Multiple-Participants Decision Making for Urban Traffic Control

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Outline

1. Multi-Participant Decision Making
   - Bayesian Decision-Making

2. Traffic control
   - Hierarchical Control
   - Multi-Agent Control

3. Multi-Agent Traffic Control
   - Step 1: Parameterization
   - Step 2: Model of consequences
   - Step 3: Ideal distributions
   - Step 4: Communication

4. Conclusion
1. System parameterization,
2. Model of consequences,
3. Description of aims (probabilistic).
Bayesian Decision Making

1. System parameterization,
2. Model of consequences,
3. Description of aims (probabilistic).

Outputs:

- **Learning**: of changes of the environment (adaptivity),
- **Strategy**: of decision making
Agents act independently (autonomously). They have individual:

1. System parameterization,
2. Model of consequences,
3. Description of aims (probabilistic).

In order to cooperate:

4. Exchange and merging of experience and ideals.
Urban Traffic Network

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Hierarchical Control

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Design of a Single Agent

\begin{equation}
\begin{aligned}
\text{Enviroment} & : \Theta_t \\
\text{decision-maker} & : D_t \\
\end{aligned}
\end{equation}

\begin{align*}
\text{Param.} & \quad \text{Observations} \quad \text{Internals} \quad \text{Actions} \quad \text{Experience} \\
y_t & \quad \Theta_t \quad u_t \quad D_{t-1}
\end{align*}
Design of a Single Agent

- **Param. Models**
  - Observations: $y_t$
  - Internals: $\Theta_t$
  - Actions: $u_t$
  - Experience: $D_{t-1}$

- **Models**
  - Observations: $f(y_t|\Theta_t, D_{t-1})$
  - Internals: $f(\Theta_t|\Theta_{t-1}, u_t)$
  - Actions: $f(u_t|D_{t-1})$
  - Experience: $f(\Theta_t|D_{t-1})$
Design of a Single Agent

<table>
<thead>
<tr>
<th>Param. Models</th>
<th>Observations</th>
<th>Internals</th>
<th>Actions</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_t$</td>
<td>$f(y_t</td>
<td>\Theta_t, D_{t-1})$</td>
<td>$f(\Theta_t</td>
<td>\Theta_{t-1}, u_t)$</td>
</tr>
<tr>
<td>$\Theta_t$</td>
<td>$f(\Theta_t</td>
<td>\Theta_{t-1}, u_t)$</td>
<td>$f(u_t</td>
<td>D_{t-1})$</td>
</tr>
<tr>
<td>$D_t$</td>
<td>$f(y_t</td>
<td>\Theta_t, D_{t-1})$</td>
<td>$f(\Theta_t</td>
<td>\Theta_{t-1}, u_t)$</td>
</tr>
</tbody>
</table>
Design of a Single Agent

**Observations**
- \( y_t \)
- \( f(y_t|\Theta_t, D_{t-1}) \)
- \( \ll f(y_t|\Theta_t, D_{t-1}) \)
- \( f(y_t), \ll f(y_t) \)

**Internals**
- \( \Theta_t \)
- \( f(\Theta_t|\Theta_{t-1}, u_t) \)
- \( \ll f(\Theta_t|\Theta_{t-1}, u_t) \)

**Actions**
- \( u_t \)
- \( f(u_t|D_{t-1}) \)
- \( \ll f(u_t|D_{t-1}) \)

**Experience**
- \( D_{t-1} \)
- \( f(\Theta_t|D_{t-1}) \)
Step 1: Model Parameterization

Two junctions connected by one arm:

Parameterization:

*Innovation*: Intensity $y_t$ [vehicles], Occupancy $O$ [%].
Step 1: Model Parameterization

Two junctions connected by one arm:

Parameterization:

*Innovation*: Intensity $y_t$ [vehicles], Occupancy $O$ [%].

*Ignorance*: Queue length $\xi$ [vehicles], Turning rate $r$ [%].
Step 1: Model Parameterization

Two junctions connected by one arm:

Parameterization:

*Innovation*: Intensity $y_t$ [vehicles], Occupancy $O$ [%].
*Ignorance*: Queue length $\xi$ [vehicles], Turning rate $r$ [%].
*Actions*: Relative green $u$ [%].
Multi-Agent Scenario

Agents interaction over a single arm:

Parameterization:

A1

Observed: $y_1, y_2$

Unobserved: $\xi_{[1], t}, O_{[1], t}$

Controlled: $u_{[1], t}$

A2

Observed: $y_1, y_2$

Unobserved: $\xi_{[2], t}, O_{[2], t}$

Controlled: $u_{[2], t}$
Step 2: Model of consequences

Internal model (without uncertainty):

\[
\begin{bmatrix}
\xi_t \\
O_t
\end{bmatrix} =
\begin{bmatrix}
A & B
\end{bmatrix}
\begin{bmatrix}
\xi_{t-1} \\
O_{t-1}
\end{bmatrix} + Bu_{t-1} + F
\]

Observation model (without uncertainty):

\[
\begin{bmatrix}
\eta_t \\
O_t
\end{bmatrix} =
\begin{bmatrix}
C & 0
\end{bmatrix}
\begin{bmatrix}
\xi_t \\
O_t
\end{bmatrix} + G
\]

Adding uncertainty:

- Internal model: \( f(\Theta_t|\Theta_{t-1}, u_{t-1}) = \mathcal{N}(A\Theta_{t-1} + Bu_{t-1} + F, Q) \)
- Observation model: \( f(y_t|\Theta_t) = \mathcal{N}(C\Theta_t + G, R) \)
- \( \mathcal{N}(\mu, \sigma) \) is a Gaussian pdf
- \( A, B, C, F, G \) are matrices from deterministic system description
- matrices \( Q, R \) describe allowed variance in the model description
Step 3: Ideal distributions

Every agent wants to:

- minimise its queue lengths:
  \[ L_f(\xi_t) = tN(0, V_\xi, \langle 0, \xi_{\text{max}} \rangle) \]

- favours high intensities:
  \[ L_f(y_t|\xi_t) = tN(\mu(\xi_t), V_y, \langle 0, y_{\text{max}} \rangle) \]
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\[ f(y) \]

Step 1

Step 2

Step 3

Step 4
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Step 4: Communication

Since $\xi_t$ is internal for each agent, we can exchange only marginal distributions:

$$\mathcal{I} f(y_t | \xi_t) \rightarrow \mathcal{I} f(y_t)$$

Since fully probabilistic design is a special case of dynamic programming, we need to communicate multi-step ahead predictions, i.e.

$$\mathcal{I} f(y_t), \mathcal{I} f(y_{t+1}), \ldots, \mathcal{I} f(y_{t+h})$$

These are presented only to the neighbours, however, they influence the neighbours predictions, which are communicated further.

This is a gateway for long-distance communication.
Conclusion

Vision of Traffic Control in Urban Areas using Bayesian theory of Multiple Participant Decision-Making (Bayesian Agents)

Early stages of development.
Further work:
- Reliable software framework for testing,
- Double check of the traffic model,
- Experiments with merging algorithms,
- Understanding the role of the Ideal distributions.