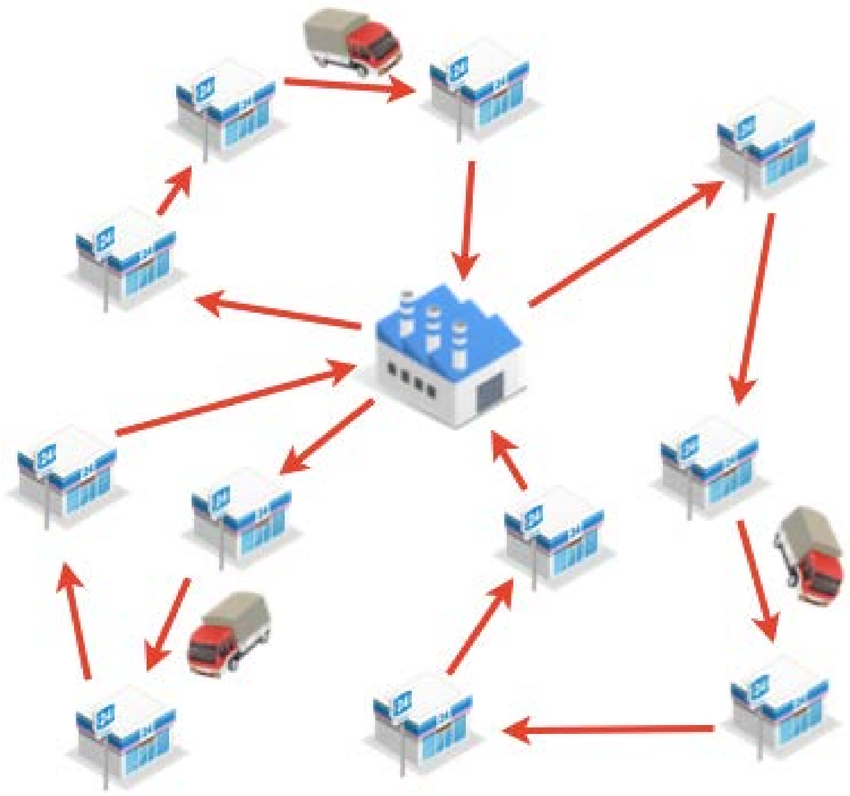
TOWARDS NEXT-GENERATION FLEET MANAGEMENT SYSTEMS



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FLEET MANAGEMENT SYSTEM (FMS)

- Considerable interest in FMS for autonomous vehicles (AVs) in both academia and industry in recent times.
- R&D in progress related to FMS:
  - CityMobil2: EU project since 2012 by 45 partners companies/institutes
  - Japan plans to build robot taxis for 2020 Olympics.
  - Similar initiatives in Singapore
  - …
- Technological needs
  - Need for integrated **optimization** platform for FMS that takes various aspects into account, e.g., behavior of AVs, demand profile, traffic and weather conditions
  - Need for integrated **simulation** platform for FMS to test various what-if scenarios and real-life conditions, various designs of AVs, etc.

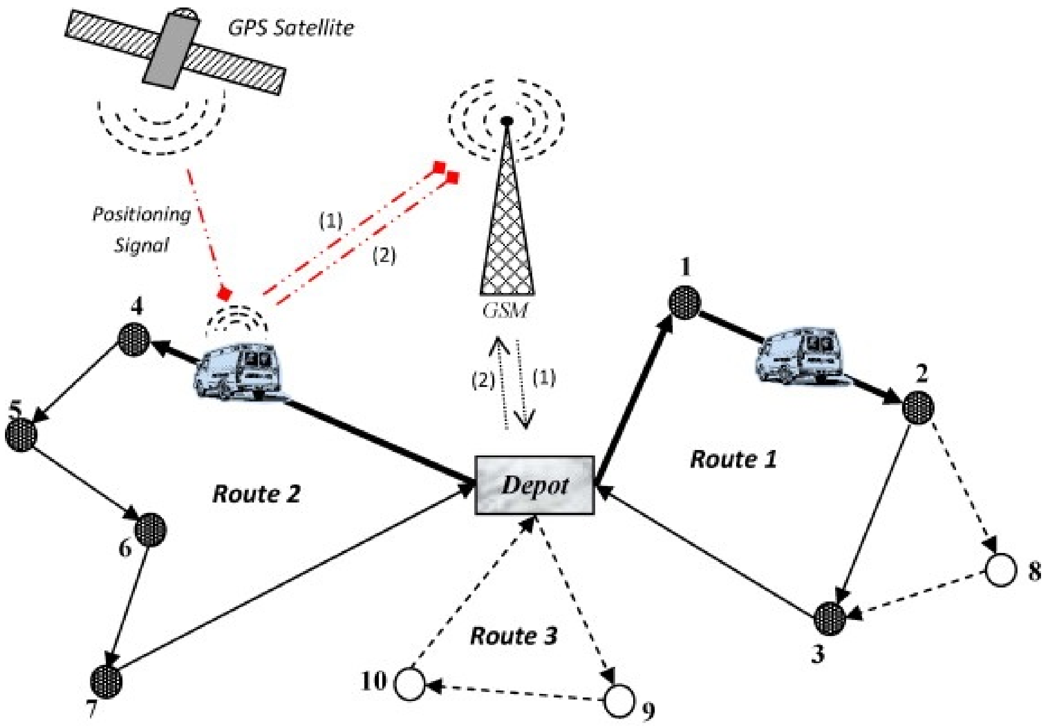
FMS: DEFINITION AND APPLICATIONS

- **Definition**: FMS comprises the optimal route planning, supervision and control of the fleet operations based on the available resources.
- A special focus is on the integration of organizational processes with modern information systems such as GPS, mobile phone apps using internet, etc.

- **Fields Of Application**:
  - Route Planning
  - Vehicle tracking
  - Fuel and speed management
  - Pick-up and delivery
  - …

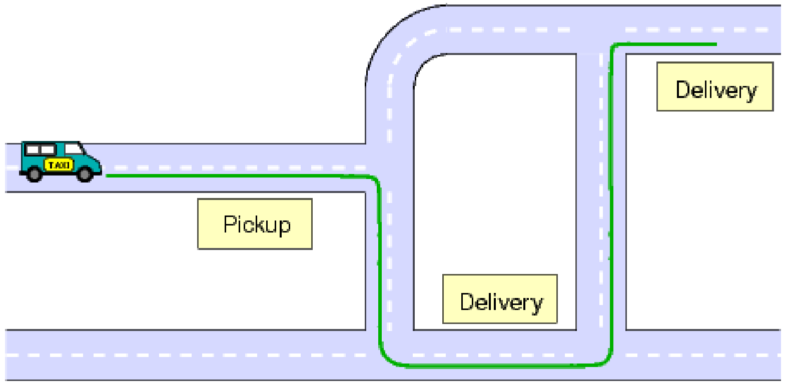
VEHICLE ROUTING PROBLEM (VRP)

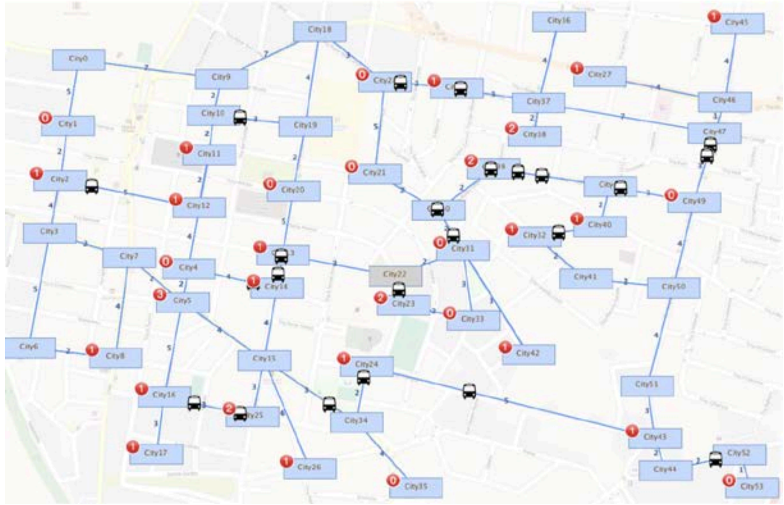
- **Objective:** To deliver customers/goods on minimum-cost vehicle routes originating and terminating at a depot.
- **How?** – By designing vehicle routes to serve the geographically dispersed customers/goods.
- VRP is one of the most challenging combinatorial optimization problems.
- Types of VRP:
  - VRP with time-windows
  - Capacitated VRP
  - Multi-depot VRP
  - VRP with backhauls, etc.



DIAL-A-RIDE PROBLEM (DARP): A VARIANT OF VRP

- **Objective:** To design vehicle routes and schedules for n users who specify pickup and delivery requests.
- **How?** - By planning a set of m minimum cost vehicle routes to serve maximum possible requests, under a set of constraints.
- A generalization of Pickup and Delivery Vehicle Routing Problem (PDVRP) and the Vehicle Routing Problem with Time Windows (VRPTW).
- Example: Mobility on demand.
- Trade-off: User convenience and operational costs.





METHODS TO SOLVE DARP

Exact

- Dynamic Programming
- Branch & Cut and Price
- Column generation
- Bender's Decomposition
- L-shaped algorithm, etc.

Heuristic and Meta-heuristics

- Tabu search
- Ant colony optimisation
- Simulated annealing
- Variable neighbourhood search
- Genetic algorithm, etc.

OPTIMISATION METHOD	PROS	CONS
EXACT	Guaranteed convergence to global optimum.	Computationally intensive.
HEURISTICS	Computationally efficient.	Traps at local optima.

Real world scenarios – Heuristics

OUTLINE

- Introduction
- DARP using Ant Colony Optimization
- DARP using Tabu Search
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- Dynamic DARP
- Simulations
- Conclusions

ANT COLONY OPTIMIZATION

It is a population based search technique for the solution of combinatorial optimisation problems.

- Inspired from real ants.
- Ants (who are almost blind) can find the shortest route to food source.

Approach:

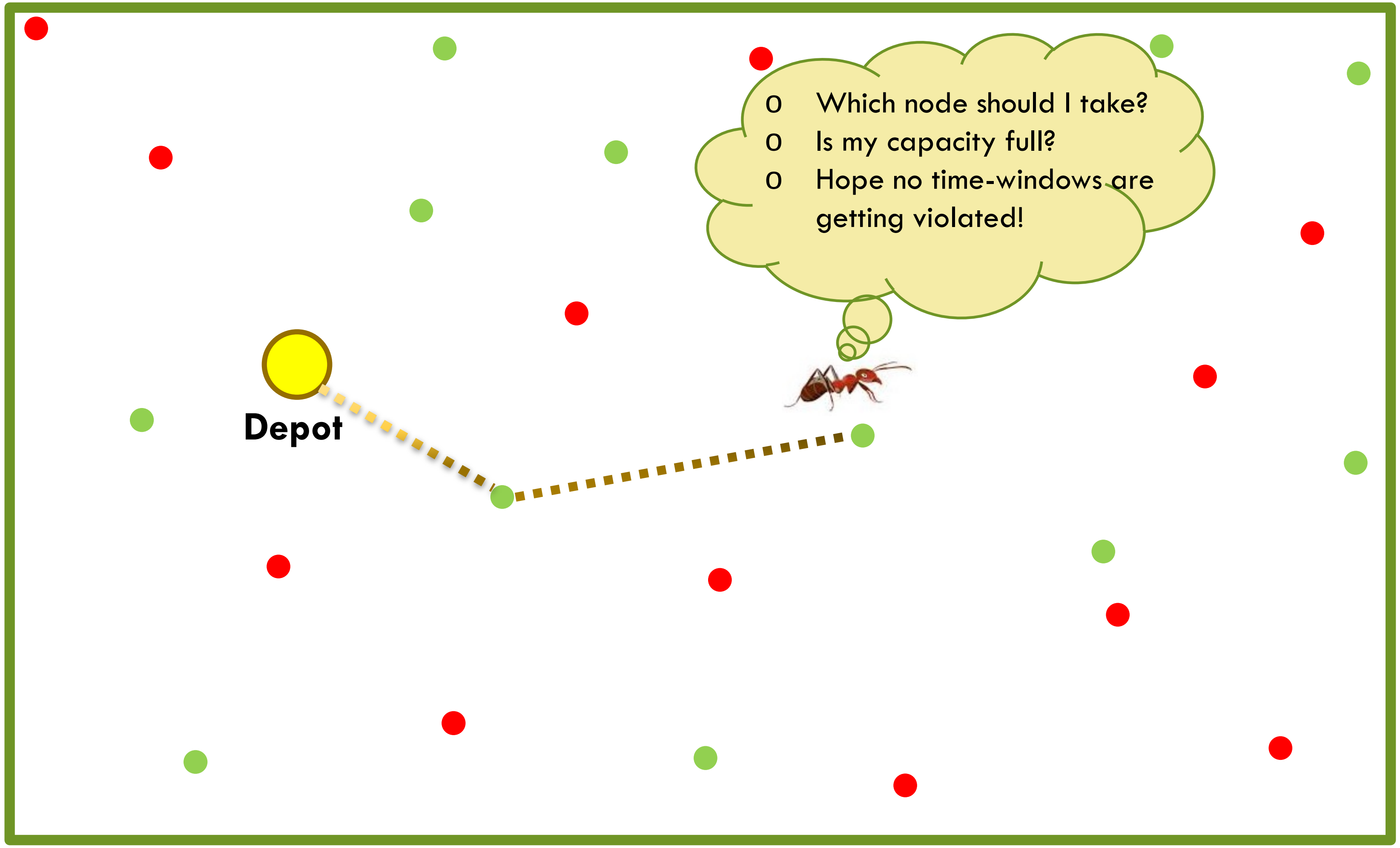
- Ants lay pheromones as signals for other ants.
- More ants follow a route, higher is its pheromone.
- Because of pheromone evaporation, always shorter routes are favoured.

Characteristics:

- Positive feedback.
- Distributed computation.

Step 1:

- Each ant chooses the next node.
- Iteration = Iteration + 1



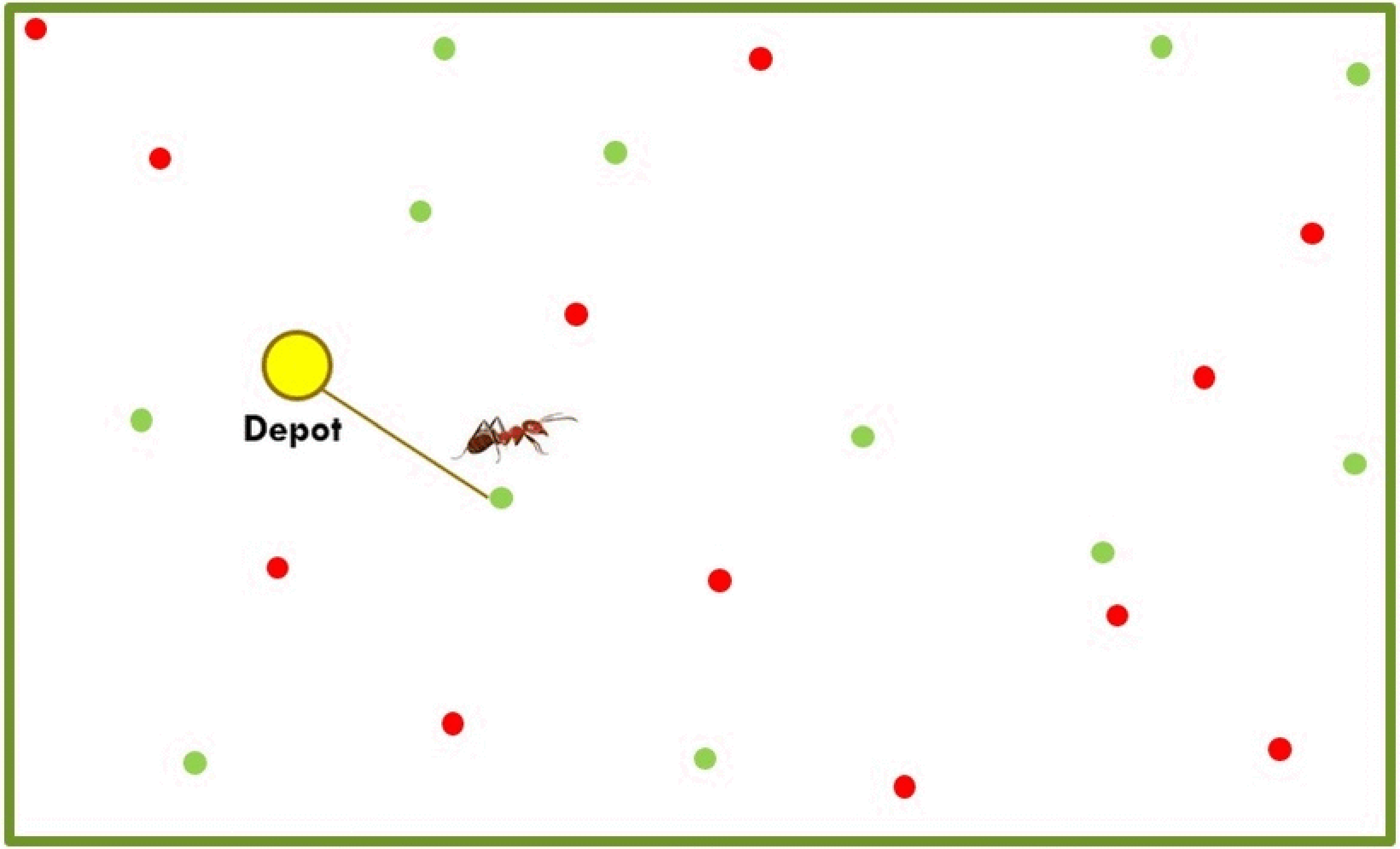
Pick-up node
Drop-off node
Pheromone trail

Mechanism:

1. Ants choose next node based on pheromone (and shortest distance).
2. Pheromone decays with time.

Step 2:

Each ant builds its route.

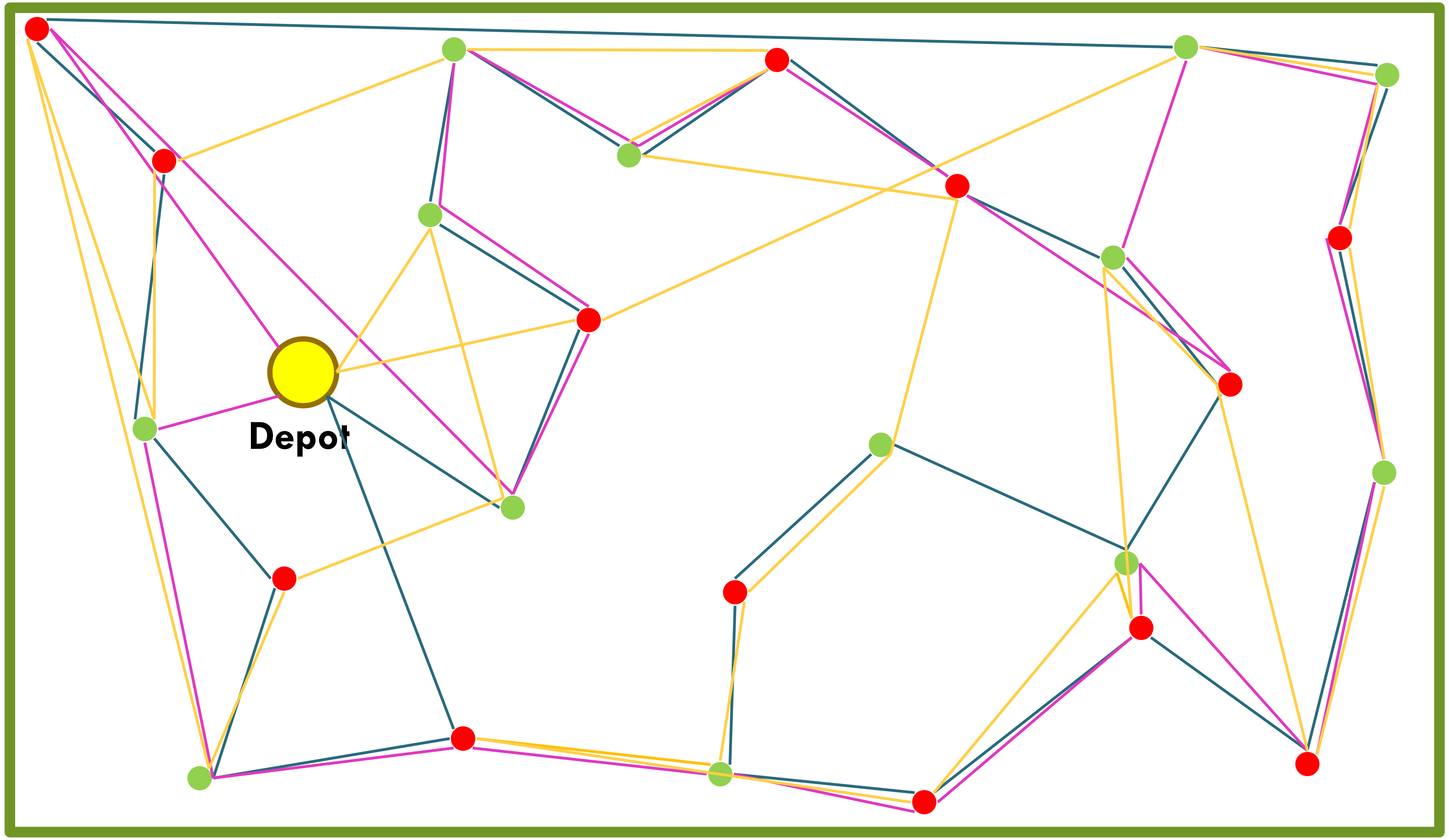


Route Building:

- This process repeats for each ant.
- Cost of each route is computed.

Step 3:

Routes of all the ants are compared.



Costs of routes of different ants:

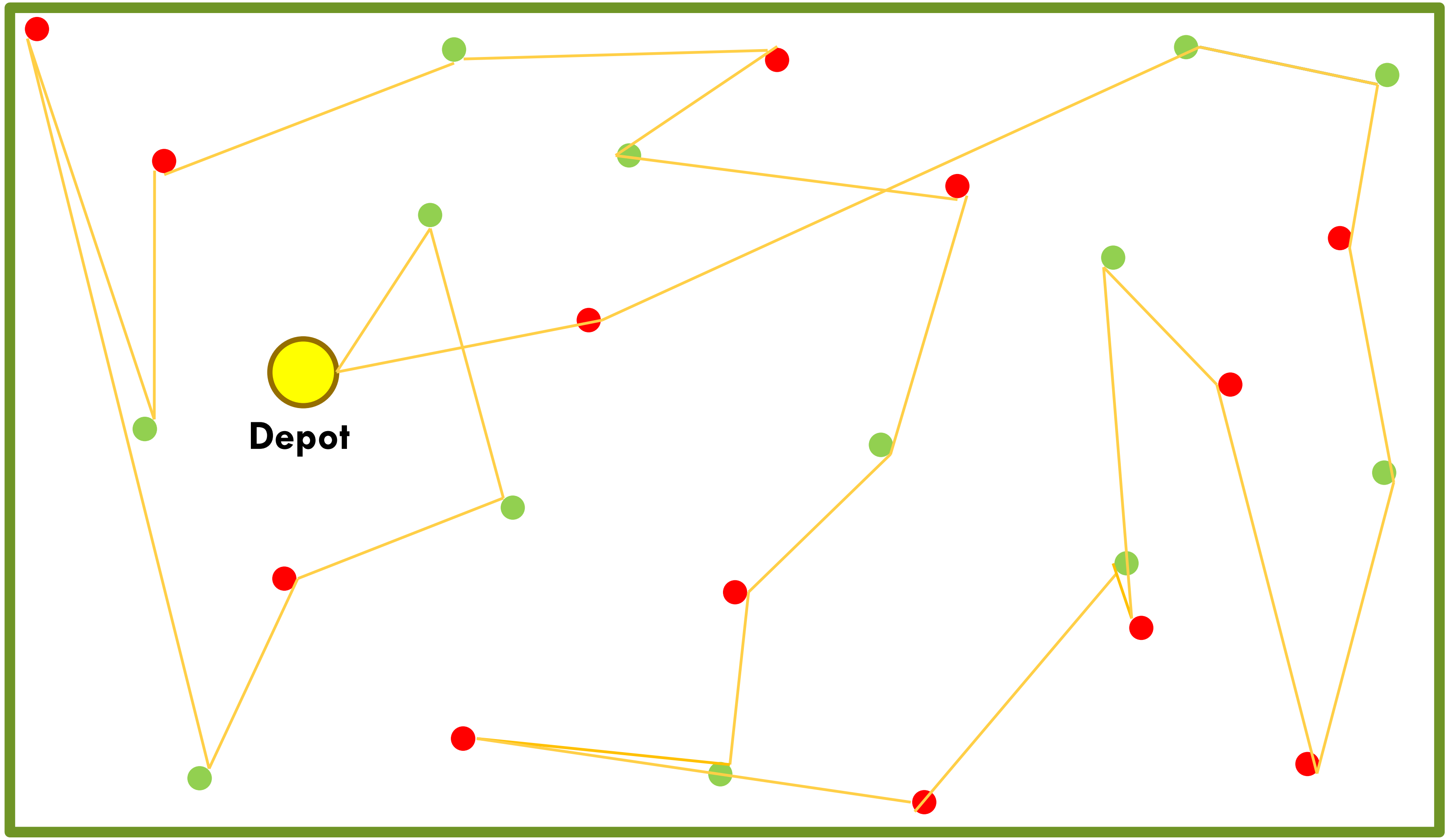
- 172
- 154 ✓
- 180

Pheromone Update:

- Path with shortest cost is chosen.
- Pheromone is updated on that path.

Step 4: Check if maximum iteration count is reached?

- Yes – Stop generating routes.
- No – Steps 1 to 3 are repeated.



Best route:

■	172
■	154 ✓
■	180

Iterations over:

The current route (solution) is accepted as the best one!

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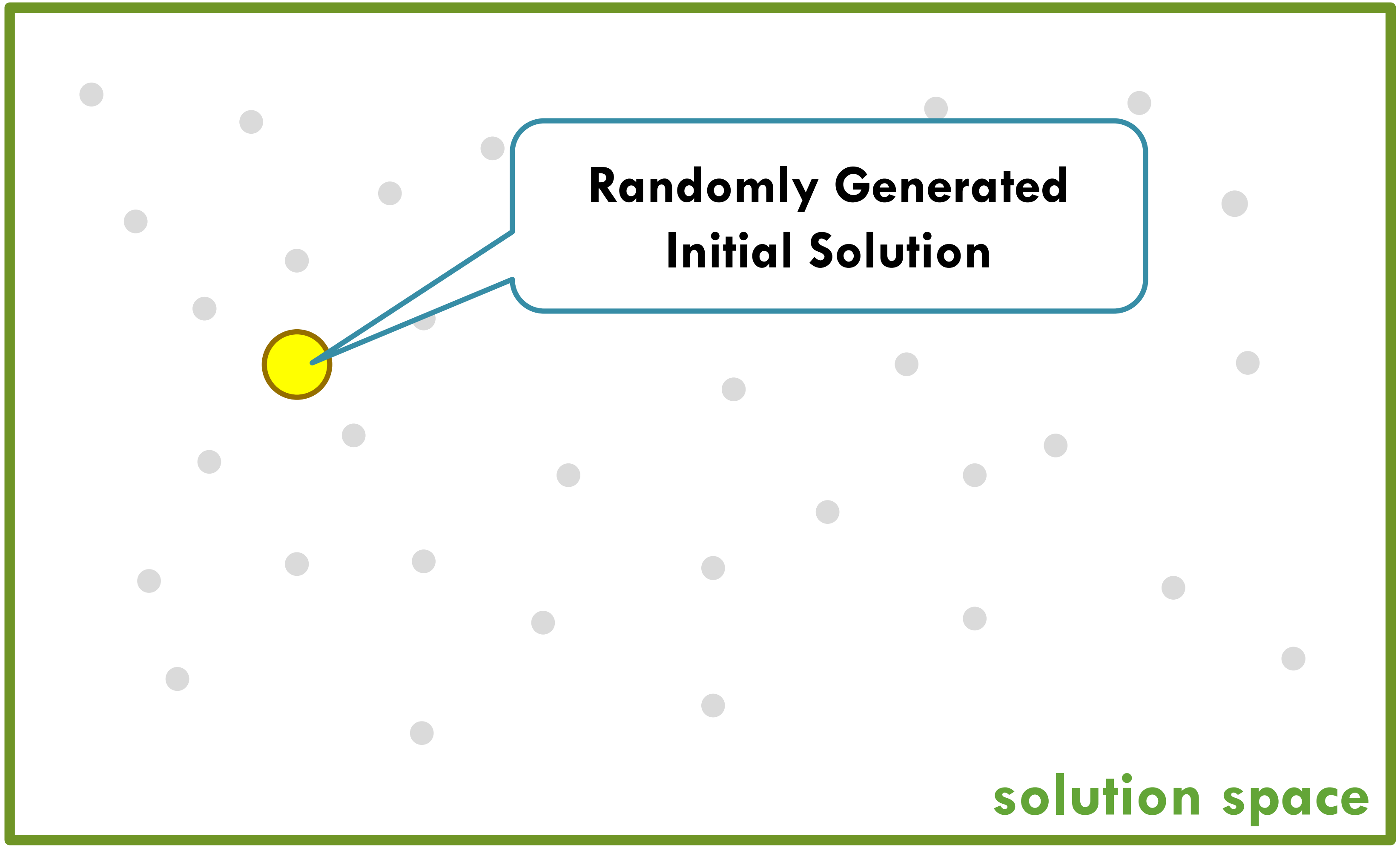
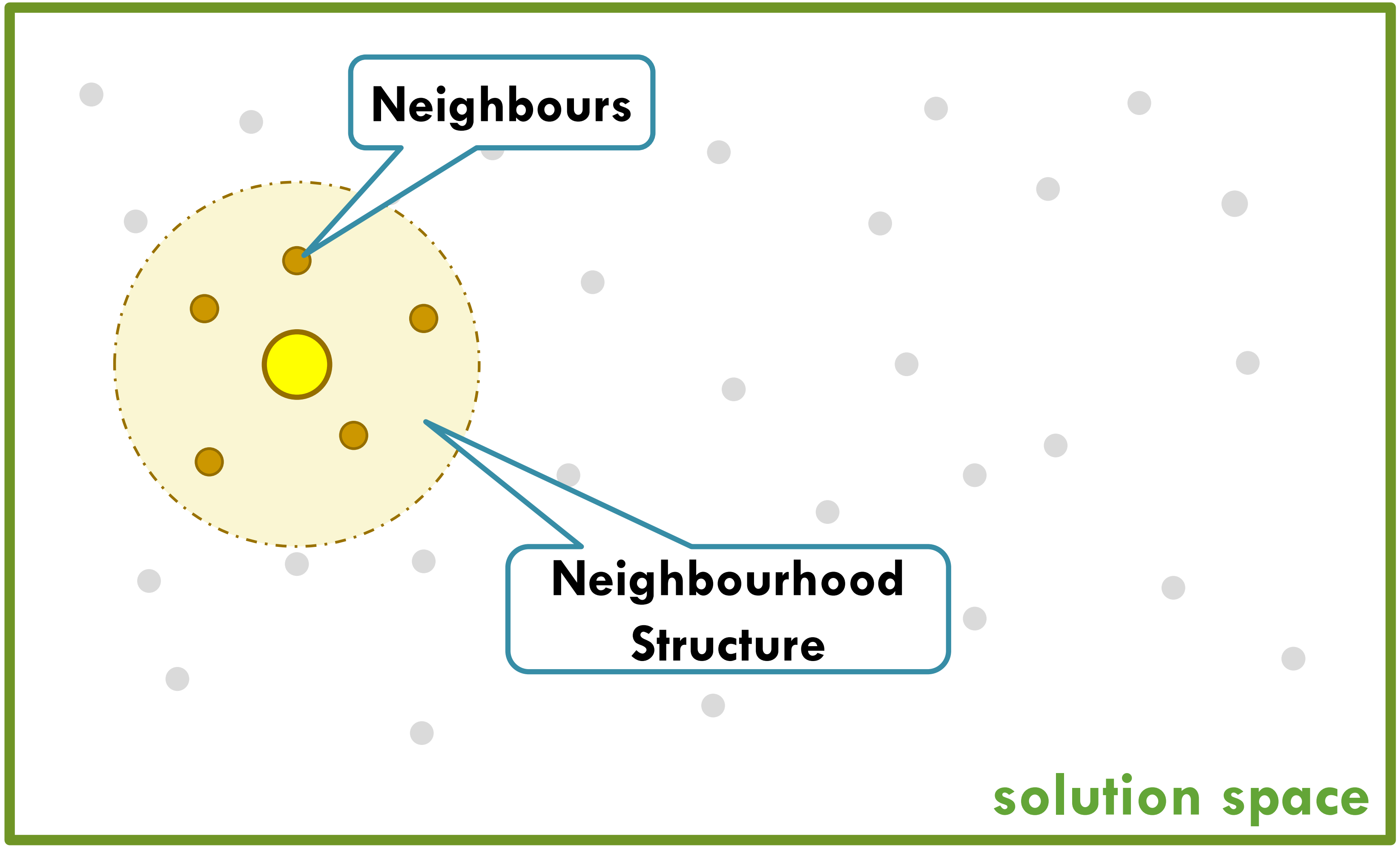
Step 1:

Randomly generate an initial solution



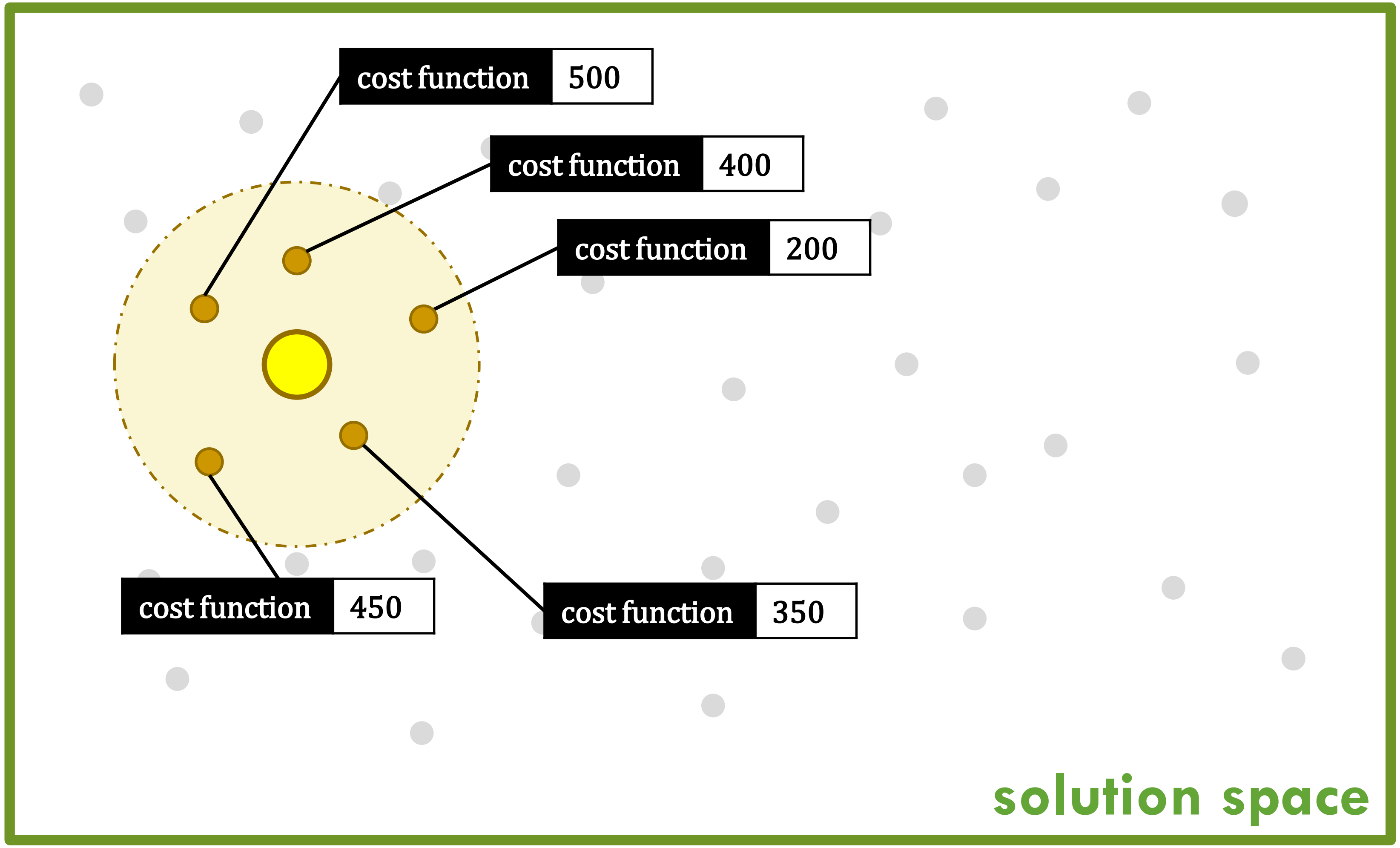
Step 2:

Explore all neighbours in a defined neighbourhood structure



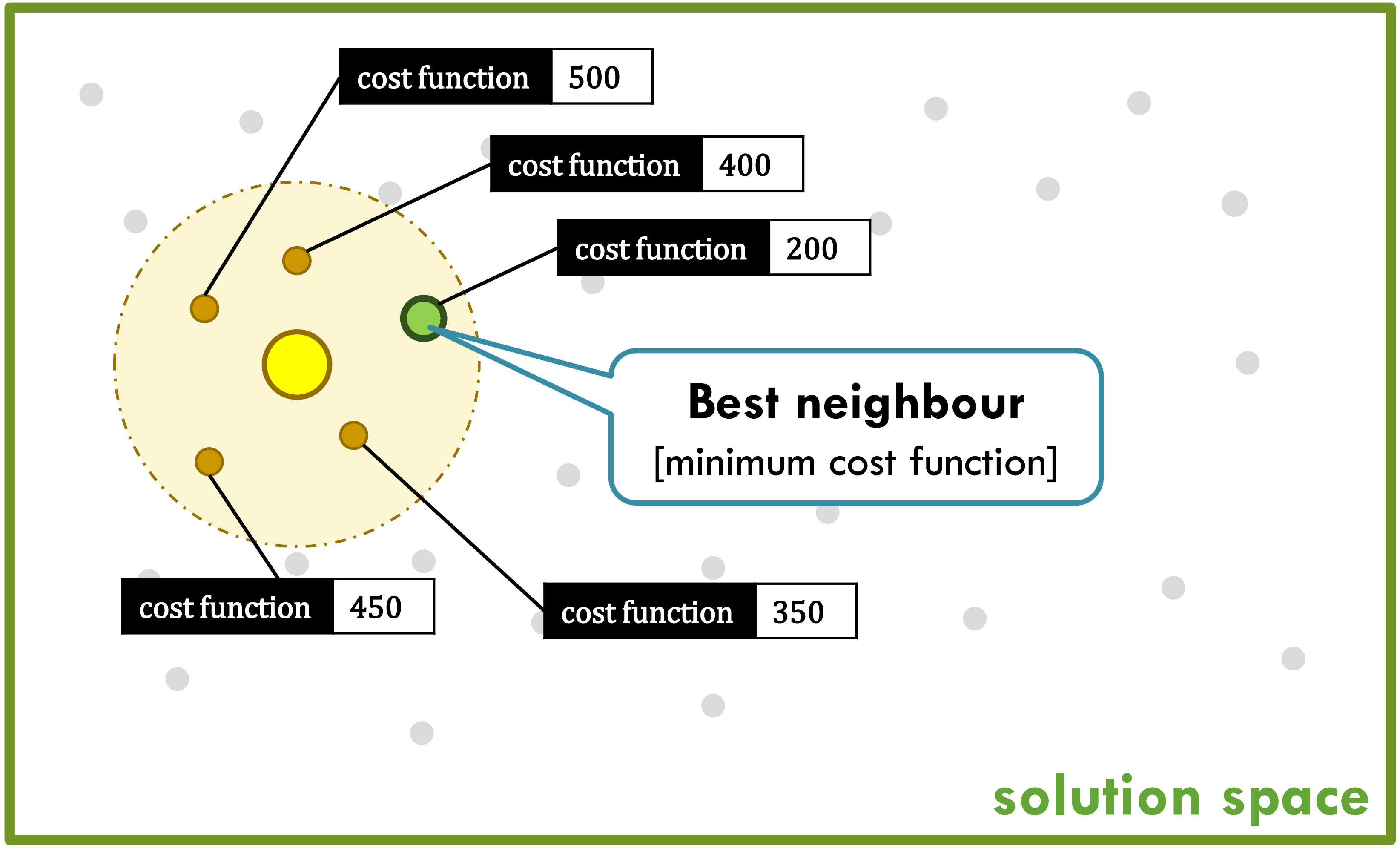
Step 3:

Evaluate the cost functions for all neighbours



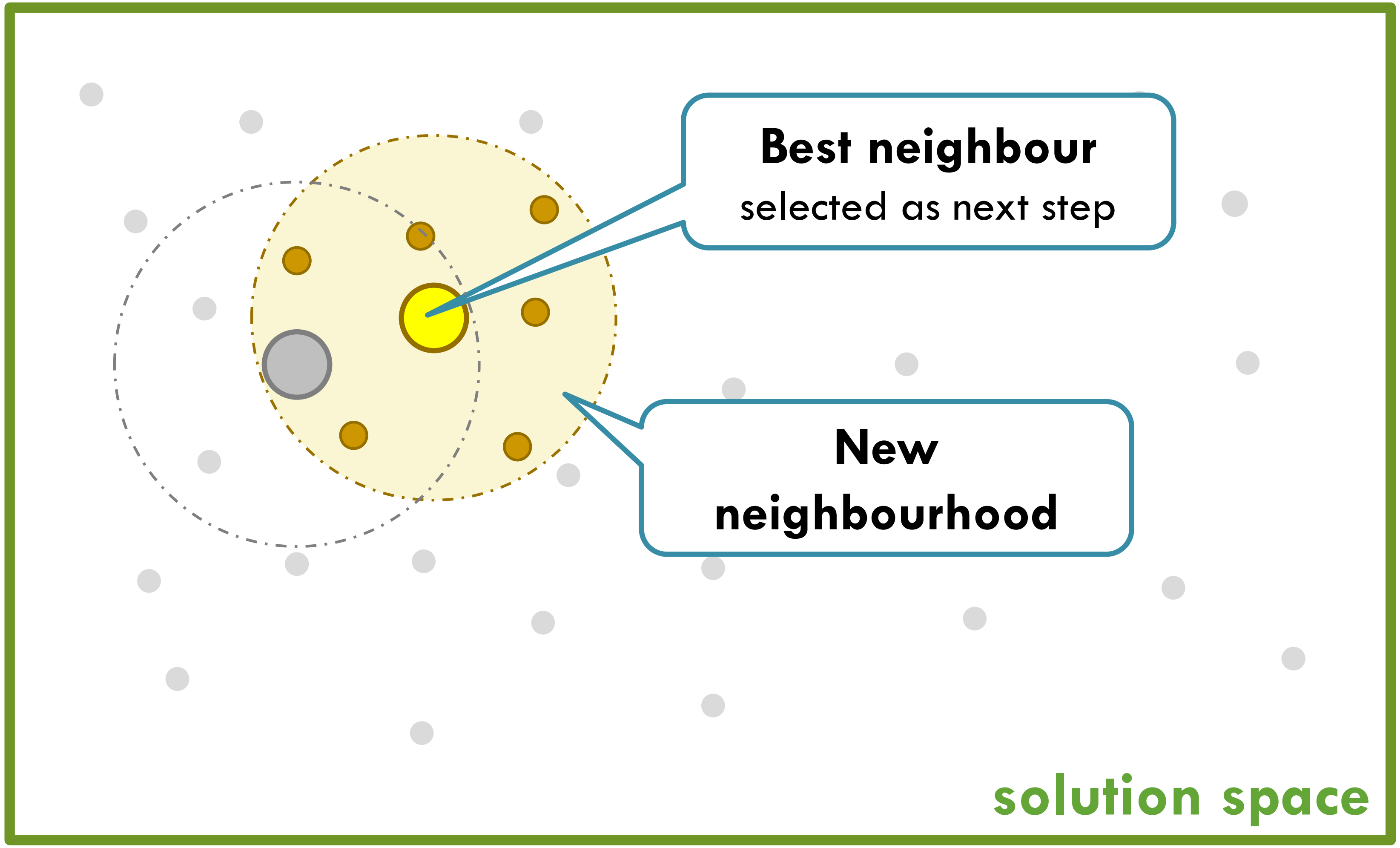
Step 4:

Find the best neighbour (neighbour with least cost function)



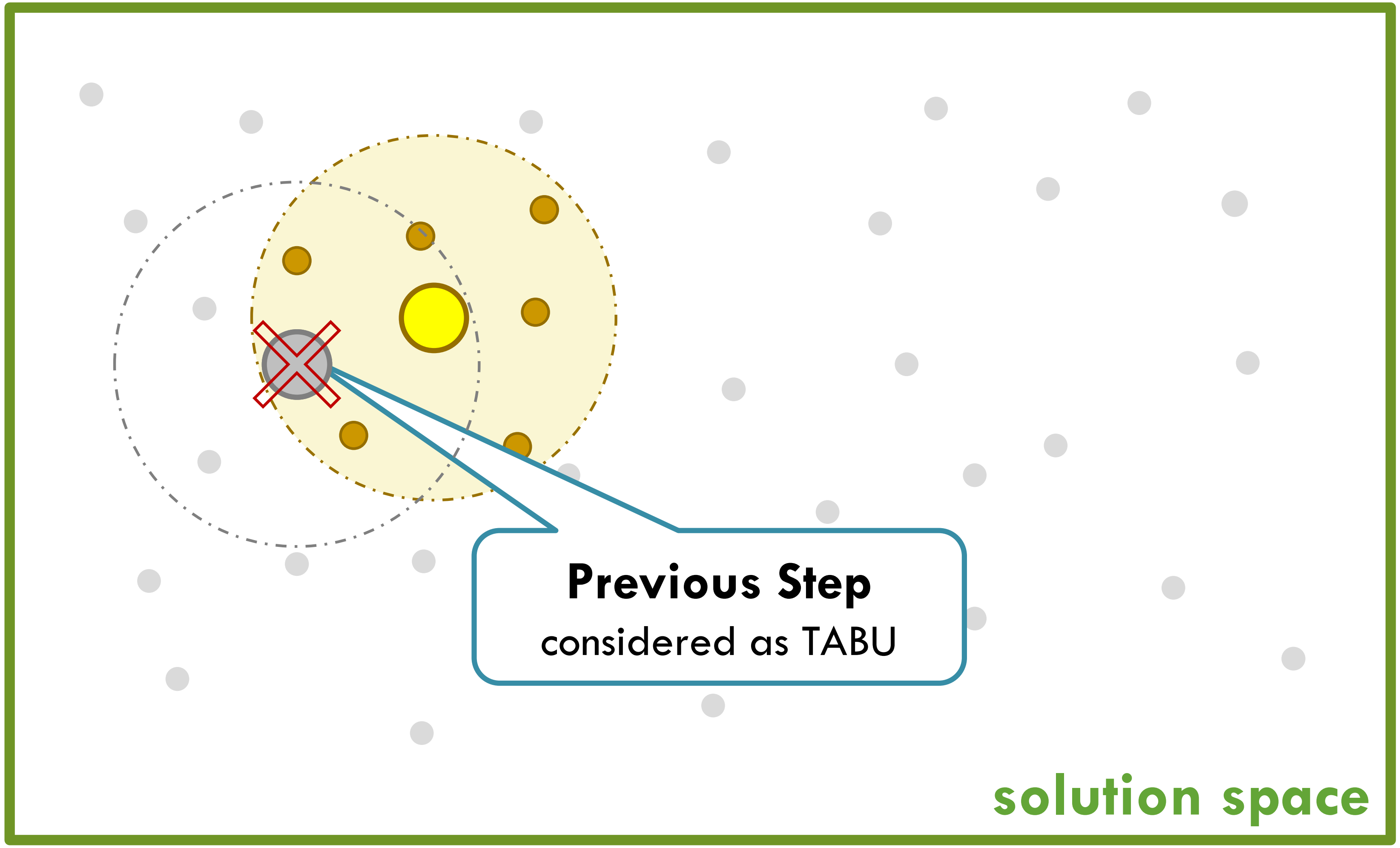
Step 5:

Select best neighbour as the next step



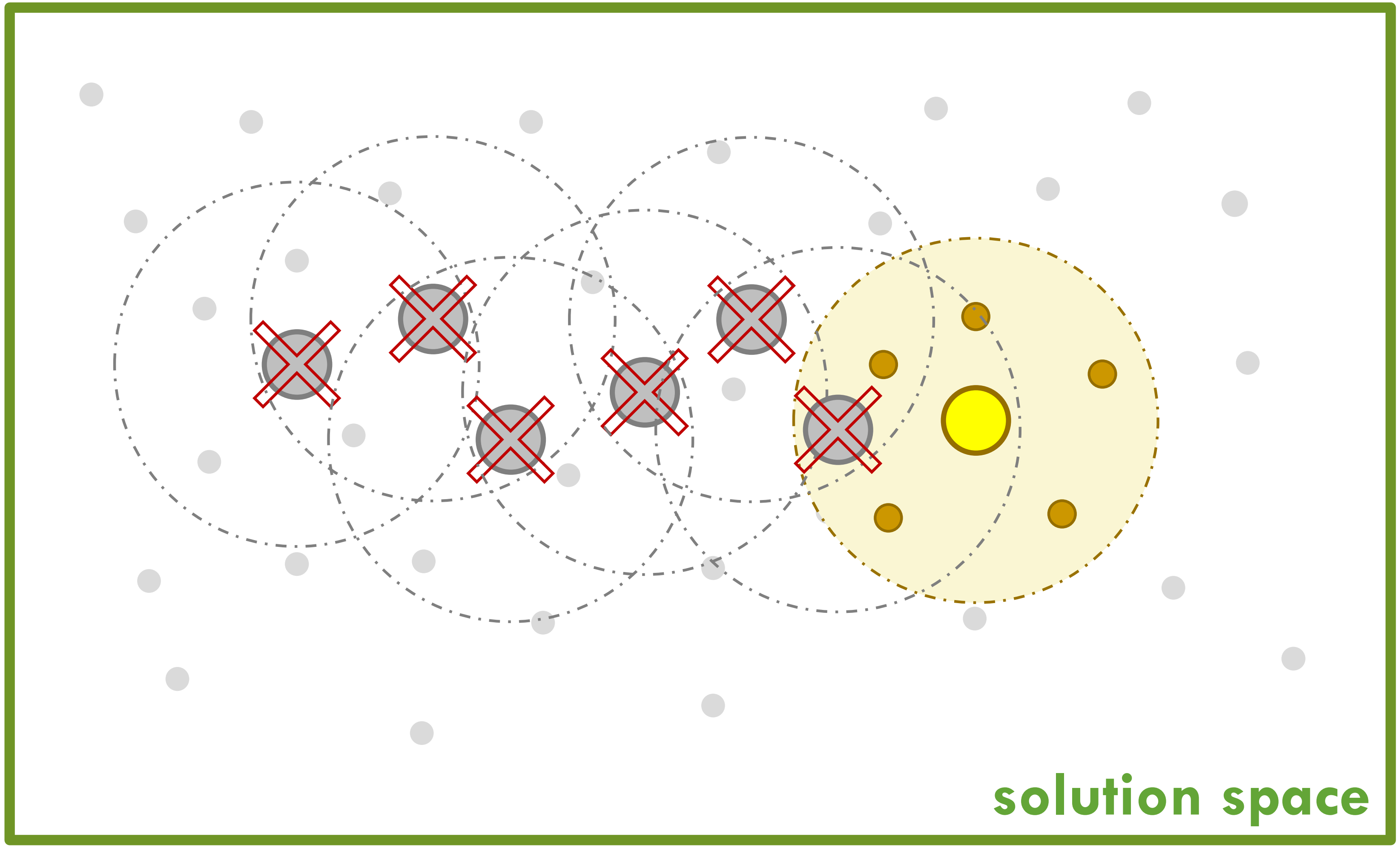
Step 6:

Previous step(s) are considered as TABU for several iterations



Step 7:

Repeat the steps until an optimal solution is obtained



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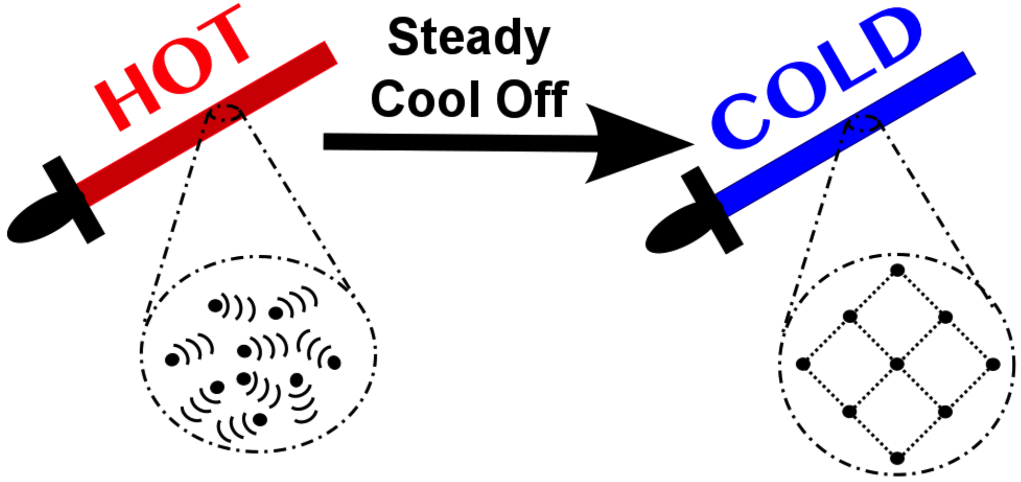
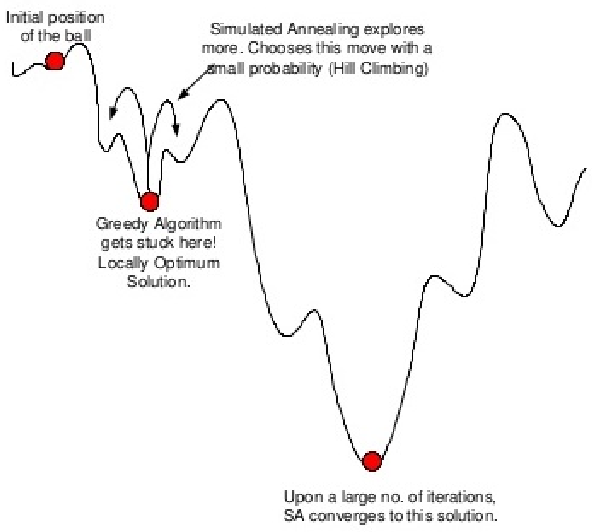
SIMULATED ANNEALING (SA)

A heuristic technique that mathematically mirrors the cooling of a set of atoms to a state of minimum energy.

Can avoid local extrema!





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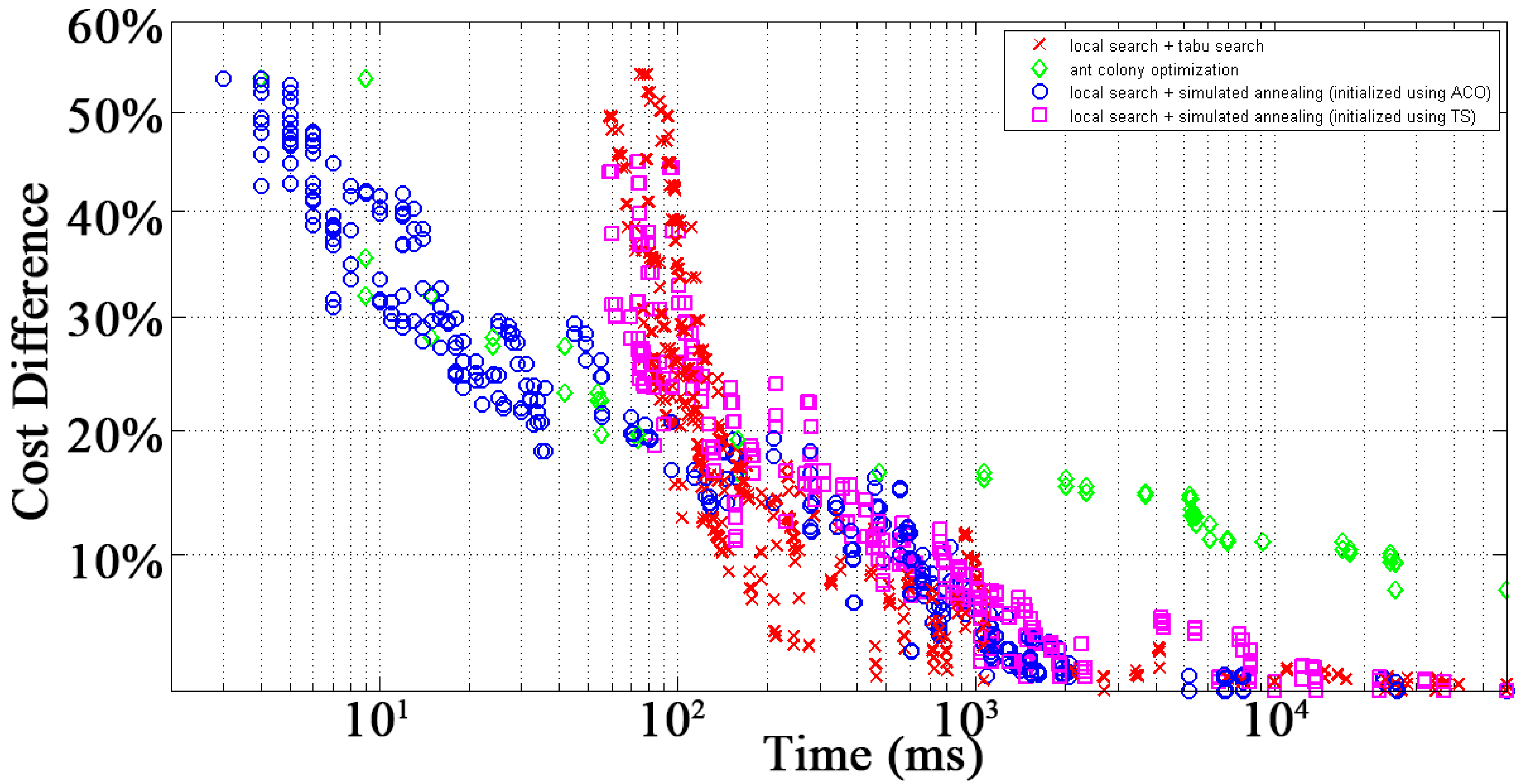
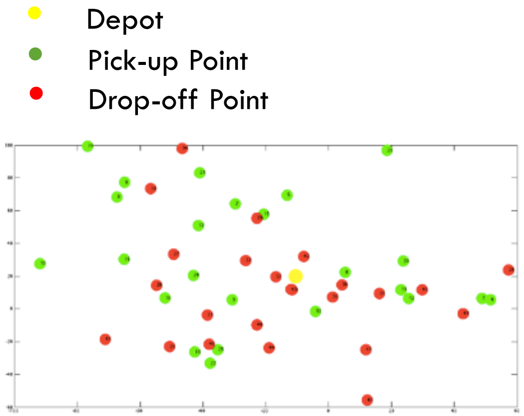
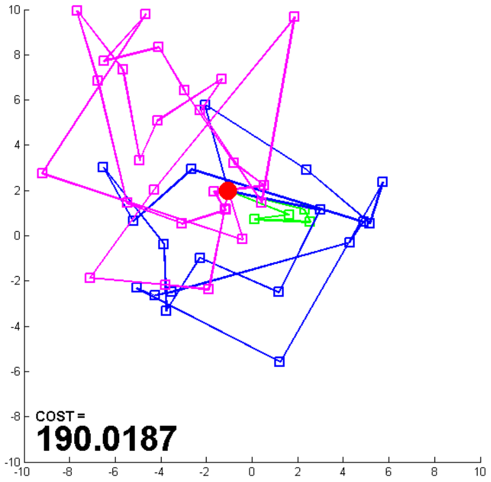
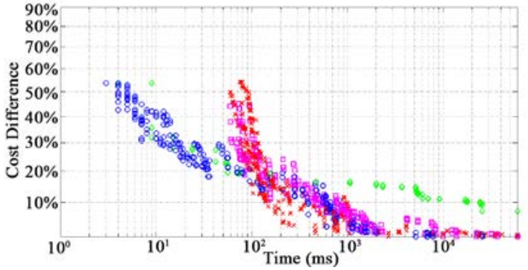
PR01: $24\ requests, 3\ vehicles\ (STATIC)$





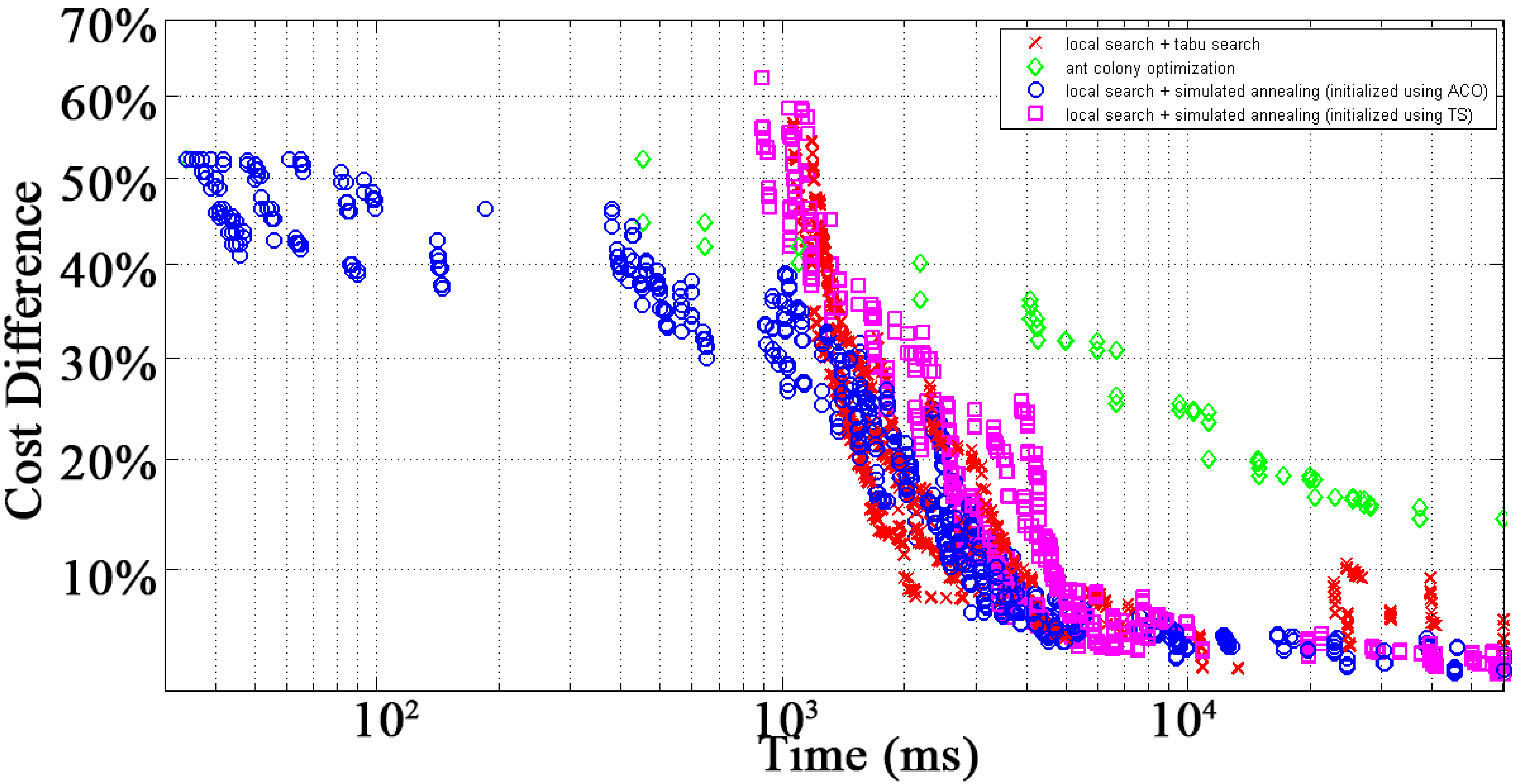


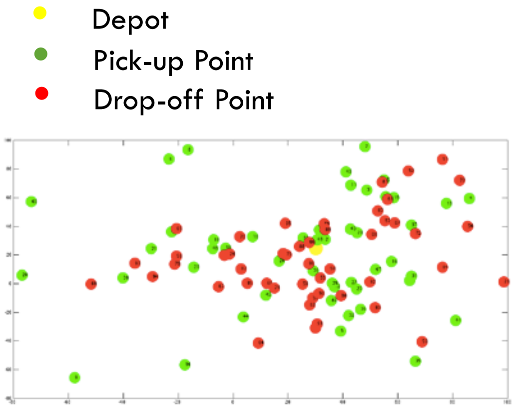


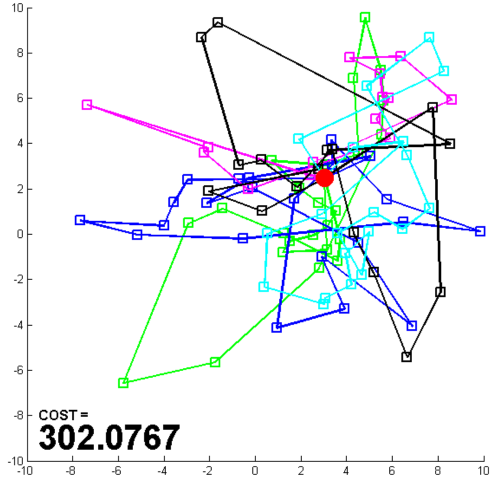
PR Data-sets for DARP: www.neumann.hec.ca/chairedistributique/data/darp/tabu

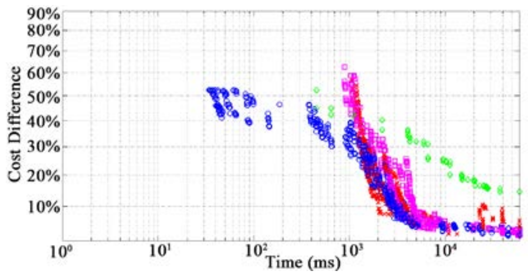
Cordeau, J.-F., and Laporte, G., A tabu search heuristic for the static multi-vehicle dial-a-ride problem, Transportation Research Part B: Methodological, vol. 37, no. 6, pp. 579-594, 2003.

PR02: $48\ requests, 5\ vehicles\ (STATIC)$









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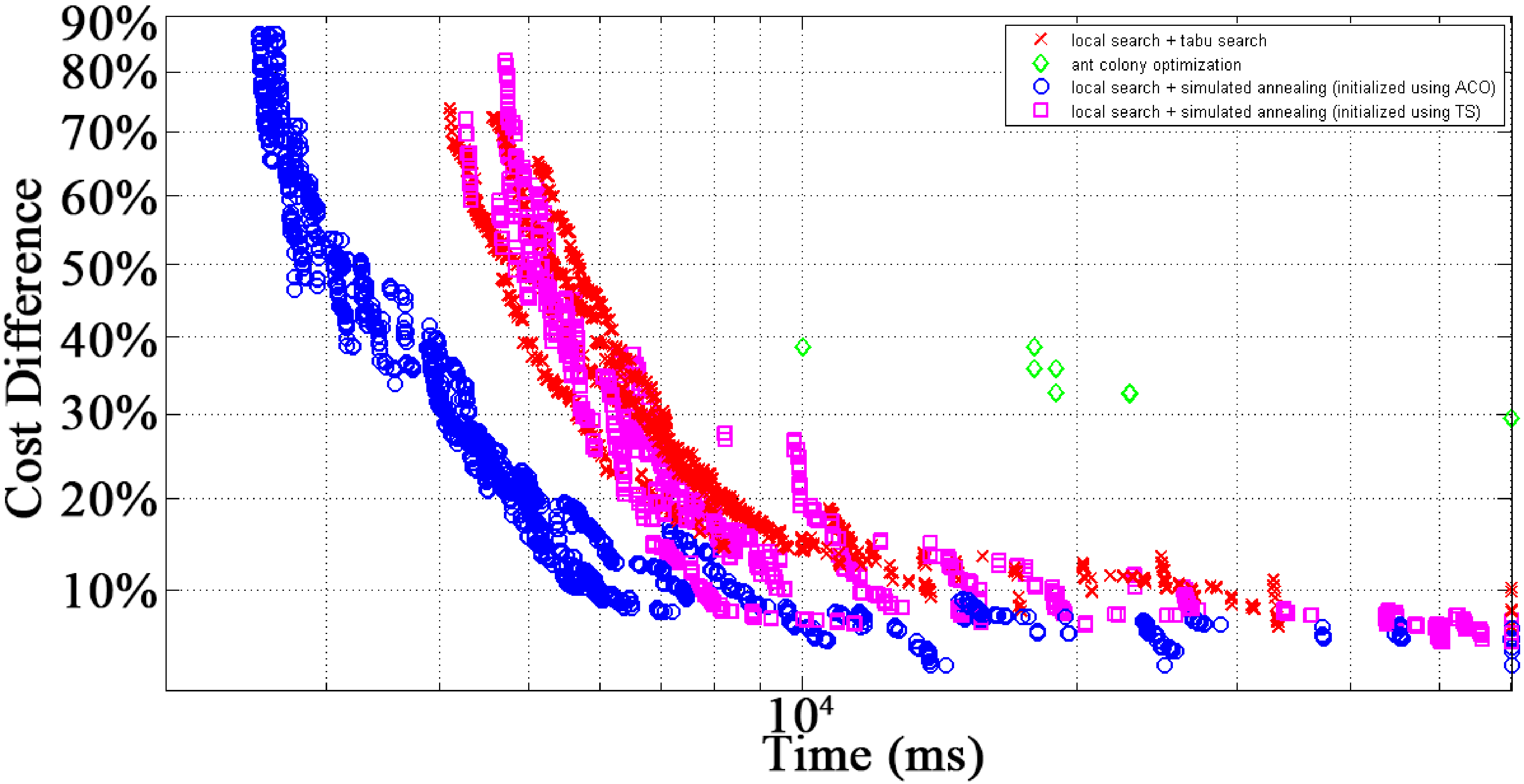
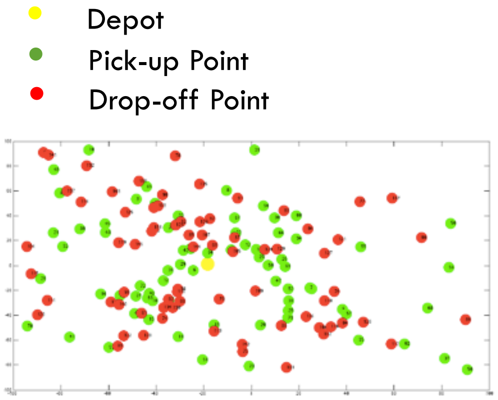
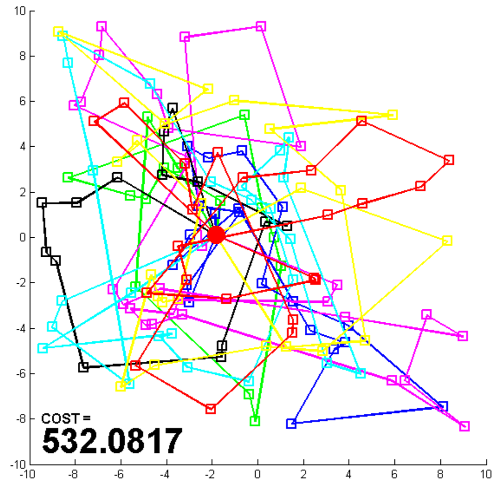
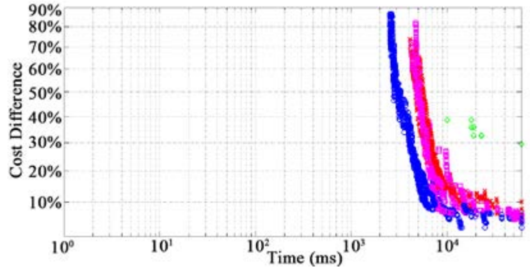
PR03: $72\ requests, 7\ vehicles\ (STATIC)$









PR Data-sets for DARP: www.neumann.hec.ca/chairedistributique/data/darp/tabu

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COMPARISON WITH BENCHMARK

Test Instances	Benchmark	Local Search + Tabu Search	Ant Colony Optimization	Local Search + Simulated Annealing (Initialized using ACO)	Local Search + Simulated Annealing (Initialized using TS)
PR01	190.019	190.019	203.896	**190.019**	190.019
PR02	301.34	306.546	345.272	**305.348**	305.258
PR03	532.00	564.730	689.023	**548.283**	556.698

Observation:

- Ant colony optimisation takes longer time to converge to global optimum.
- Tabu search is more likely to be trapped in local minima compared to simulated annealing.
- The performance of simulated annealing is affected by the initial solution.

PR Data-sets for DARP: www.neumann.hec.ca/chairedistributique/data/darp/tabu

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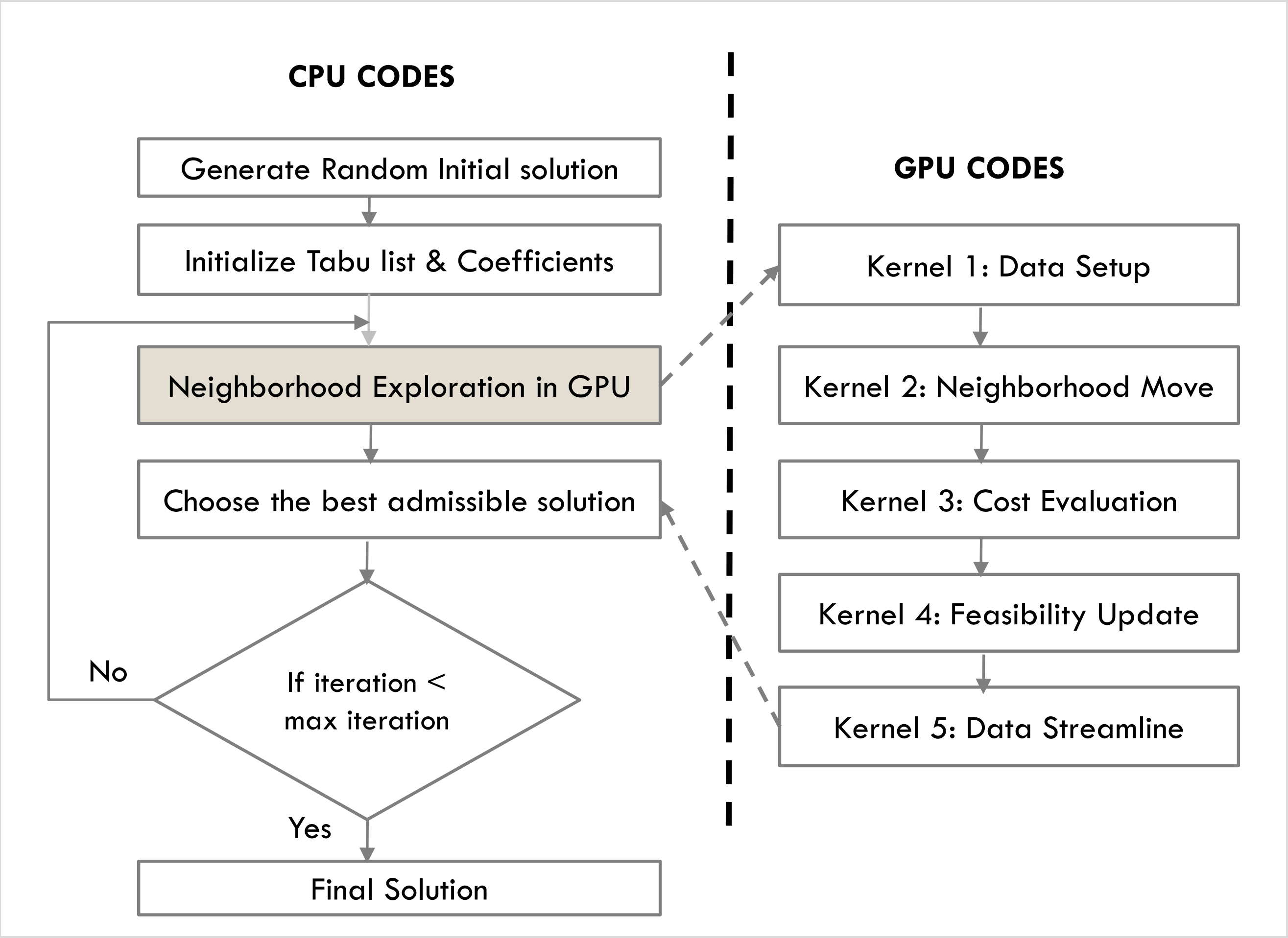
GPU-ACCELERATED CLASSICAL TABU SEARCH

- 81.1% time spent on Neighborhood exploration phase for tabu search, and its independency makes it possible for parallel exploration.

<u>Exploitation of heterogeneous platforms:</u>

- Faster convergence to global optimal solution
- Faster attainment of initial solution
- Exploration of complete neighborhood structure
- Efficiently solve bigger instances of dial-a-ride problem

OVERALL IMPLEMENTATION & CHALLENGES (RESOLVED)



Challenges (Resolved):

- **Thread Divergence**

  Neighborhood move with 100% branch efficiency

- **Communication Latency**

  <0.03% overhead as leveraged by the data streamline kernel.

- **Memory Hierarchy**

  Efficient Mapping of data structures appropriately into the GPU's platform

- **Kernel Grid Heuristic**

  Dynamic kernel configuration tuning for maximum possible acceleration.

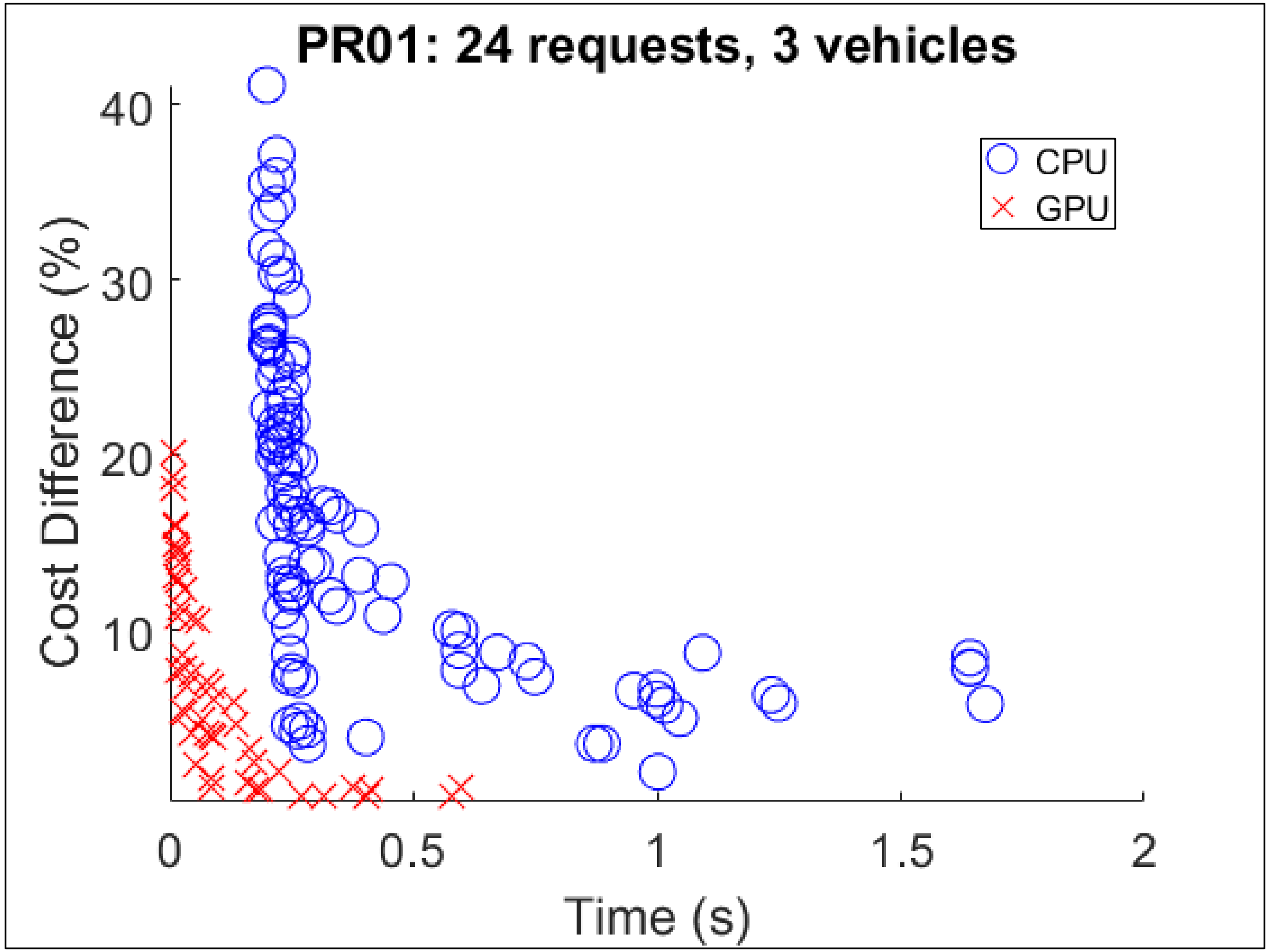
- **Synchronization Time**

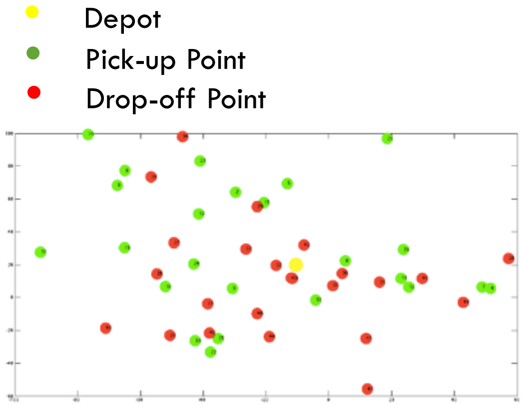
  Efficient organization of kernels in non-blocking whenever possible.

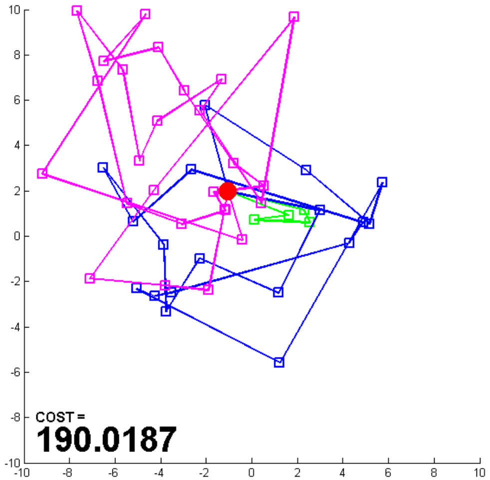
- **Algorithm Scalability**

  Host Streams with concurrent kernel design.

PR01: $24\ requests, 3\ vehicles\ (STATIC)$







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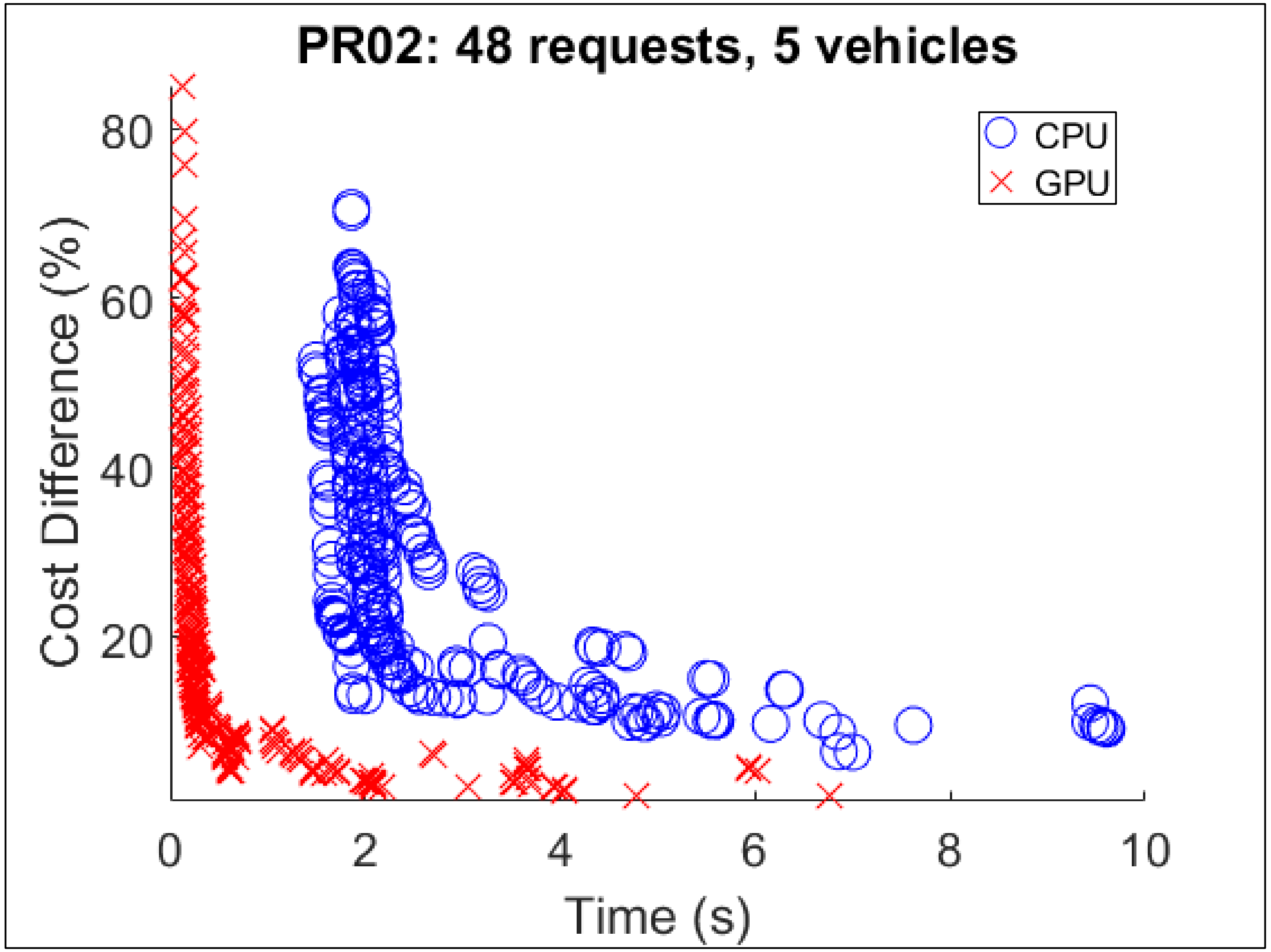

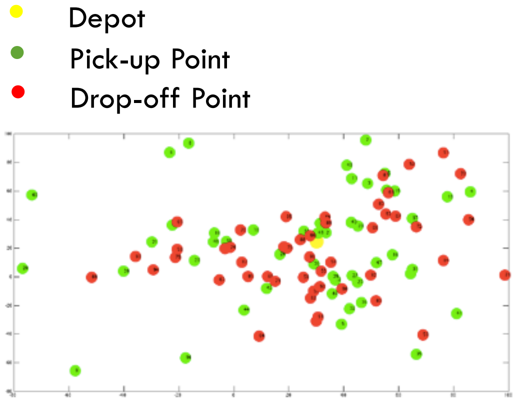

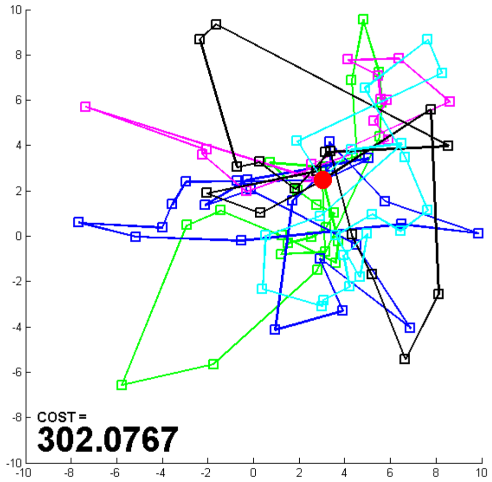

PR Data-sets for DARP: www.neumann.hec.ca/chairedistributique/data/darp/tabu

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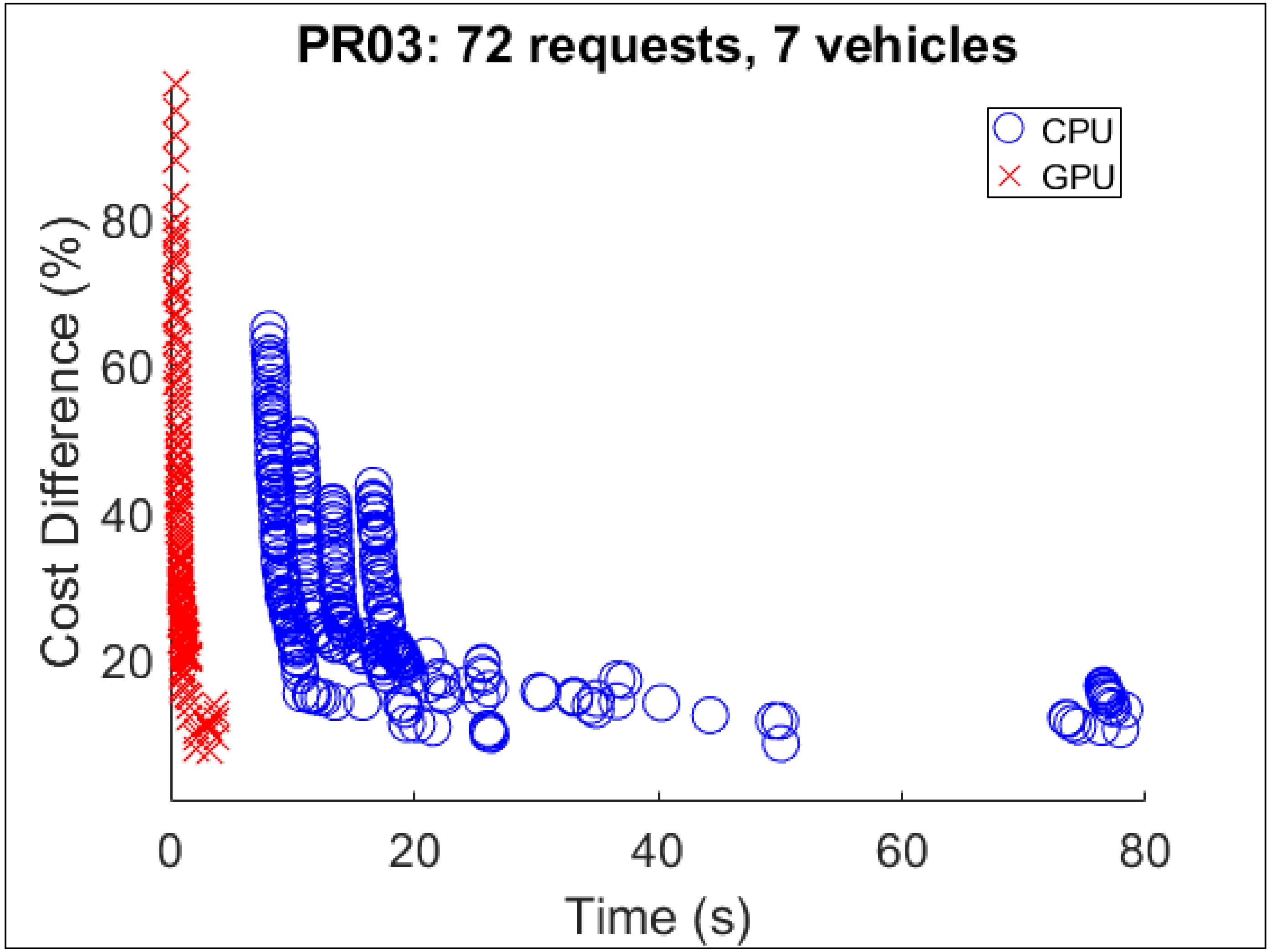
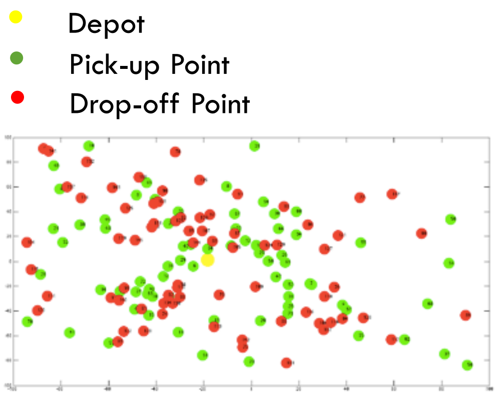
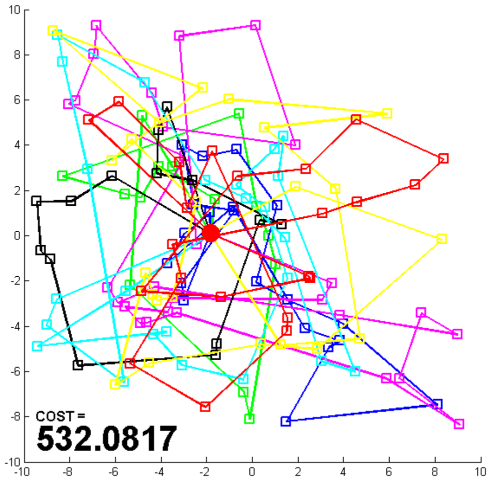
PR03: $72\ requests, 7\ vehicles\ (STATIC)$







PR Data-sets for DARP: www.neumann.hec.ca/chairedistributique/data/darp/tabu

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COMPUTATIONAL TIME COMPARISON: CPU VS GPU

Test Instances	Benchmark	Requests	Vehicles	Average Time for 10% Convergence		Average Speed up for 10% convergence (GPU vs CPU)
				CPU	GPU	
PR01	190.019	24	3	0.056	0.681	12.16 x
PR02	301.34	48	5	0.360	7.463	20.73 x
PR03	532.00	72	7	4.751	81.656	17.81 x

Accomplished

- Developed GPU-accelerated Classical Tabu Search Algorithm to solve multi-vehicle DARP instances.
- Several times faster attainment of near optimal solutions by using GPU on (Single Core) CPU.
- <0.03% communication latency between CPU-GPU makes the architecture scalable to multiple GPUs.
- Next: Revisit other algorithms to solve DARP by exploiting massively parallel platforms.

PR Data-sets for DARP: www.neumann.hec.ca/chairedistributique/data/darp/tabu. Each Instance is validated for 5 times repeatedly.

Cordeau, J.-F., and Laporte, G., A tabu search heuristic for the static multi-vehicle dial-a-ride problem, Transportation Research Part B: Methodological, vol. 37, no. 6, pp. 579-594, 2003.

FLEET SIZE MINIMISATION

<u>Objective:</u>

- To optimise the number of vehicles needed to solve dial-a-ride problems.

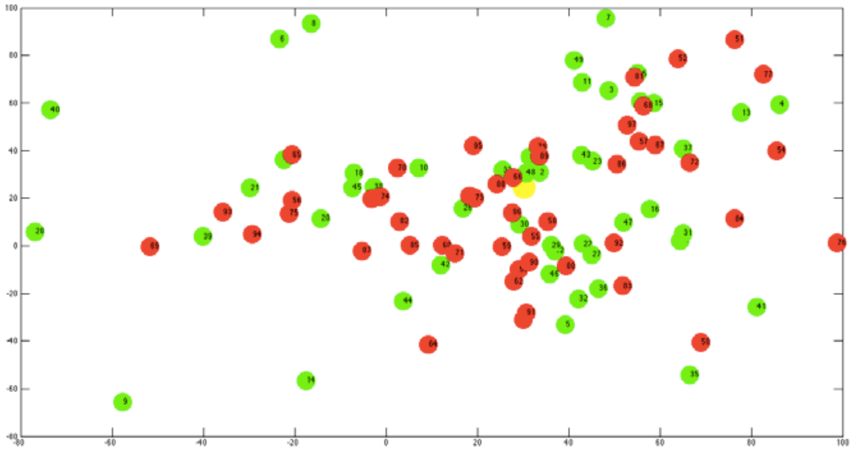
<u>Motivation:</u>

- To operate with minimum possible fleet of vehicles to improve fuel efficiency.
- To increase the throughput (revenue, labour costs, etc.).

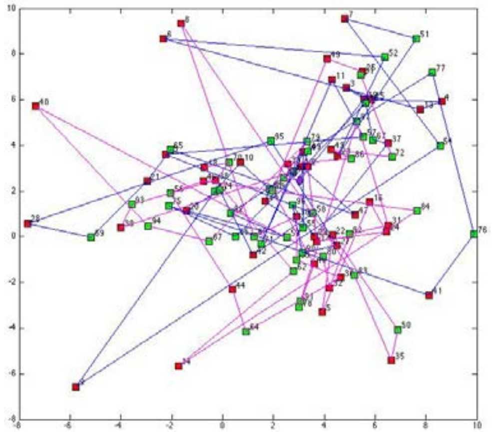
RESULTS

- **Given:**
  - Number of requests = 48
  - Number of vehicles = 5.
- **Cost minimisation:**
  - Number of requests = 48.
  - Number of vehicles = 5.
  - Cost = 345.37 km.
- **Fleet size minimisation:**
  - Number of requests served = 48.
  - Number of vehicles used = 2.
  - Cost = 361 km.

PR02 Test Instance



Vehicles Routes



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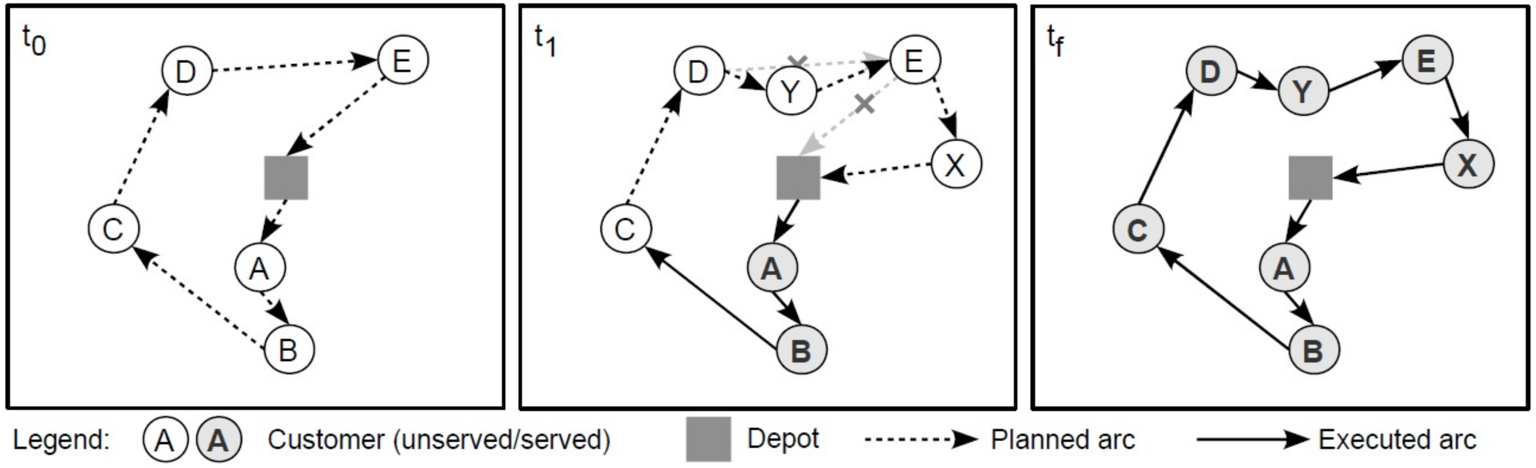
DYNAMIC DIAL-A-RIDE PROBLEM

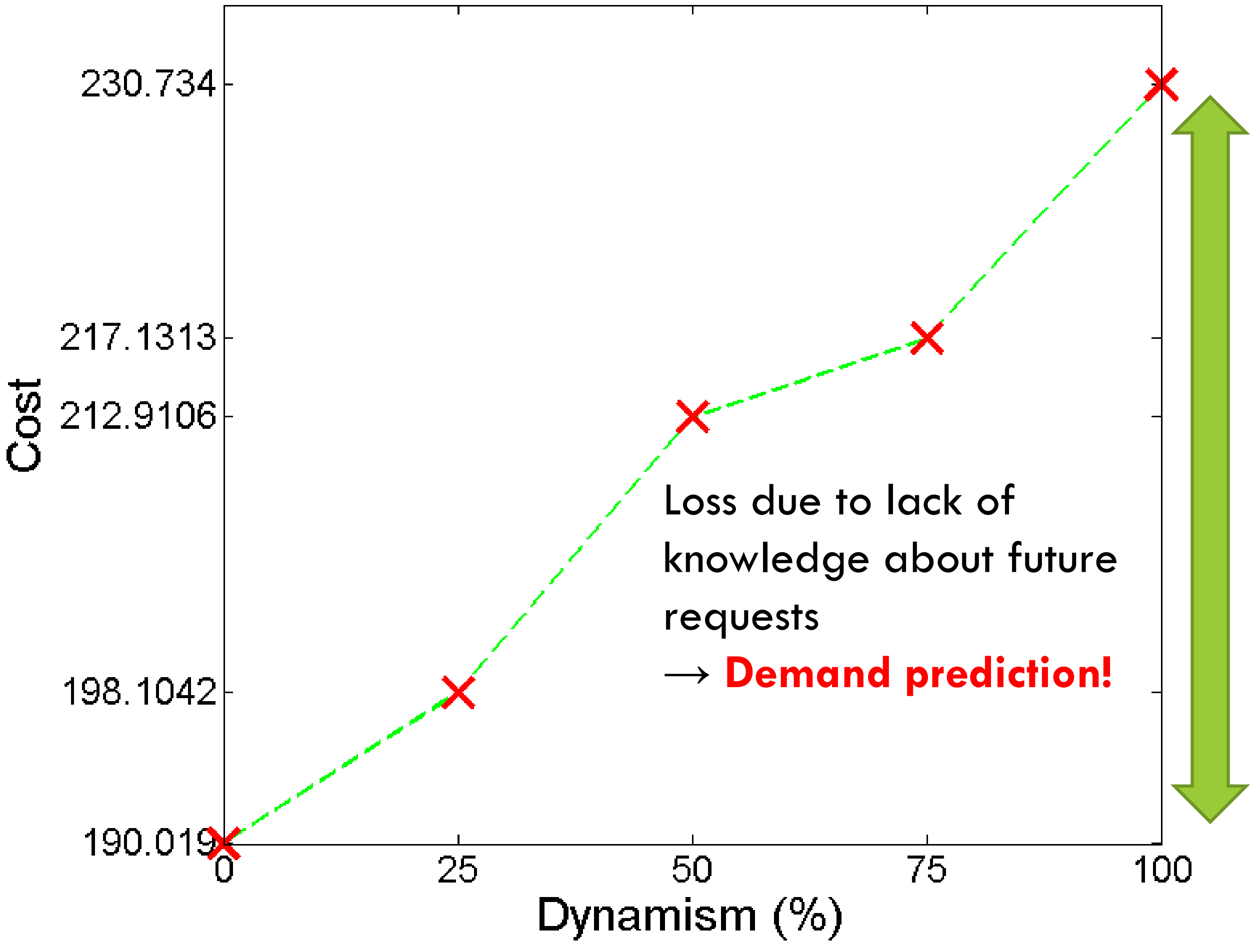
- In dynamic DARP, new requests can arrive when the vehicles have started serving existing requests.
- **Objective:** To generate an online routing plan for the vehicles as and when new requests arrive.
- The existing routes might change to accommodate the new requests.

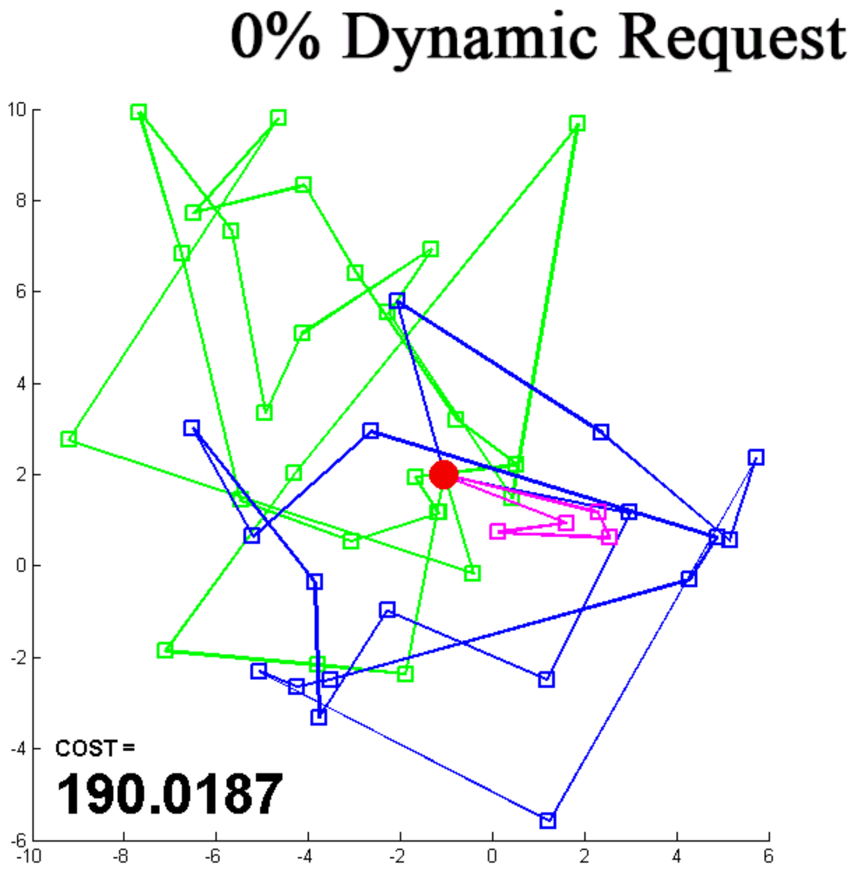


DYNAMISM

0% Dynamism (Static)	25% Dynamism	50% Dynamism	75% Dynamism	100% Dynamism
24 static requests + 0 dynamic request	18 static requests + 6 dynamic requests	12 static requests + 12 dynamic requests	6 static requests + 18 dynamic requests	0 static request + 24 dynamic requests
Total = 24 requests				

HIGHER DYNAMISM → LESS TIME TO PLAN AHEAD





TOWARDS SMARTER ROUTING ALGORITHMS

- Determine routes based on anticipated demand
  - This will lead to more efficient routes

- Take real-time traffic conditions into account
  - This will lead to more robust routes
  - Continuous monitoring and potential adjustment of planned routes

OUTLINE

- Introduction
- DARP using Ant Colony Optimization
- DARP using Tabu Search
- Simulated Annealing
- Static DARP
- Dynamic DARP
- Simulations
- Conclusions

SIMULATION ENGINE

High-fidelity simulation platform to verify routing algorithms in real-life scenarios.

- Traffic data
- Weather information
- Road congestion due to accidents, blockages, etc.

- Less expensive than field trials.
- Low-cost tool for prototyping FMS algorithms

TEST CASE: SENTOSA, SINGAPORE

Simulation:

- Replication of routes and intersections in Sentosa from Google maps.
- Includes public transportation.
- Identification of conflict areas and assigning 'right-of-the-way'.
- Heterogeneous traffic with realistic traffic delays and other vehicle behaviours.
- Initial steps towards demand modeling
- Implementation of routing algorithms using Vissim COM.

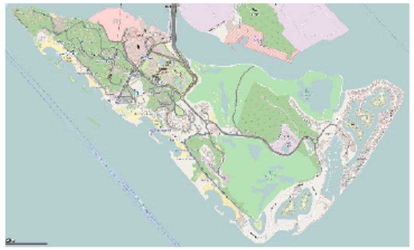
Singapore Map

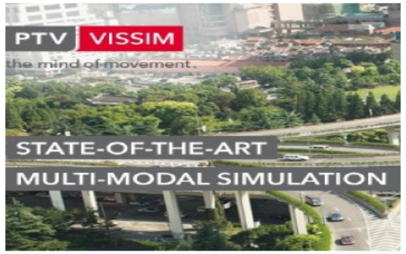
Sentosa Map

Conflict Areas on the Map

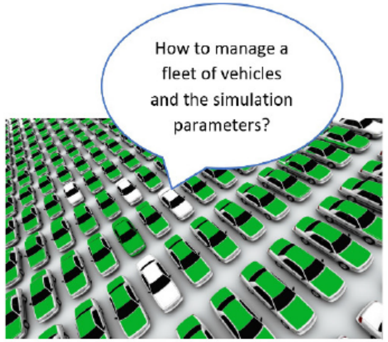
Public Transport & Heterogeneous Fleet

SIMULATION ENGINE - ARCHITECTURE





- Simulation Engine
  - Road network creation in Vissim
  - Fleet manager
    - Add vehicle
    - Stop vehicle
    - Update vehicle parameters
  - Link network map creation
  - Routing manager
    - Move vehicle from link A to B
    - Routing status
    - Route update
    - Read link parameters



SINGLE VEHICLE DARP SIMULATION

Single Vehicle Dial-A-Ride Problem

Principal Investigator: Prof. Justin Dauwels

Researchers: Dr. Sarat Chandra Nagavarapu, Dr. Twinkle Tripathy, Ramesh Ramasamy Pandi, Ho Song Guang

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

NATIONAL RESEARCH FOUNDATION
PRIME MINISTER'S OFFICE SINGAPORE

ST Engineering

OUTLINE

- Introduction
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CONCLUSION & FUTURE WORK

Conclusion:

- Solved the dial-a-ride problem using different meta-heuristic algorithms.
- Carried out a comparative study on the performance of various meta-heuristic algorithms on different test instances.
- Solved the dynamic dial-a-ride problem using different meta-heuristic algorithms.
- Proposed an approach to optimise the fleet size in DARP.

Future Work:

- **Customer demand modelling** to design robust algorithms for on-demand mobility.
- **Real-time traffic data** (time-varying travel times)


thank you
danke
謝謝
ngiyabonga
rахмат
рахмат
Баярлалаа
спасибо
teşekkür ederim
gracias
tapadh leat
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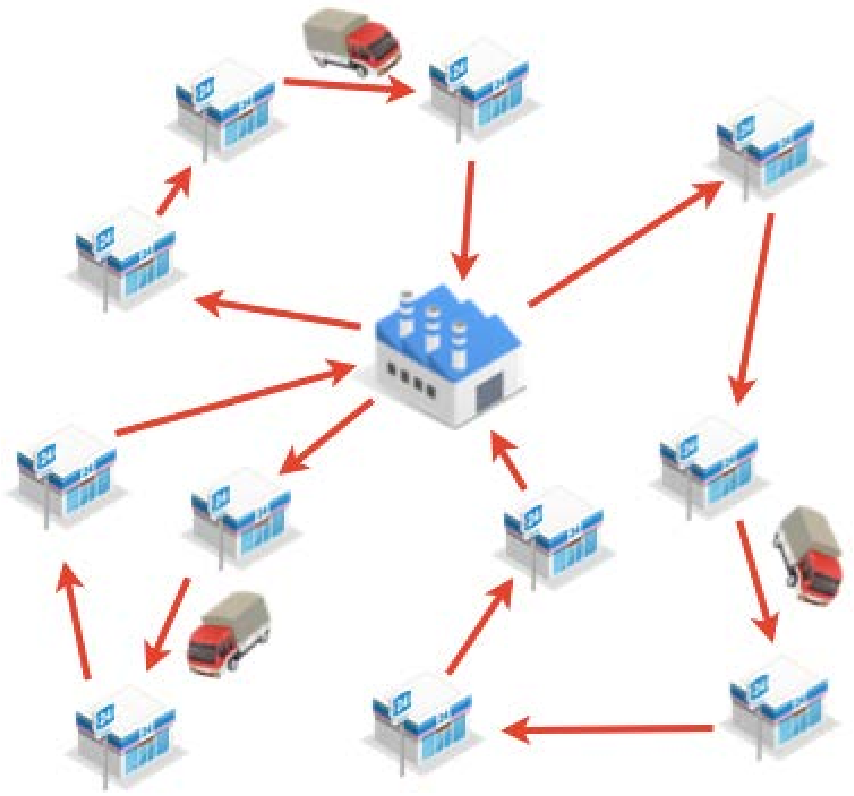
TOWARDS NEXT-GENERATION FLEET MANAGEMENT SYSTEMS



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