An Integrative Cooperative Search approach for rich vehicle routing problems

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1st Collab Workshop, Holmen fjordjotell, 2010.04.11-13.

Plan

- Goals, objectives, inspiration / fundamental ideas
- The Integrative Cooperative Search approach
- Rich VRP
- Illustration: ICS for MDPVRP
- Perspectives

Rich Problem Setting

- Large number of interacting attributes (characteristics)
  - Larger than in “classical” (“academic”) settings
  - Problem characterization
  - Objectives
  - Uncertainty
- That one desires to (must ☺) address simultaneously

Design of Wireless Networks

- Simultaneously determine the
  - Appropriate number of base stations
  - Location
  - Height & power
  - Number of antennas/station
  - Tilt & orientation of each antenna
  - Optimize cost, coverage & exposure to electrosmog

Rich VRP

- Vehicle routing in practice
- Attributes of several generic problems
  - Time windows
  - Vehicle capacities
  - Route duration & length
  - Topology of routes
  - Multi-compartment
  - Multi-depot
  - Multiple periods
  - Pick up at (small but numerous) suppliers
  - Deliveries at (few) plants (very different in capacity)
  - Mixing pickups and deliveries (sometimes)
  - Multiple tours
  - Complex "cost" functions
- Plan now by firm, execute repetitively later by carriers

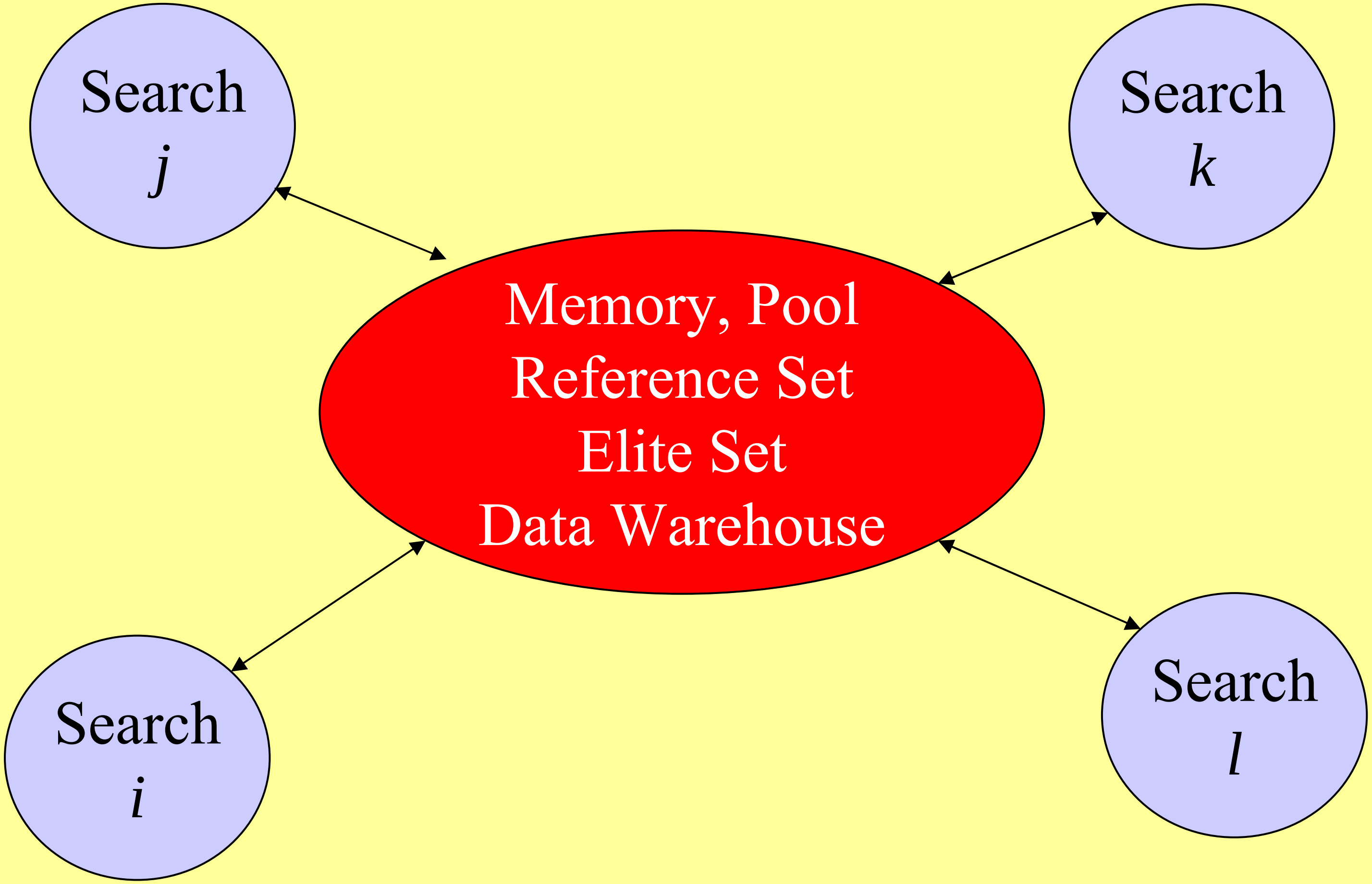
What Methodology for Rich Problems?

- Simplify (!!)
- Series of simpler problems
- Simultaneous handling of multiple attributes
- A more complex problem to address!
- Propose a “new” approach

Sources of Inspiration

- Decomposition
  - Major methodological tool in optimization
  - Domain decomposition in parallel computation
  - Solution reconstruction? "Partition" modification?
- Simplification
  - Fixing part of a rich problem may yield an easier case to address
- Cooperative (parallel) multi-search meta-heuristics successful in harnessing the power of different algorithms (guidance mechanisms)

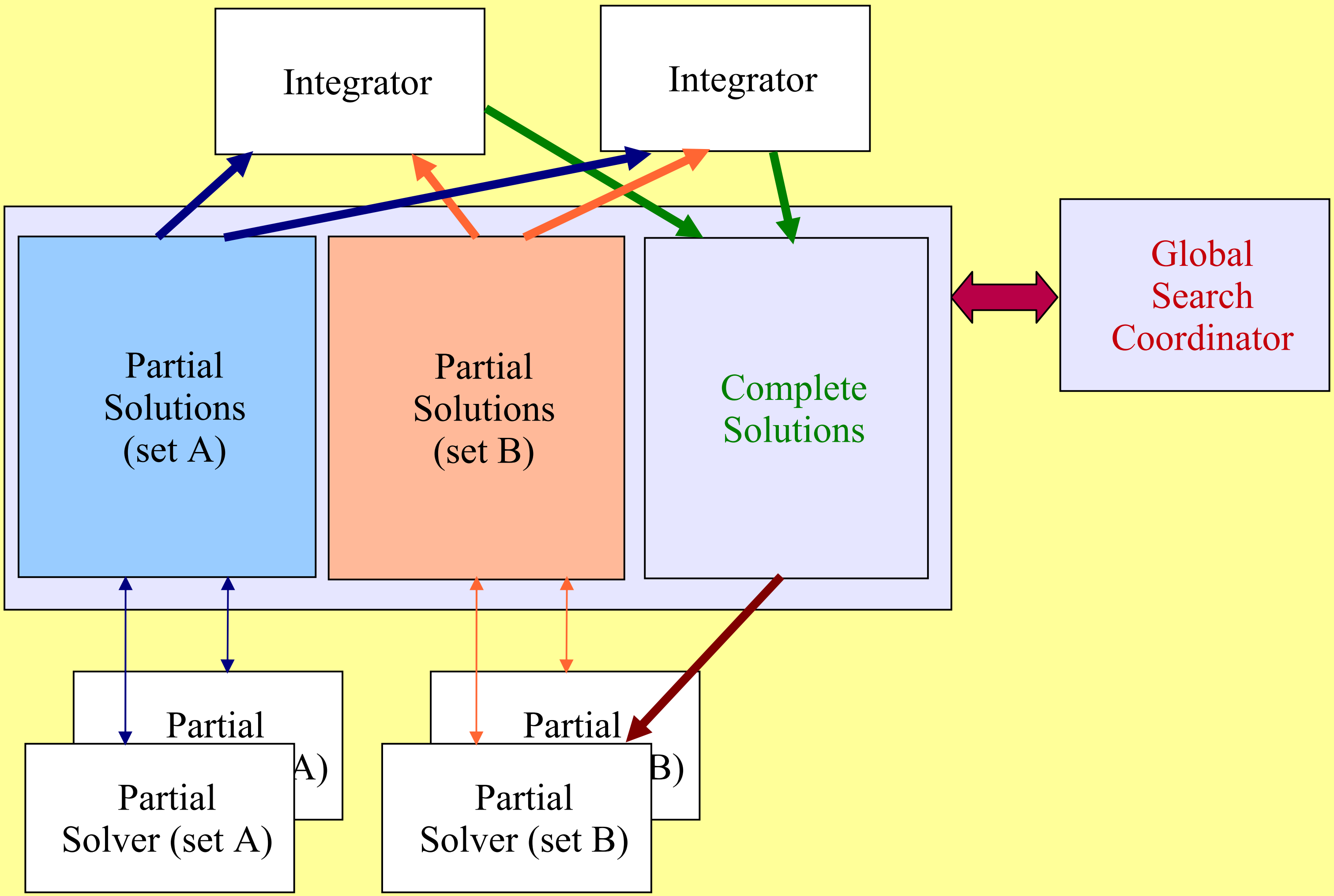
Indirect, Memory-based Cooperation



ICS Fundamental Ideas & Concepts

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

Shared-Memory ICS



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
  - Our idea: be opportunistic!

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

Decomposition by Attribute (3)

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

Reconstructing Complete Solutions

- Recombining Partial Solutions to yield complete ones
- Integrator search threads/operators: Partials → Complete
  - Select and forward
  - Population-based methods: GA & Path Relinking
  - Mathematical programming-based models
- Issues and challenges: Selection of
  - Partial solutions for combination
  - Complete solutions for the central-memory population
    - Which subproblems?
    - What quality? What diversity?

Improving Complete Solutions

- Search threads – Solvers (*to come*)
- Evolve & improve complete solution population
- These are difficult problems!
  - If they were "easy", we would not need ICS!
- Should modify solutions differently from partial solvers
  - Post-optimization
  - Large neighbourhoods for "few" iterations
  - Select few solutions and solve an exact problem
  - Local branching on variables from different attribute sets

Global Search Coordinator

- A "richer" role: purposeful evolution
  - Reconstruct / approximate global status of the search
  - Avoid "heavy-handed" process control: cooperation
  - Information exchange mechanisms
  - Guidance for Partial Solvers & global search
- Monitor
  - Pools / populations
    - Complete solutions (direct)
    - Partial solutions (& integrators) (direct or indirect)
  - Exchanges / communications (possibly)

Global Search Coordinator – Monitoring

- Classical (central) memory statistics
- A "richer" memory through analysis of solutions & communications
  - Quality of solution & evolution of population
  - Impact on population (quality & diversity)
  - Presence of solutions or solution elements in various types/classes of solutions
    - Arcs, paths, …
    - Good, average, poor solutions
    - Solutions with particular attribute sets, …

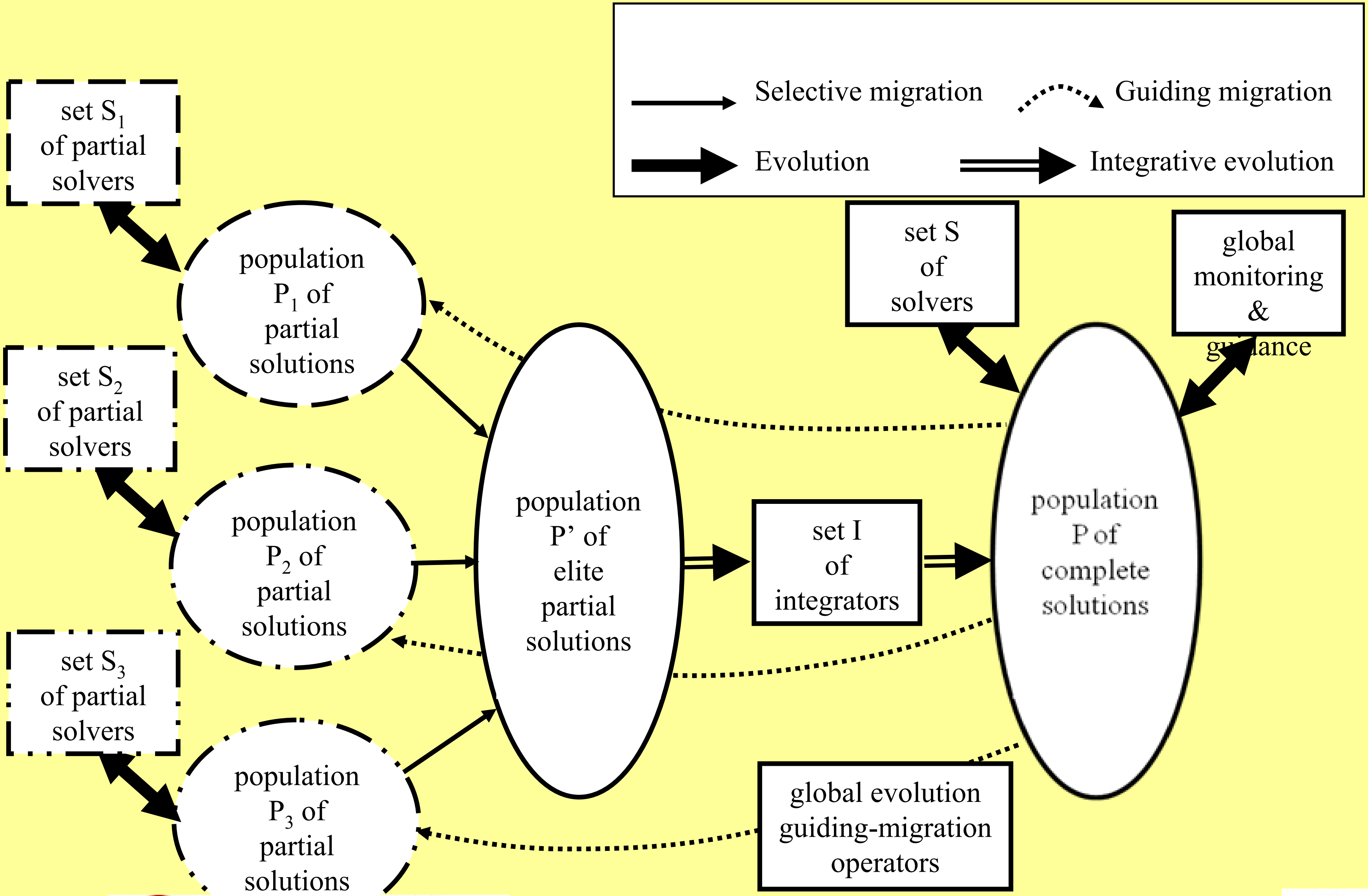
Global Search Coordinator – Monitoring (2)

- The process – Partial Solver, Integrator, Solver – that produced the solution
- Search space covering
  - Attribute values (combinations of) corresponding to visited search space regions
    (how often, quality measures)
- …

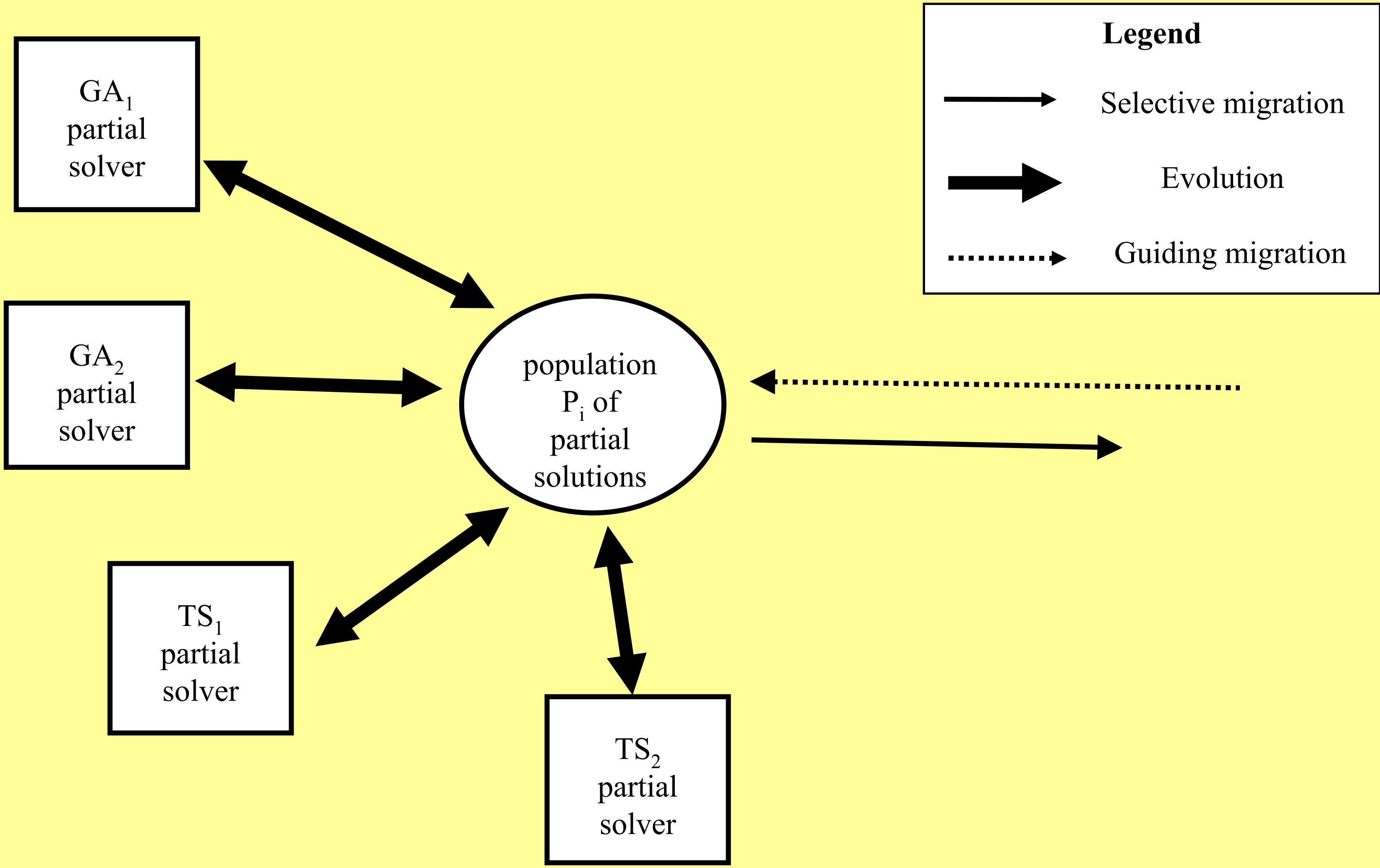
Global Search Coordinator – Guidance

- Partial Solvers cooperate and communicate according to their own internal logic
- Based on monitoring results, "instructions" (solutions, often) are sent GSC → Partial Solver (pool) or Integrator
  - Enrich quality or diversity
  - Modify the values of the fixed attributes ⇔ Moving the search to a different region
  - Modify the sets of attributes defining the partition
  - Modify parameter values or method or replace method

ICS Concurrent Evolution



Zoom on Partial Solver Organization



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

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

Current Solvers

- A neighbourhood-based search based on the Unified Tabu Search (UTS) procedure of Cordeau et al. (2001)
- A new hybrid population-based solver
  - Giant tour with no delimiters representation + split algorithm (Prins 2002) + pattern chromosome
  - Admits infeasible solutions with respect to capacity and route length constraint violations, with self-adjusting penalties (UTS)
  - Offspring education: local search (route, patterns)
  - Population management; in parent selection as well

An Evolutionary ICS MDPVRP Illustration

- 3-population scheme
  - P0: “Global” population
  - P1: Fixed patterns
  - P2: Fixed depots
- 3 solvers for each population: 2 GA, 1 UTS
- GA as Integrator
- GA as Partial Solver: education does not change the patterns corresponding to the “fixed” attributes

ICS MDPVRP Illustration – Integrators

- 2 Integrators: Random select in 25% best
  - 2 parents → extract depot and period patterns → generate population → evolve → send best valid
  - 100 couples: crossover + educate & repair → send best (valid)

ICS MDPVRP Illustration – Guidance

- Information collection on (customer/depot/pattern)
  - No. occurrences
  - Frequencies in best/average/bad sub-populations
  - Best fitness and average rank, …
  - Build good "guiding" individuals, with *promising* attributes in relation with previous measures
  - Guiding migration on partial population stalling
  - Send guiding individuals + a good complete solution + some random ones

Preliminary Results

- Gaps with respect to the best known solutions

GA		P-GA	ICS with Guidance		
1h00	3h00	3 x 1h00	5 min	15 min	30 min
0,65%	0,44%	0,33%	0,58%	0,34%	0,26%
			ICS without Guidance		
			5 min	15 min	30 min
			0,66%	0,41%	0,30%

- Guidance improved average results
- 5 min of ICS competitive with 1h of sequential solving

Conclusions & Perspectives

- Rich (combinatorial optimization) problems present interesting challenges and opportunities
- Parallel cooperation performs very well
- ICS appears promising when complexity grows
- Still a lot of work on all aspects of the approach and applications