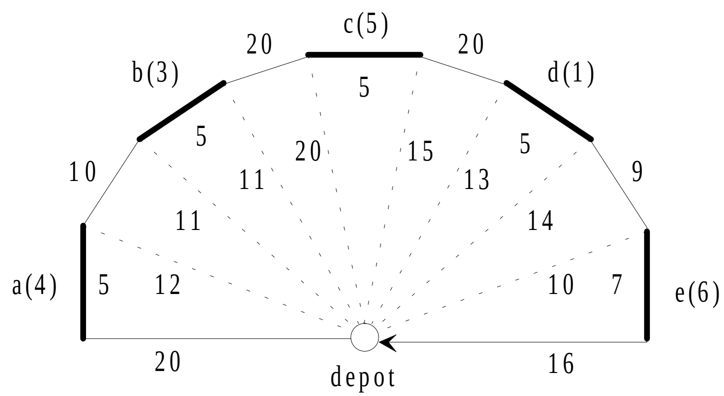
```
LOX      random cut points
                ↓     ↓
P1    : 1  3  2|6  4  5|9  7  8
P2    : 3  7  8|1  4  9|2  5  6

C1    : 3  7  8  6  4  5  1  9  2
C2    : 3  2  6  1  4  9  5  7  8
```

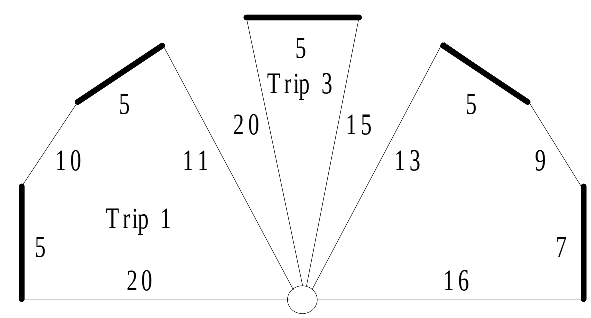
```
OX       random cut points
                ↓     ↓
P1    : 1  3  2|6  4  5|9  7  8
P2    : 3  7  8|1  4  9|2  5  6

C1    : 8  1  9  6  4  5  2  3  7
C2    : 2  6  5  1  4  9  7  8  3
```

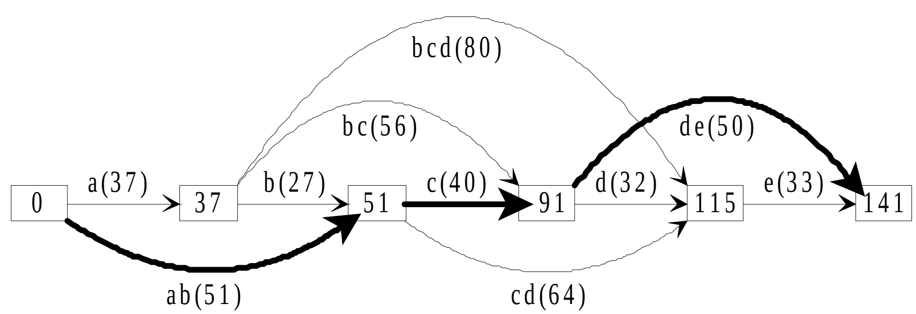
CARP GA: evaluation procedure SPLIT



Chromosome S = (a,b,c,d,e)
Implicit shortest paths between tasks



OPTIMAL splitting, cost 141



Auxiliary graph of possible trips for *W*=9 and shortest path in boldface

CARP GA : comparison with the TS CARPET (Hertz et al., 2000)

	DeArmon 23 pbs, t ≤ 55		*Belenguer 34 pbs, t ≤ 97*		*Eglese 24 pbs, t ≤ 190*	
Criterion	*Carpet*	*GA*	*Carpet*	*GA*	*Carpet*	*GA*
Avg. dev. to LB %	0.48	0.15	1.90	0.61	4.74	2.47
Max. dev. to LB %	4.62	1.78	8.57	4.26	8.61	4.46
LB reached	18	21	15	22	0	0
No of best solutions	19	22	17	32	0	19
Avg. CPU time (s)	9.02	5.29	63.87	38.35	unknown	526.99

Notes:

- bounds from Belenguer and Benavent (1997, 2003)
- standard setting of parameters
- DeArmon files are too easy and should no longer be used

CARP GA : publications

- ♣ C. Prins. Competitive GAs for the open-shop scheduling problem. *Math. Methods Oper. Res.*, 51, pp. 540-564, 2000.
- ♣ P. Lacomme, C. Prins, W. Ramdane-Chérif. A GA for the CARP and its extensions. In: E.J.W. Boers et al. (eds), *Applications of evolutionnary computing,* Lecture Notes in Computer Science 2037, Springer, pp. 473-483, 2001.
- ♣ P. Lacomme, C. Prins, W. Ramdane-Chérif. *Competitive memetic algorithms for arc routing problems*. Report RR-LOSI-2001-01, UTT. In revision for Annals of OR, 2001.

The VRP: adaptation of the GA

- Gendreau et al. (1998): "Published GAs for the VRP cannot compete with the best TS methods." → TRUE
- Schmitt (1995) uses chromosomes with trip delimiters.
- An adaptation of our CARP GA (which does not use trip delimiters) gives very good results on the 14 classical VRP instances from Christofides (50-199 client nodes).
- C. Prins, *A simple and effective evolutionary algorithm for the VRP*, MIC 2001, Porto.

VRP GA: results

Kind	Authors	Year	Dev. to best solns	Nb of best
TS	Taillard	1993	0.05 %	12
GA	Prins	2001	0.08 %	10
TS	Gendreau et al.	1994	0.20 %	8
TS	Taillard	1992	0.39 %	6
TS	Rego and Roucairol	1996	0.55 %	6
TS	Gendreau et al.	1991	0.68 %	5
TS	Rego and Roucairol	1996	0.77 %	4
TS	Gendreau et al.	1994	0.86 %	5
GA	Prins (3000 Xovers)	2001	0.90 %	5
TS	Osman	1993	1.01 %	4
SA	Osman	1993	2.09 %	2

14 instances of Christofides 50-199 nodes.

Updated from Golden et al., *Fleet Management and Logistics*, Kluwer, 1998.

The Extended CARP (ECARP)

In cooperation with J-M. Belenguer and E. Benavent

Goal: tackling realistic street networks (waste collection)

MCARP (Mixed CARP) - Mixed graph with two kinds of links:

- ♣ edges: 2-way streets with bilateral service (any direction)
- ♣ arcs: 2-way streets with independent sides or 1-way streets
- ♣ two costs per link: deadheading and service

ECARP – More complications:

- ♣ Parallel links, windy edges, maximum trip length
- ♣ Forbidden turns and turn penalties
- ♣ Intermediate facilities

The ECARP: results

See the talk of José-Manuel and Enrique

Two new sets of instances:

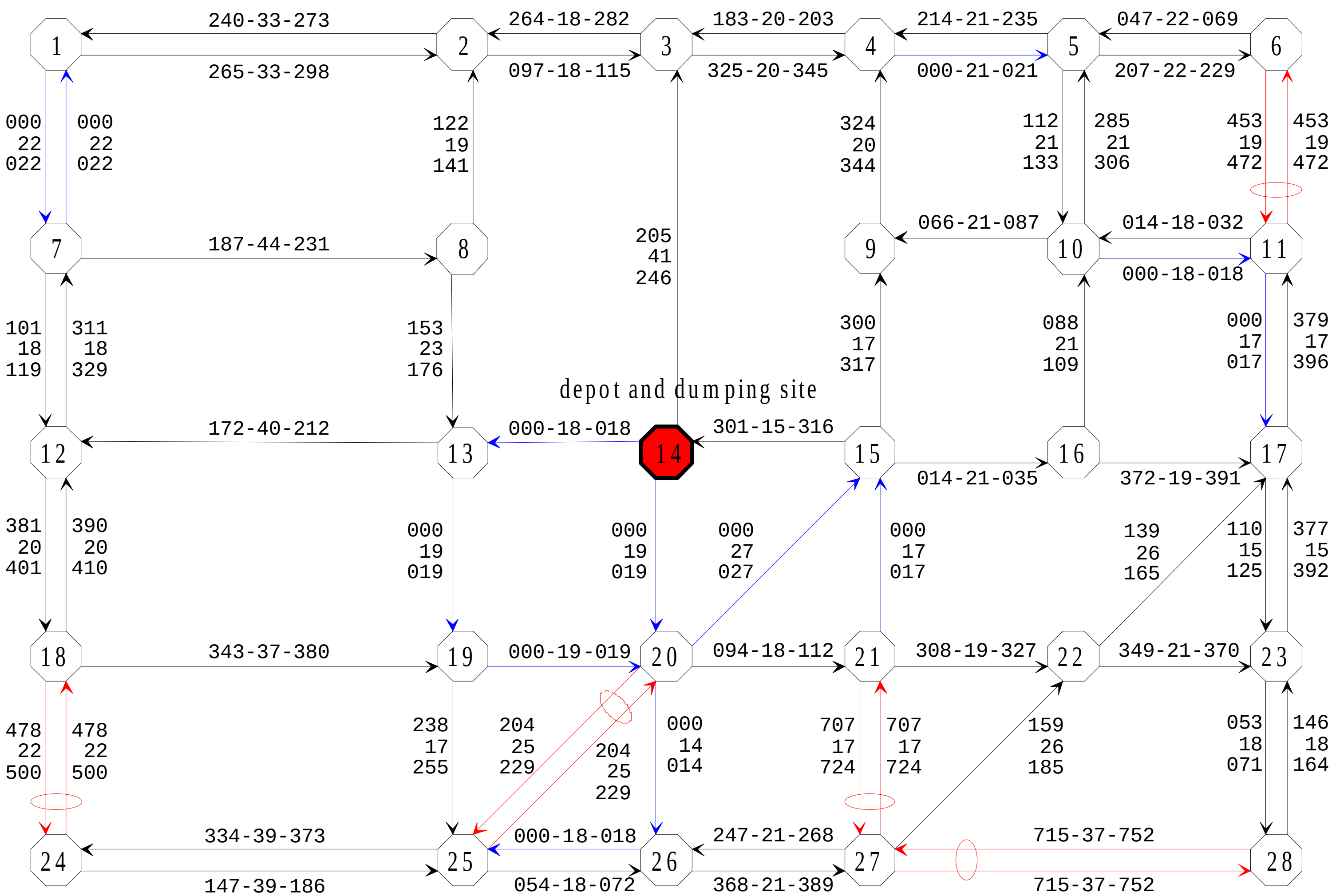
- ♣ 34 derived from Belenguer & Benavent CARP files
- ♣ 15 imitating real networks, up to 1000 links

Generalization of CARP heuristics and of the CARP GA

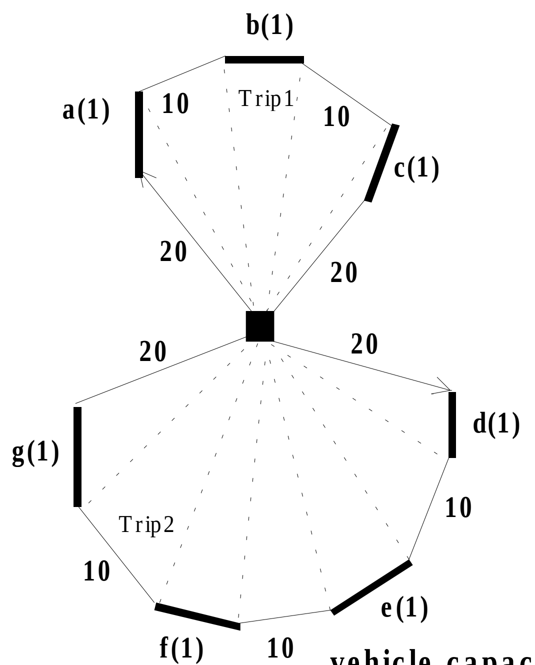
Generalization of the CARP lower bound (cutting plane)

Very promising results: average deviation GA/LB ≈ 0.5%

Example - Smallest File: n=28, m=68, t=50

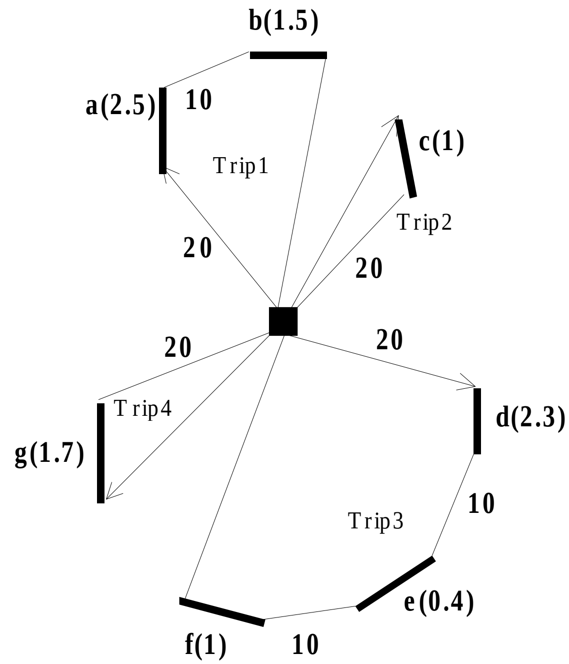


The Stochastic CARP (SCARP)



vehicle capacity 4

solution de coût : 137
trip1 :cost = 63 , load = 3
trip2 :cost = 74 , load = 4



solution de coût : 157
trip1 :cost = 42 , load = 4
trip2 :cost = 31 , load = 1
trip3 :cost = 53 , load = 3.7
trip4 :cost = 31 , load = 1.7

The SCARP: a simple approach

- ♣ gaussian demands with mean q_{ij} and std dev like $q_{ij}/10$
- ♣ the GA is run with the means → planned trips
- ♣ simulation on solutions to evaluate robustness
- ♣ simple correcting policy: keep a *slack* in each truck

GDB13	Planned		Simulations		
Capacity	Cost	Trips	Cost	Trips	Prob. extra trips
W=41	536.0	6	584.8	8.81	97.6%
W×0.9	544.2	7	544.2	7.01	1.2%

P. Lacomme et al., Robustness of solutions for the CARP, *AIS 2002*, Lisbon, pp. 290-295. In revision for *JORS*.

The SCARP: a truly robust GA

- Robust GAs in optimisation use noising or simulation to evaluate chromosomes (Tsutsui 1997, Branke 1998).
- For the SCARP with our assumptions (no cooperation of crews, gaussian demands), analytical formulas are possible for the expected cost and its standard dev.
- This enables a robust GA minimizing the expected cost. Solution quality is confirmed by simulation.
- To be presented at Odysseus 2003, Palermo, Italy.

The PCARP (Periodic CARP)

PCARP data (basic version):

- undirected network *G*
- planning horizon *H* of *np* periods or "days"
- for each task *u*, *frequency* *f*(*u*) (# of services in *H*)
- demand *q*(*u*), traversal cost *c*(*u*), service cost *w*(*u*)

Goal:

- assign the services of each task *u* to *f*(*u*) distinct days
- solve the resulting *np* single-period CARPs
- to minimize the total cost of trips over *H*
- NP-hard. Corresponds to the PVRP in noide routing.

The PCARP: varying demands & costs

PVRP: $q(u)$ and $w(u)$ do not depend on period p !!!

Demands often result from daily productions:

- constant production : $prod(u,p) = prod(u)$
- global trend $\alpha(p)$: $prod(u,p) = \alpha(p) \cdot prod(u)$
- general case : distinct $prod(u,p)$, $p = 1 \ldots np$

If last visit in period q, the amount collected in period p is:

$$q(u,p) = \sum_{k=q+1}^{p} prod(u,k)$$

Processing time: $w(u,p)$ function of $q(u,p)$ and $length(u)$

The PCARP: spacing constraints

Two types (convertible into each other):

- ♣ min & max time lag between 2 visits: *spmin*(u), *spmax*(u)
- ♣ set of allowed day combinations: *comb*(u)

Day combinations are preferred:

- ♣ reasonable number for small horizons (1 week → 1 month)
- ♣ spacing is implicitly satisfied
- ♣ demands can be computed in advance for each day

Example of Troyes: $np = 7$, no work on week-ends, $f(u) = 1,2,5$.
8 combinations are used: {1,2,3,4,5},{1,4},{2,5},{1}...{5}

A memetic algorithm: chromosome

Each task u (street) has a set *comb*(u) of day combinations.

Chromosome S:

- ♣ np sublists $S(1)...S(np)$, *i.e.* one *CARP chromosome* per day
- ♣ u occurs $f(u)$ times in S, according to one day combination
- ♣ u occurs at most once in each sublist $S(k)$

Chromosome length:

$$L = \sum_{u \in R} f(u)$$

No trip delimiters: evaluation by applying SPLIT toi each day.

A memetic algorithm: PLOX crossover

u	*f*(*u*)	*comb*(*u*)	*u*	*f*(*u*)	*comb*(*u*)
1	3	{1,3,4},{2,3,4}	5	1	{1},{2}
2	2	{1,3},{2,4}	6	3	{2,3,4},{1,2,4},{1,2,3}
3	1	{1},{4}	7	2	{2,4},{1,3}
4	1	{1}	8	1	{2},{4}

	Mon				Tue			Wed			Thu			
P1	1	2	3	4	**5**	**6**	**7**	**1**	2	6	1	6	7	8

	Mon				Tue				Wed		Thu			
P2	7	6	5	4	8	6	2	1	7	1	3	6	1	2

	Mon		Tue						Wed		Thu			
C1	6	4	**5**	**6**	**7**	8	2	1	**1**	6	7	3	1	2

The PCARP: results

23 PCARP instances (33-132 services, avg. 70)

Three simple constructive heuristics and a lower bound

- ♣ F. Chu, N. Labadi, C. Prins. Periodic arc routing problems: linear programming model and heuristics, *ACS'02*, Szczecin, Poland, pp. 409-418, 2002. In revision for JIM.

A memetic algorithm for the PCARP

- ♣ P. Lacomme, C. Prins, W. Ramdane-Chérif, Evolutionnary Algorithms for Multiperiod Arc Routing Problems, *IPMU 2002*, Annecy, pp. 845-852. Submitted to EJOR.

Node, Edge & Arc Routing Problem (NEARP)

Could be called "Mixed and Capacitated GRP"

Mixed graph + required nodes, edges and arcs!

One single memetic algorithm for node and arc routing !

Instances	CARP - DeArmon		VRP – Christofides	
	Hertz TS	GA	Taillard TS	GA
Dev. to BKS	0.48%	0.36%	0.05%	0.25%
BKS retrieved	18/23	18/23	12/14	8/14

23 NEARP instances, max. 150 nodes and 212 tasks: 9.5% saved from 3 constructive heuristics followed by local search. Presented at WOMA-3 (PPSN-7) Granada, sept. 2002.

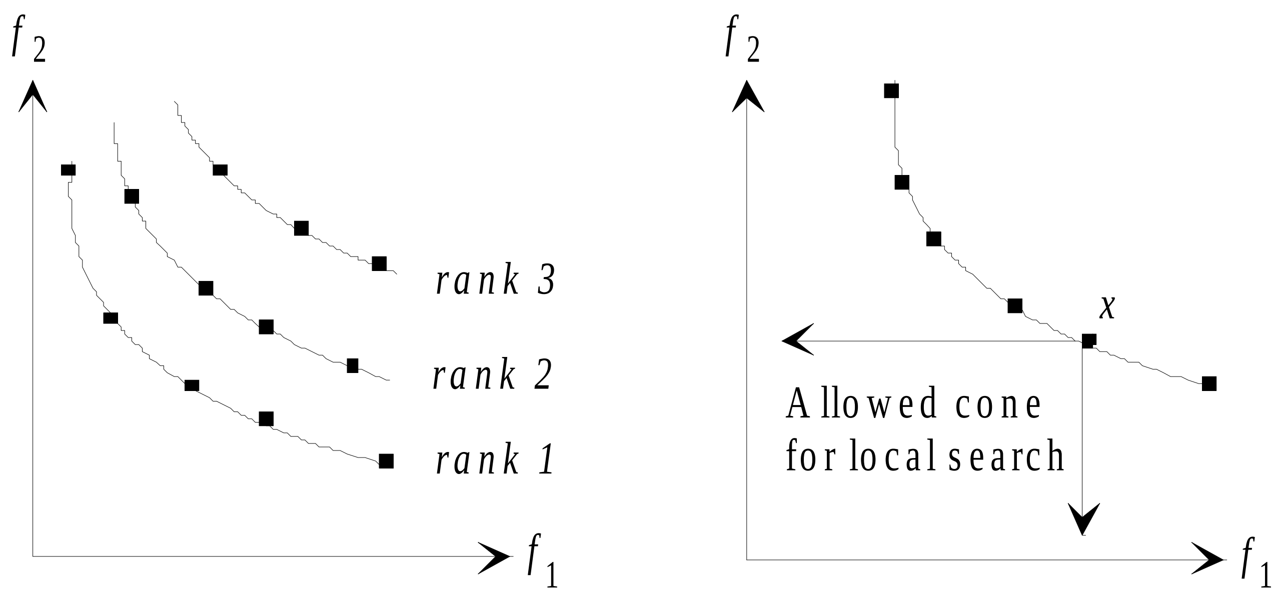
The Multi-Objective CARP (MOCARP)

To be presented at EMO 2003, Faro, April 2003

F1(*S*) = total duration, F2(*S*) makespan

Goal: to compute a set of non-dominated solutions

Method: NSGA-2 template (Deb, 1999) + local search



Conclusion

- Starting from the CARP, development of good memetic algorithms for more realistic arc routing problems
- Rafa underlined the connections with Scatter Search (small populations, distinct solutions, local search...).
- Population-based heuristics can easily handle multiple objectives or compute robust solutions.
- The strength of our GAs comes from a "good" encoding of solutions. This aspect is always more important than the metaheuristic used (SA, TS, GA, SS).