# Solving the Dial-a-Ride Problem with the Firefly Metaheuristic

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# Introduction & Motivation

- The DARP: A vehicle routing problem characterized by
  - User-orientation
  - Small vehicles, like vans, shared by users
  - Flexible routes and schedules
- In Germany: (An-)Rufbus or Taxibus. In Switzerland: Publicar
- Example of application: Patients of hemodialysis
- Their need: Door-to-door transport from home to the hospital

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- Example of application: Patients of hemodialysis
- Their need: Door-to-door transport from home to the hospital
- **Motivations:**
  - Improvement of urban mobility and public transportation
  - Reduction of costs for people who need this kind of transport

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# Approach & Contribution

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- Subject to a set of constraints that guarantee comfort
- We proceed with 2 approaches:
  - Exact approach with a generic solver
  - Near-optimal approach with the implementation of a metaheuristic
- Our contribution:
  - Comparison of the generic solver with the metaheuristic
  - Application of swarm intelligence to the DARP
  - New way to represent the solution

# The Dial-a-Ride Problem (DARP)

- The DARP is a vehicle routing problem, proven to be $\mathcal{NP}$-hard
- It "extends" the *Pickup and Deliver Vehicle Routing Problem* and the *Vehicle Routing Problem with Time Windows*

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- The DARP is a vehicle routing problem, proven to be $\mathcal{NP}$-hard
- It “extends” the *Pickup and Deliver Vehicle Routing Problem* and the *Vehicle Routing Problem with Time Windows*
- There is a fleet of **homogeneous vehicles** with a **unique depot**
- Set of transport requests from passengers, known beforehand (**static** version)
- Maximal vehicle route duration and vehicle capacity
- Maximal user ride time

# Request Characteristics

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  - V is the set with every location of every request
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- The costs and time are assumed to be the *Cartesian distance* between the locations

# Goal

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**Optimal Solution:** Feasible solution whose total duration time is less than or equal to any other feasible solution's total duration time

# Exact Approach

- **Integer Linear Programming**
- Method commonly used in mathematics and operations research
- Represent the problem in a mathematical language (e.g. *AMPL*)
- Solve via generic solver (e.g. *GNU Linear Programming Kit*)
- Algorithms behind it: *Simplex*, *branch and bound*, *cutting plane*

# Near-optimal Approach

- Implement a metaheuristic named **Firefly Algorithm (FA)**
- Other examples: *Simulated annealing*, *genetic algorithms*
- The FA is nature-inspired and applies the concept of swarm intelligence
- Similar to: *Ant colony*, *particle swarm optimization*

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- The FA is nature-inspired and applies the concept of swarm intelligence
- Similar to: *Ant colony*, *particle swarm optimization*
- Represent the position of a firefly as a vector
- Represent a solution as a firefly (i.e. the vector of its position)

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- The better the solution represented by a firefly, the brighter is its emitted light
- The attractiveness of a firefly **x** to another one **y** is directly proportional to the brightness of **y** and inversely proportional to the distance between them
- **Result:** Ideally, there will be a convergence of fireflies to the optimum

# Solution Representation

- $\mathbf{v} = (v_1, v_2, ..., v_{k+1})$, where $v_1, v_2, ..., v_{k+1} \in \mathbb{N}_{\geq 0}$ and $k$ is the number of vehicles
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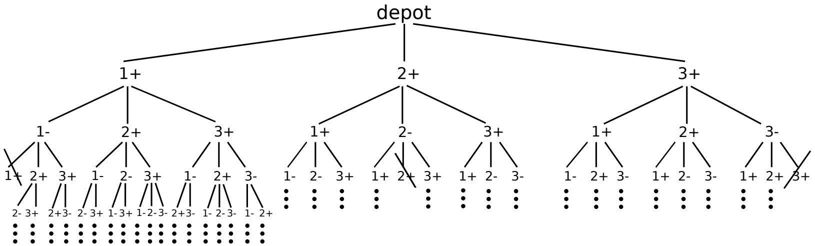
- Initial solution easily generated, simply random numbers in an interval
- A value in $v_1$ represents a unique assignment from requests to vehicles, it may vary between 0 and $k^n$, where $n$ is the number of requests

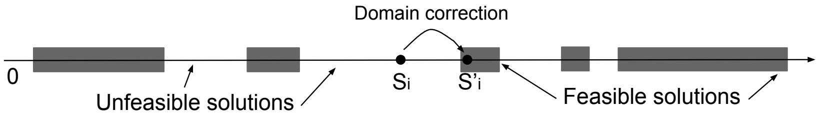
# Solution Representation

- The values in $v_2, \ldots, v_{k+1}$ represent each vehicle's routes, analogously to $v_1$
- The possible arrangement of the requests can be seen as a tree



# Correction of Unfeasibility

- Time constraints cause unfeasibilty of solutions
- Fireflies in these unfeasible regions should be moved into a feasible one
- Constraint satisfaction problem + Arc Consistency #3



# Generic Solver vs. Metaheristic

- CPU: Intel Xeon 2.3 GHz 64bits, 15GB of RAM, Linux OS
- Generic solver: GNU Linear Programming Kit.
- Metaheuristic implemented in Python with SciPy
- Instances created from an instance of the literature

# Generic Solver vs. Metaheristic

- Solution through GLPK is impracticable. Exponential growth of time
- Firefly implementation shows a steady growth of CPU time

Table: Results of the first evaluation

| Inst. | Req. | Opt. | CPU-GLPK | Firefly Sol. | % Opt. | CPU-Firefly |
|---|---|---|---|---|---|---|
| Test-1 | 2 | 58.05 | 0.1 | 69.75 | 83.2% | 7.4 |
| Test-2 | 4 | 68.10 | 0.9 | 98.51 | 69.1% | 11.7 |
| Test-3 | 5 | 76.27 | 2.0 | 134.29 | 56.8% | 2.5 |
| Test-4 | 6 | 96.54 | 45.0 | 149.32 | 64.6% | 3.3 |
| Test-5 | 8 | - | - | 158.67 | - | 5.7 |

# Metaheristic with Literature Instances

- 24 instance from the literature
- Smaller instances: 90% of optimality in average
- Deviation to the initial solution varies considerably

Table: Results of the second evaluation – Quality and progress

| Instance | Optimum | Final Sol. | Optimality | Initial Sol. | Dev. to Initial Sol. |
|---|---|---|---|---|---|
| a2-16 | 294.25 | 312.96 | 94.02% | 335.85 | 6.81% |
| a2-20 | 344.83 | 373.89 | 92.23% | 427.48 | 12.54% |
| a2-24 | 431.12 | 442.85 | 97.35% | 496.92 | 10.88% |
| a3-18 | 300.48 | 347.10 | 86.57% | 374.20 | 7.24% |
| a3-24 | 344.83 | 409.73 | 84.16% | 456.86 | 10.32% |
| a3-30 | 494.85 | 614.13 | 80.58% | 615.99 | 0.30% |
| a3-36 | 583.19 | - | - | - | - |
| a4-16 | 282.68 | 310.84 | 90.94% | 354.54 | 12.33% |

# Metaheristic with Literature Instances

- Optimality sinks as instance sizes rise

Table: Results of the second evaluation – Quality and progress

| Instance | Optimum | Final Sol. | Optimality | Initial Sol. | Dev. to Initial Sol. |
|---|---|---|---|---|---|
| a4-24 | 375.02 | 481.16 | 77.94% | 567.63 | 15.23% |
| a4-32 | 485.50 | 639.73 | 75.89% | 665.27 | 3.84% |
| a4-40 | 557.69 | 780.13 | 71.49% | 841.92 | 7.34% |
| a4-48 | 668.82 | 956.90 | 69.89% | 1032.38 | 7.31% |
| a5-40 | 498.41 | 779.32 | 63.95% | 818.14 | 4.74% |
| a5-50 | 686.62 | 926.23 | 74.13% | 1018.84 | 9.09% |
| a5-60 | 808.42 | 1195.94 | 67.60% | 1257.38 | 4.89% |
| a6-48 | 604.12 | 993.08 | 60.83% | 1025.55 | 3.17% |

# Metaheristic with Literature Instances

- Comparison of CPU times to another two approaches
- $CPU^1$: Parragh (2011). $CPU^2$: Parragh and Schmid (2013).

Table: Results of the second evaluation – Running time

| Instance | $CPU^1$ | $CPU^2$ | CPU-Firefly |
|---|---|---|---|
| a2-16 | 68.2 | 0.12 | **63.3** |
| a2-20 | 133.8 | 0.28 | 160.5 |
| a2-24 | 187.8 | 0.35 | 419.3 |
| a3-18 | 45.4 | - | **29.5** |
| a3-24 | 86.8 | 0.29 | **77.4** |
| a3-30 | 105.6 | 0.50 | 151.2 |
| a3-36 | 162.6 | 0.83 | 370.6 |
| a4-16 | 26.0 | - | **14.5** |
| a4-24 | 50.8 | - | **37.0** |
| a4-32 | 86.0 | 0.55 | 129.4 |
| a4-40 | 130.6 | 0.78 | 233.5 |
| a4-48 | 253.8 | 1.62 | **222.3** |

# Conclusion

- Solution via generic solver is impracticable
- Solution via FA can solve much larger instances, though not the largest ones
- Main issue: The time constraints (time windows and ride time)
- How to overcome: Rethink solution representation, for example
- Improve efficiency: Reduce domain corrections and improve transformation functions

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# Thank you for your attention

## Questions...