### System overview

**Phenomenon**
- Time

**Sensor**
- Location
- Dynamics
- Context

**Phase I**
- Dynamic Bayesian Network
  - Particle Filter
  - Time Series

**Intermediate**
- Path generation
- Projection

**Phase II**
- Clean-up
- Transit Line Recognition

**Output**
- Multimodal Itinerary

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### Transportation Network

**OpenStreetMap**
- Train Lines Alignment

**Transit Schedules**
- (General Transit Feed Specification)

**Transportation Network**

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### Algorithm

**Phase I**
- Dynamic Bayesian Network with time-span \( T \)
  - \( y_t \in \text{Edge} \times \text{Direction} \times \text{Mode} \times \text{Speed} \times \text{Path} \times \cdots \)
  - Finite-domain random variable describing the traveler’s state
  - Rao-Blackwellized particle filter sampling \( y_{1:T} \), while keeping \( x_{T} \) in closed form using a Kalman Filter
  - Output: \( y_{1:T} \)’s MAP estimate \( \sim y_{1:T} \) maximizing:

\[
\Pr(y_{1:T} = y_{1:T} | o_{1:T}) = \int_{x_T} \Pr(y_{1:T}, x_T | o_{1:T}) \, dx_T
\]

**Phase II**
- Clean-up
- Transit Line Recognition

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### Smartphone Data

**Observation sequence** \( o_{1:T} \), one per second
- Location \( \times \) Dynamics \( \times \) Context

**Location**
- GPS
  - Accuracy: 10m
  - Availability: Mostly outdoors
- Wi-Fi
  - Accuracy: 100m
  - Availability: Populated areas
- GSM
  - Accuracy: 1000m
  - Availability: Most areas

**Dynamics**
- Accelerometer
  - Activity Recognition
  - Dynamics \( \in \{\text{stationary, foot, bicycle, motorized}\} \)

**Context**
- Underground/Indoors:
  - Indicated by the availability of GPS/GLONASS signal
- Public Transportation:
  - Suggested by the number of nearby Bluetooth devices

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### Evaluation

42.5 hours of annotated journeys from users in the Paris region

**Confusion matrix by transportation mode**

<table>
<thead>
<tr>
<th>Mode</th>
<th>foot</th>
<th>bike</th>
<th>car</th>
<th>bus</th>
<th>train</th>
<th>tram</th>
<th>Total Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>time (min)</td>
<td>87</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1068</td>
</tr>
<tr>
<td>bike</td>
<td>2</td>
<td>98</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>69</td>
</tr>
<tr>
<td>car</td>
<td>5</td>
<td>2</td>
<td>82</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>718</td>
</tr>
<tr>
<td>bus</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>90</td>
<td>1</td>
<td>0</td>
<td>419</td>
</tr>
<tr>
<td>train</td>
<td>12</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>83</td>
<td>0</td>
<td>149</td>
</tr>
<tr>
<td>tram</td>
<td>15</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>75</td>
<td>129</td>
</tr>
</tbody>
</table>

**Precision**
- 91%
- 36%
- 96%
- 80%
- 81%
- 92%
- 2552

**Transit Line recognition rates**

<table>
<thead>
<tr>
<th>Mode</th>
<th>bus</th>
<th>train</th>
<th>tram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (%)</td>
<td>95</td>
<td>78</td>
<td>99</td>
</tr>
<tr>
<td>Total Time (min)</td>
<td>381</td>
<td>127</td>
<td>98</td>
</tr>
</tbody>
</table>