Enhancing the Urban Road Traffic with Swarm Intelligence: A Case Study of Córdoba City Downtown

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Introduction

- Nowadays, the **excessive vehicular traffic** in current cities provokes severe problems related to: pollution, congestion, security, noise, and many others.
- Improving the flow of vehicles is a **mandatory task**.
- Traffic lights are **configurable devices** that partially control the flow of vehicles.
- Nevertheless, the **increasing** number of traffic lights require a highly **complex scheduling**.
- A **great number of combinations** (color states and phase durations) appear that should be considered (explored) by experts.

**Motivation:**

Providing the experts with **automatic intelligent tools** to obtain optimized traffic lights schedules for large urban areas.
Introduction

Hypothesis:
Metaheuristics approaches (concretely PSO) can find successful schedules of traffic lights for heterogeneous urban scenarios in reasonable time

- **Our proposal:** A Swarm Intelligence approach (Particle Swarm Optimization) coupled with SUMO (Microscopic Simulator of Urban Mobility), to **automatically search quasi-optimal solutions** (traffic lights schedules)

- **Case Study:** realistic metropolitan area in the city center of Córdoba
The Problem: Optimal Cycle Programs of TLs

- All traffic lights located in the same intersection are governed by a common program, e.g., the combination of color states during a cycle period is kept valid (it must follow specific traffic rules of intersections).

- Main objective: find optimized cycle programs (CP) for all the TLs in a given area. CPs are referred to the time span (or phase duration) a set of TLs, in a given intersection, keep their color states.

- As in real schedules, CPs are designed for established time periods with certain vehicle densities and speeds (rush hours, nocturne periods, etc.).
The Problem: Optimal Cycle Programs of TLs

- **Solution encoding**: vector of integers where each element represents a phase duration of one state of TLs in intersections (SUMO structure of CPs)

- **Adjacent intersections** have to be also coordinated in order to improve the global flow of vehicles
The Problem: Optimal Cycle Programs of TLs

**Fitness function:** maximizing the number of vehicles that reach their destinations and minimizing the global trip time of all the vehicles, during the simulation time

\[
\text{fitness} = \frac{TT + SW + (NV \times ST)}{V^2 + P}
\]

**Values collected during the simulation process**

\[
P = \sum_{k=0}^{tl} \sum_{j=0}^{ph} s_{k,j} \times \left( \frac{G_{k,j}}{r_{k,j}} \right)
\]

**Definitions:**
- **V**: Number of vehicles that reach their destinations
- **TT**: Global trip time of all the vehicles
- **ST**: Simulation time
- **NV**: Vehicles that do not reach their destinations
- **SW**: Mean time each vehicle must stop and wait
- **P**: Proportion of colors in each phase and intersection
- **tl**: Intersection
- **ph**: phase
- **G**: Number of traffic lights in green
- **r**: Number of traffic lights in red
- **S**: phase duration
Optimisation Strategy

Optimisation algorithm (PSO) with Simulation procedure (SUMO)

Algorithm 1: Pseudocode of Standard PSO 2007 for OCP

1: initializeSwarm()
2: \textbf{while} $t < \text{maxIterations} \ \textbf{do}$
3: \hspace{1em} \textbf{for} each particle $x^i_p$ \textbf{do}
4: \hspace{2em} $b^n_p = \text{bestNeighbourSelection}(x^i_p, n)$
5: \hspace{2em} $v^t_{g+1} = \text{updateVelocity}(v^t_g, x^i_g, \varphi_1, p_g, \varphi_2, b^n_p)$ \hspace{1em} //Eq. 4
6: \hspace{2em} $x^t_{g+1} = Q(\text{updatePosition}(x^t_g, v^t_{g+1}))$ \hspace{1em} //Eqs. 3 and 5
7: \hspace{2em} evaluate($x^t_{g+1}$) \hspace{1em} //SUMO Simulation and Eq. 1
8: \hspace{2em} $p^t_{g+1} = \text{update}(p^t_g)$
9: \hspace{1em} \textbf{end for}
10: \textbf{end while}

Mid-Thread quantisation

$$Q(x) = \Delta \cdot \left[ \frac{x}{\Delta} + 0.5 \right]$$
Scenario Instance: Córdoba

- Scenario generated from actual information in real digital maps
- A urban area of approximately 0.75km² comprising: Ronda de los Tejares, Alfaros, Claudio Marcero, and Cervantes street
- 30 intersections each one of them including from 4 to 16 TLs. A total number of 152 TLs (solution dimension). Simulation time 500 s
- Three scenario versions with traffic densities: 100, 300, and 500 vehicles
Experimental Setup

- Comparison of Standard PSO 2007, Differential Evolution (DE), Random Search (RAND), and SCPG (deterministic cycle program generator provided by SUMO according to human expert information)

- Implementation in C++ MALLBA Library [online available]

- Standard PSO and DE, with populations of 100 vector solutions and performing 200 iteration steps, e.g. total number of 20,000 function evaluations (simulations)

- Random Search also performing 20,000 function evaluations

- Phase durations (variables) initialized in the range of [6,31]

<table>
<thead>
<tr>
<th>Solver</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSO</td>
<td>Swarm Size</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Particle Size (N. Traffic Lights)</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>Local and Social Coefficients ($\varphi_1 = \varphi_2$)</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>Neighborhood size ($n$)</td>
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<tr>
<td></td>
<td>Inertia Weight ($w$)</td>
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<tr>
<td>DE</td>
<td>Population Size</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Individual Size (N. Traffic Lights)</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>Mutation Constant ($F$)</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Crossover Probability ($Cr$)</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Performance Comparison

- PSO obtains the best results in general, followed by DE, SCPG (♦) and Random Search
- Statistically, each distribution pair (Wilcoxon) obtained significant differences ($\alpha=0.05$), excepting for DE and RAND with (500 vehicles)
- The higher the traffic density, the greater the benefits of using PSO
Performance Comparison

- The **global trip time** becomes shorter as the PSO approaches the stop condition (improvement of 17.45% respect to SCPG solutions)

- The **number of vehicles that reach their destinations** increases along with the search progress
Simulation snapshots of resulted cycle programs generated by PSO and SCPG with 500 vehicles (initial traffic density)

A low traffic density can be observed in PSOs’ solutions, but traffic jams appeared in SCPG ones.
Conclusions

- We have proposed a Swarm Intelligent approach that, coupled with the SUMO traffic simulator, is able to find successful cycle programs of traffic lights. In concrete, we have focused on a metropolitan area of the Córdoba city.

- After the experimentation, we test our initial hypothesis:
  - Our proposal performed efficiently for the studied instance. In comparison with DE, Random Search, and SCPG, our PSO showed the best performance.
  - PSO scales adequately in terms of traffic density with: 100, 300, and 500.
  - Obtained CPs by PSO can improve both, the global trip time and the number of vehicles that reach their destinations.

- Future work:
  - Tackling the problem with other metaheuristics
  - New large instances as close as possible to real scenarios of a whole city.
Thank you so much!!