New developments in Integrative Cooperative Search for rich vehicle routing problems

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3rd Collab Workshop, Holmenkollen Park Hotel, 2011.05.10-12

Outline

- Overview of ICS
- MDPVRP and MDPVRPTW
- Integrators
- More on our hybrid genetic solver (HGSADC)
- Multi-objective ICS

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ICS Fundamental Ideas & Concepts

- Decomposition by attribute
- Concurrent population evolution
- Solver specialization
- Cooperation with self-adjusting and guidance features

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Decomposition by Attribute

- Simpler settings by fixing (ignoring) variables or constraints
  - "Eliminating" variables or constraints might yield the same sub-problems but impair the reconstruction of solutions
- Yields
  - Well-addressed, "classical" variants with state-of-the-art algorithms
  - Formulations amenable to efficient algorithmic developments

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Decomposition by Attribute (2)

- Each subproblem = Particular fixed attribute set
  - Addressed using effective specialized methods
    → Partial Solvers
- Partial Solvers focus on the unfixed attributes
  ⟶ Partial Solutions
- Multiple search threads
  - One or several methods for each subproblem
  - Meta-heuristic or exact
- Central-memory cooperation

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Decomposition by Attribute (3)

- Issues and challenges
  - Homogeneous vs. heterogeneous population
  - Purposeful evolution of partial solutions
  - Reconstruction & improvement of complete solutions

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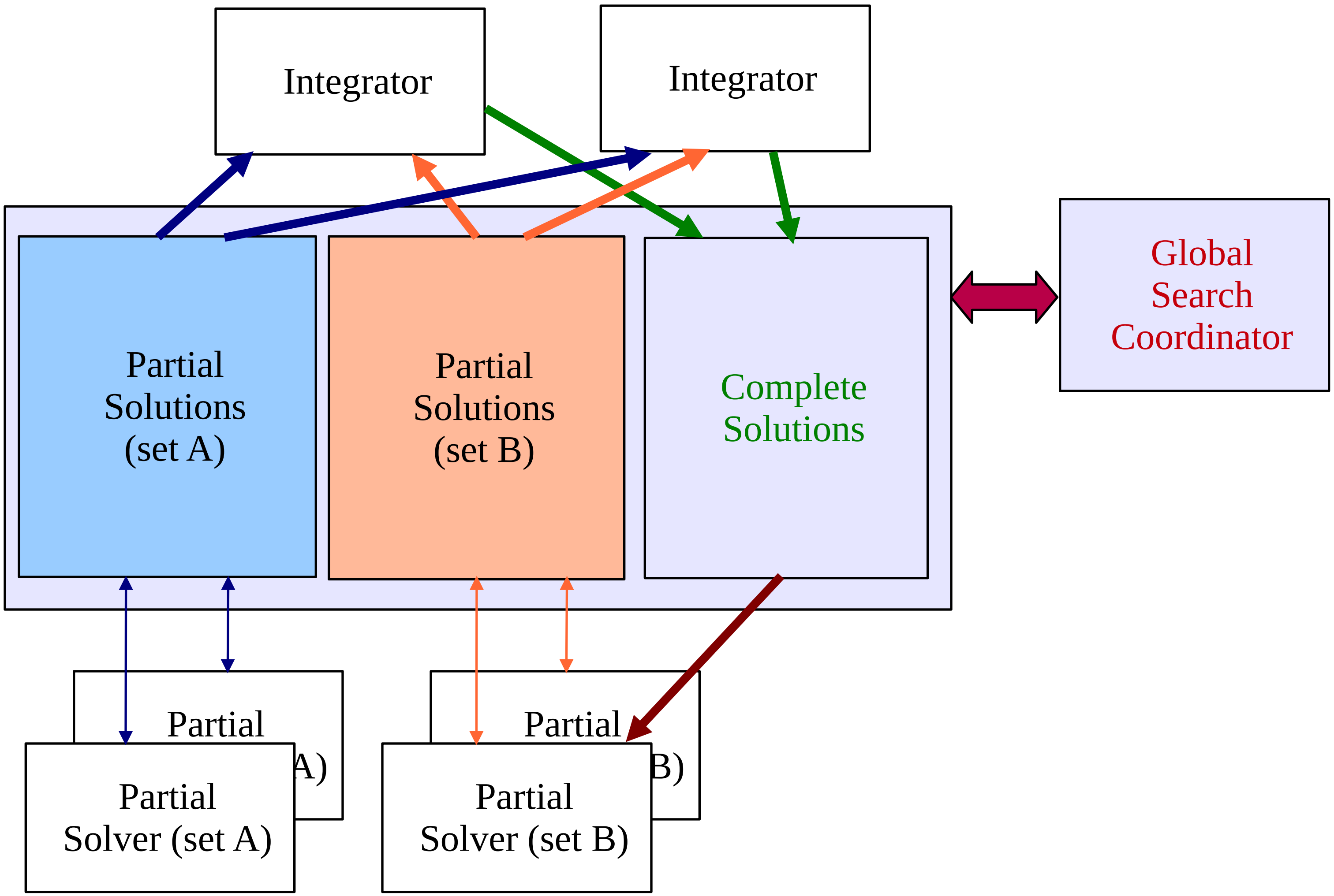
Shared-Memory ICS



MDPVRP and MDPVRPTW

- Multiple depots
  - Given number of homogeneous vehicles at each depot
- Periodic problem
  - Planning horizon of *t* “days” (periods)
  - For each customer: a list of acceptable visit day “patterns”
- Each customer must be assigned to a single depot and a single pattern and routes must be constructed for each depot & day, in such a way that the total cost of all the resulting routes is minimized

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An Important Property → Decomposition

- Any MDVRP(TW) or MDPVRP(TW) instance can be transformed into a (larger ...) PVRP(TW) instance
- One can use the same solution procedure to solve the 3 problems
- Natural decomposition of the MDPVRP(TW) into two subproblems:
  - PVRP(TW) → Fix depot assignments
  - MDVRP(TW) → Fix pattern assignments
- We can use the same solvers as Partial Solvers for the two subproblems and as Global Solver

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Integrators

- Purpose: Recombining Partial Solutions to yield complete ones
- A key component of ICS
- Besides trivial integrators (Select and forward), two main threads of work:
  - Path relinking approach (next slides)
  - Mathematical programming-based models (under development)

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Path Relinking Integrator

- Based on the classical concept of Path Relinking proposed by Glover
- The basic idea of PR is to explore solutions between good solutions found at earlier stages by another solution technique or earlier steps of the PR algorithm.
- In standard PR, an “iteration” of the method consists in selecting an initial and a guiding solutions from the current reference set and then slowly moving from the initial solution towards the guiding one.
- The reference set is updated as one proceeds by adding to it “better” solutions found along the way.

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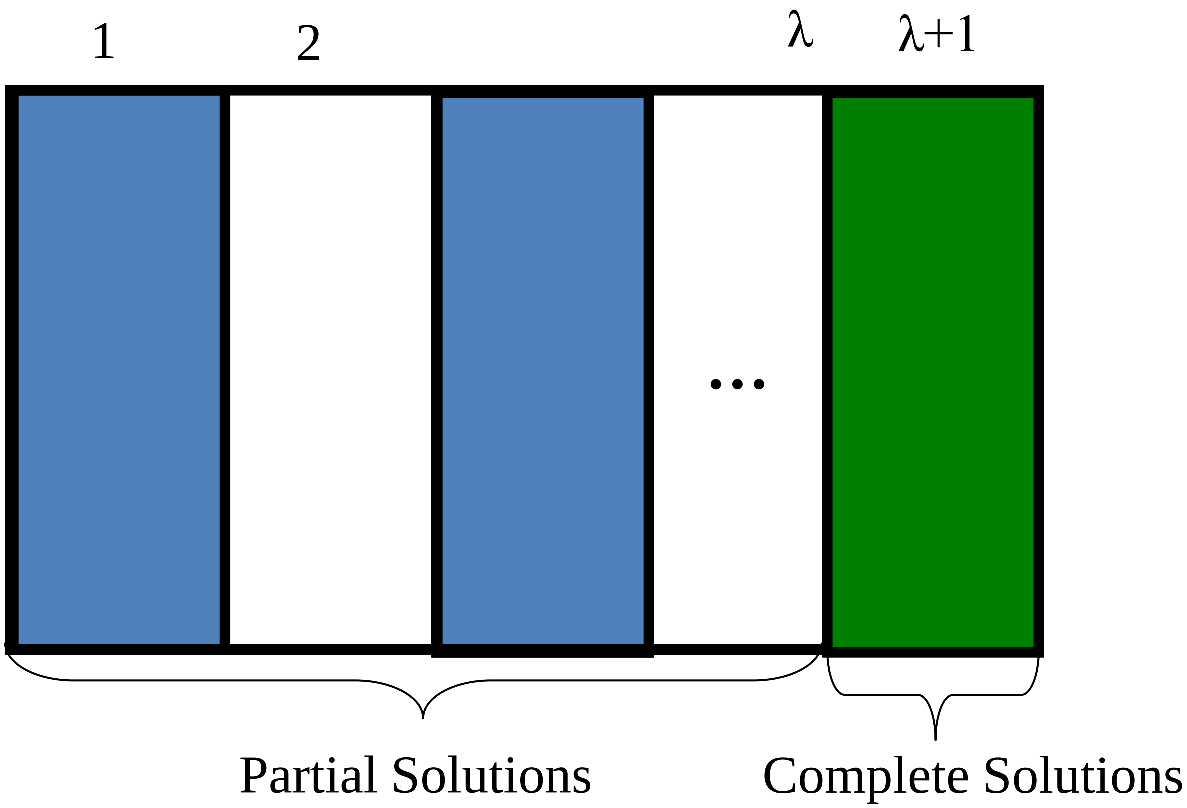
Path Relinking Integrator (2)

- The reference list, as the heart of the path relinking algorithm, is a collection of high quality and diverse solutions.



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Path Relinking Integrator (3)

- Key point: when used as an integrator, PR could end up looking at infeasible solutions → these are allowed throughout.
- Two methods for updating the reference list:
  - Internal Update Method (IUM) is used whenever a high quality complete solution is generated by the searching mechanism of the path relinking algorithm.
  - External Update Method (EUM) is implemented whenever a new partial solution is obtained by the ith partial solver in the decomposition phase of the ICS solution methodology.

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Path Relinking Integrator (4)

- Four different strategies for selecting the initial and guiding solutions.
- In the proposed algorithm, unlike the general path relinking, two moving mechanisms with different purposes are implemented in parallel.
  - Multi-echelon Searching Method (MSM)
  - Iterated neighbourhood search
- They differ in the way that they integrate features of the initial and the guiding solution.

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Path Relinking Integrator (5)

- Testing this type of procedure raises serious methodological concerns.
- Initial tests were performed using solutions obtained from “snapshots” of the partial solution pools at different stages of earlier runs of ICS.
- The computational experiments revealed that the proposed path relinking algorithm performs remarkably well on all the problem instances tested.

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The Genetic Search Solver

- Main features of the solver
  - "Giant tour with no delimiters" representation
    + split algorithm (Prins 2002)
    + pattern and depot chromosomes
  - Admits infeasible solutions with respect to capacity and route length constraint violations, with self-adjusting penalties
  - Offspring education: local search (route, patterns)
  - Population management mechanisms play a key role; the are also used in parent selection as well.

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The Genetic Search Solver(2)

- Originally developed for solving MDPVRP, MDVRP and PVRP.
- The method was slightly modified to deal with classical VRPs.
- A meta-evolutionary method, the Evolutionary Strategy with Covariance Matrix Adaptation (CMA-ES) of Hansen and Ostermeier (2001) was used to calibrate parameter values.

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The Genetic Search Solver(3)

- Some results

Table 2 HGSADC performance on PVRP instances

	CGL *(1 run)*	**HDH** *(Avg. 10 runs)*			**ALP**	**HGSADC** *(Avg. 10 runs)*		
	15.10^3 **it**	10^7 **it**	10^8 **it**	10^9 **it**	—	10^4 **it**	2.10^4 **it**	5.10^4 **it**
Time	4.28 min	—	—	—	3.64 min	5.56 min	13.74 min	28...21 min
Gap	+1.82%	+1.45%	+0.76%	+0.39%	+1.40%	+0.20%	+0.12%	+0.07%

Table 3 HGSADC performance on MDVRP instances

	CGL *(1 run)*	**PR** *(Avg. 10 runs)*		**HGSADC** *(Avg. 10 runs)*		
	15.10^3 **it**	25.10^3 **it**	50.10^3 **it**	10^4 **it**	2.10^4 **it**	5.10^4 **it**
Time	small	1.97 min	3.54 min	4.24 min	8.99 min	19.11 min
Gap	+0.96%	+0.52%	+0.34%	-0.01%	-0.04%	-0.06%

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The Genetic Search Solver(4)

- More results

Table EC.5 Results for Christofides et al. (1979) and Golden et al. (1998) CVRP instances

Inst	n	Average					BKS	
		P (1 run)	**MB** (1 run)	**NB** (10 runs)	**HGSADC** (10 runs)	**T(min)**	**prev BKS** —	**HGSADC** (all exp.)
p01	50	**524.61**	**524.61**	**524.61**	**524.61**	0.43	524.61	524.61
p02	75	**835.26**	**835.26**	835.61	**835.26**	0.96	835.26	835.26
p03	100	**826.14**	**826.14**	**826.14**	**826.14**	1.27	826.14	826.14
p04	150	1031.63	**1028.42**	**1028.42**	**1028.42**	2.87	1028.42	1028.42
p05	199	1300.23	**1291.29**	1291.84	1294.06	5.94	1291.29	1291.45
p06	50	**555.43**	**555.43**	**555.43**	**555.43**	0.48	555.43	555.43
p07	75	912.3	**909.68**	910.41	**909.68**	1.09	909.68	909.68
p08	100	**865.94**	**865.94**	**865.94**	**865.94**	1.14	865.94	865.94
p09	150	1164.25	**1162.55**	1162.56	**1162.55**	2.53	1162.55	1162.55
p10	199	1420.2	1401.12	**1398.3**	1400.23	8.22	1395.85	1395.85
p11	120	**1042.11**	**1042.11**	**1042.11**	**1042.11**	1.15	1042.11	1042.11
p12	100	**819.56**	**819.56**	**819.56**	**819.56**	0.84	819.56	819.56
p13	120	1542.97	**1541.14**	1542.99	1543.07	2.83	1541.14	1541.14
p14	100	**866.37**	**866.37**	**866.37**	**866.37**	1.19	866.37	866.37
pr01	240	5648.04	5627.54	5632.05	**5627.00**	11.68	5626.81	5623.47
pr02	320	8459.73	8447.92	**8440.25**	8446.65	20.75	8431.66	8404.61
pr03	400	**11036.22**	**11036.22**	**11036.22**	**11036.22**	27.99	11036.22	11036.22
pr04	480	13728.80	13624.52	**13618.55**	13624.52	43.67	13592...88	13624.53
pr05	200	**6460.98**	**6460.98**	**6460.98**	**6460.98**	2.56	6460.98	6460.98
pr06	280	8412.90	**8412.88**	8413.41	8412.90	8.38	8404.26	8412.90
pr07	360	10267.50	10195.56	10186.93	**10157.63**	22.94	10156...58	10102.7
pr08	440	11865.40	11663.55	11691.54	**11646.58**	40.67	11663...55	11635.3
pr09	255	596.89	583.39	**581.46**	581.79	16.22	580.02	579.71
pr10	323	751.41	741.56	**739.56**	739.86	25.86	738.44	736.26
pr11	399	939.74	918.45	**916.27**	916.44	45.61	914.03	912.84
pr12	483	1152.88	1107.19	1108.21	**1106.73**	95.67	1104.84	1102.69
pr13	252	877.71	859.11	**858.42**	859.64	9.36	857.19	857.19
pr14	320	1089.93	1081.31	**1080.84**	1082.41	14.12	1080.55	1080.55
pr15	396	1371.61	1345.23	1344.32	**1343.52**	39.15	1340.24	1337.92
pr16	480	1650.94	1622.69	1622.26	**1621.02**	58.27	1616.33	1612.50
pr17	240	717.09	707.79	**707.78**	708.09	7.06	707.76	707.76
pr18	300	1018.74	998.73	**995.91**	998.44	14.40	995.13	995.13
pr19	360	1385.60	1366.86	**1366.70**	1367.83	27.91	1365.97	1365.60
pr20	420	1846.55	**1820.09**	1821.65	1822.02	38.23	1819.99	1818.32
Avg Gap		+1.00%	+0.13%	+0.10%	+0.11%			
Avg Time		—	14.20 min	17.64 min	17.69 min			

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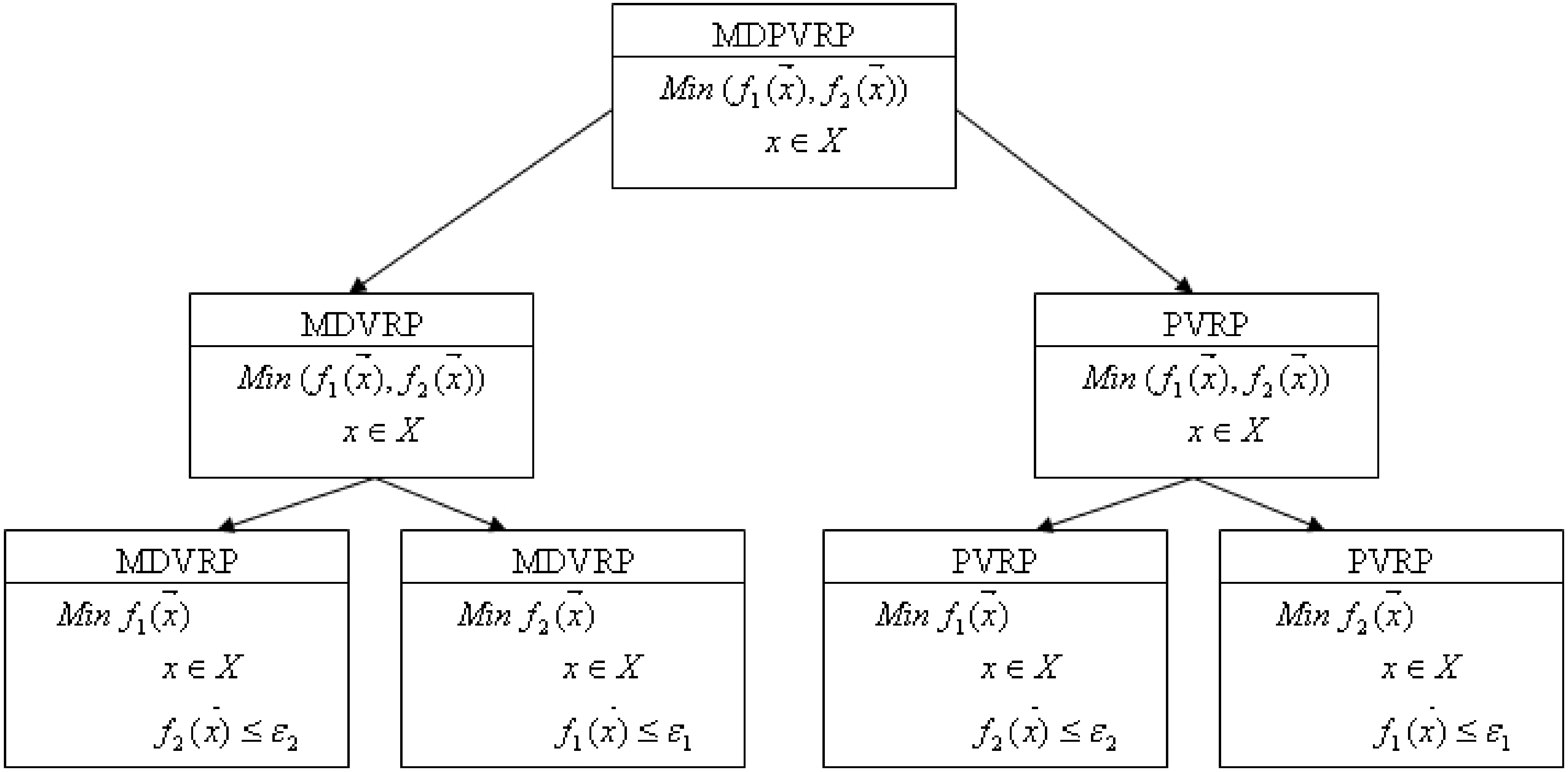
Multi-objective ICS

- We want to tackle MDPVRPs with multiple objectives:
  - Minimize the number of vehicles
  - Minimize total distance
- We can extend ICS to deal with that.

Multi-objective ICS(2)



Perspectives

- Complete work on math programming integrators.
- Thoroughly calibrate and test ICS.
- Pursue multi-criteria work.

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