ITS: Simulating Urban Mobility
Contents

• Reasons for an open-source traffic simulation
• Needed models, data, and its processing
• SUMO Overview
Open Source Road Traffic Simulation

Applications for a road traffic simulation

- reproducible, computerized evaluation of
  - real-world network performance
  - new concepts for
    - modern traffic signal control
    - traffic surveillance
    - traffic forecasting
    - traffic management
    - dynamic routing methods
    - car2car/car2infrastructure communication
  - traffic models
- instructive visualization
- planning
Open Source Road Traffic Simulation

Needed Components

- road network
- vehicles / flow
- signalling
Open Source Road Traffic Simulation

Why an open source road traffic simulation?

Common procedure
• An academic organization wants to evaluate an aspect of traffic
• Builds an own traffic simulation; needs
  – A network representation including speed limits, right-of-way – rules, etc.
  – A representation of vehicles, their movement, routes, etc.
  – A representation of signals, variable message signs, etc.
... yields in
Many (incomplete) simulations which results can not be compared
→ Solution: an extendable simulation as a base for own development
Open Source Road Traffic Simulation Design criteria

• Portability
  – Achieved by using c++ and portable libraries only

• Performance
  – High execution speed
  – No limitations in network size and number of simulated vehicles

• Extendibility

• Open source
  – Licensed under GPL
  – Hosted at sourceforge (http://sumo.sourceforge.net)

• Microscopic
  – Each vehicle is modeled explicitly
Road Traffic Simulation

Road Traffic Flow Dynamics (one of)

Fundamental diagram of traffic (counted through induction loops)

As interpreted by Kerner

As interpreted by Kim and Keller
Road Traffic Flow Simulation Classes

Macroscopic

Mesoscopic

Microscopic

Sub-microscopic
Road Traffic Flow Simulation
Microscopic Models

 Mostly:
  • discrete in time
  • “Car Following Models”:
    vehicle’s speed depends on the preceding vehicle

\[ d(v_l) + g \geq d(v_f) + v_f \tau \]
Road Traffic Flow Simulation
Car Following Model by Krauß*

Features:
• continuous in space
• discrete in time
• accident-free
• stochastic driver model

Parameters:
̸ acceleration \( a \)
̸ deceleration \( b \)
̸ max. speed \( v_{max} \)
̸ driver’s imperfection \( \epsilon \)

\[
\begin{align*}
v_{safe}(t) &= v_i(t) + \frac{g(t) - v_i(t) \tau}{\frac{v}{b(v)} + \tau} \\
v_{des}(t) &= \min\{v_{safe}(t), v(t - 1) + a, v_{max}\} \\
v(t) &= \max\{0, \text{rand}[v_{des}(t) - \epsilon a, v_{des}(t)]\}
\end{align*}
\]

Road Traffic Flow Simulation
Further Models needed

• Lane Changing
  – Navigation (I have to turn left on next junction)
  – Tactical (left lane allows me to move faster)

• Interaction with the network
  – Stops at red traffic lights
  – Decelerate if other vehicles have a higher right to move on the next junction

• Extensions
  – Vehicle classes, such as busses, which use own lanes
  – Bus stops
Microscopic Road Networks
Needed vs. given Information

Needed street attributes:
• Number of lanes
• Allowed speed
• Per-lane restrictions
• Allowed continuations

Needed junction attributes:
• Right-of-way
• Traffic lights program

Given: a graph with only few information
⇒ Number of lanes (often vague)
⇒ Allowed speed (often vague)
Microscopic Road Networks
Size and Complexity

Additional problems:
• very large networks
• complex junctions
Example: computation of lane-to-lane connections:

1. for each edge: compute turnaround edges
2. for each node: sort each node’s edges
3. for each node: compute each node’s type
4. for each node: set edge priorities
5. for each edge: compute edge-to-edge connections
6. for each edge: compute lanes-to-edge connections
7. for each node: compute lane-to-lane connections
8. for each edge: recheck lanes
9. for each edge: append turnarounds
Traffic Demand

Needed Information

Each vehicle is modeled explicitly

mandatory attributes:

– ID (name)
– Vehicle type (including Krauß-parameter)
– Complete route through the network
– Depart time

optional attributes:

```
<vehicle id="bus100_west_0d" type="BUS" depart="0" color="1,0,1">
  <route>-572658025 -572658026 -572658027 -572658024 ...</route>
  <stop bus_stop="west1" duration="20"/>
  <stop bus_stop="west2" duration="20"/>
</vehicle>
```
Traffic Demand
Possible Sources

- Real (physical) measures are done at induction loops
  - Accurate but sparse
  - No information about who is driving from which place to which place, only how many vehicles have passed a certain place

- Counts at junctions may provide flows and turning ratios
  - Less accurate than induction loops and sparse, too – mainly for some major inner-city junctions
  - Information about flow spread on junctions

- Traffic scientists estimate demands on district level
  - Even less accurate (estimated), but cover a complete area
Traffic Demand
Possible Sources

- Real (physical) measures are done at induction loops

  induction-loop measures \rightarrow \text{DFROUTER} \rightarrow \text{SUMO-routes}

- Counts at junctions may provide flows and turning ratios

  turning ratios \rightarrow \text{JTRROUTER} \rightarrow \text{SUMO-routes}
  flows \rightarrow \text{JTRROUTER} \rightarrow \text{SUMO-routes}

- Traffic scientists estimate demands on district level

  \text{OD-matrix} \rightarrow \text{OD2TRIPS} \rightarrow \text{DUAROUTER} \rightarrow \text{SUMO-routes}
**SUMO - Modules**

**Included Applications**

- **SUMO**: command line simulation
- **GUISIM**: simulation with a graphical user interface
- **NETCONVERT**: network importer
- **NETGEN**: network generator
- **OD2TRIPS**: converter for O/D-matrices
- **JTRROUTER**: router based on turning ratios
- **DUAROUTER**: router based on a dynamic user assignment
- **DFROUTER**: router which uses detector data
SUMO Features

• Microscopic: all vehicles are modeled explicitly
• Time-discrete, space-continuous car-following model by S. Krauß
• Multi-lane traffic, right-of-way rules
• Around 100,000 cars in real-time (without graphical output)
• Traffic lights with time schedules, other traffic management devices
• Complex networks / Import support
• Dynamic Routing based on Dynamic User Assignment
• Other routing modules

Projects at the DLR where SUMO was used 2002-2006

- **INVENT**
  Implementation and verification of traffic management strategies for large urban areas
- **OIS**
  Verification of benefits arising from usage of new optical sensors
- **Traffic Tower**
  Virtual Traffic Management Environment
- **WJT2005 / Soccer2006**
  Integration of standard and airborne detectors into a traffic portal with forecast functionality
- **TrafficOnline**
  Traffic surveillance via in-vehicle GSM phones
WJT2005 / Soccer2006 → DELPHI

Description

• Used in the city of Cologne during
  – The pope’s visit (world youth day 2005)
  – The world soccer cup 2006
• Traffic surveillance using
  – Highway induction loops
  – Inner-city induction loops
  – Airborne traffic recognition system
    (mounted on a zeppelin)
• Traffic visualization
  – Integration of gained information into a
  – Presentation for the police
• Traffic forecast
  – 30 min into the future using a simulation
    (extended SUMO)
DELPHI
System Overview

ARGOS: Access via db, webserver

Induction loops:

Floating Car Data:

Datenbank:
- MySQL with InnoDB tables
- No built-in logic

Aggregation/Correction:
- Guessing missing values
- Data fusion
- Done using python scripts

Webserver:
- Tomcat Servlet Container
- Visualization (Images and traffic)

Webbrowser:
- JavaScript Browser
- asynchronous XML-Requests

Simulation:
- Areal extrapolation of measured data
- Forecast generation (30min)
- Fed from db using python

ARGOS: Access via db, webserver

Induction loops:

Floating Car Data:
SUMO – Example Results
Flow Comparison
Case Study

Introducing Cellular Network Layer into SUMO for Simulating Vehicular Mobile Devices’ Interactions in Urban Environment

• Motivation:
  – Constraints on accessing the mobile users related data
  – Producing the logs - enabling new possibilities in the research field.
  – Vehicle-To-Everything (V2X) communication

Cellular Network

- Base station
- Base station transmitter
- Cells - signal coverage
- User equipment - mobile
Mobility Data

- Mobile technologies 1G to 5G
- Mobility data:
  - CDR - like logs
  - GPS data
  - RFID
  - Wireless access point related log
  - etc

Many unstandardized technologies
Challenges in analyzing CDR logs

- Sparse Events
- Unreliable Coverage Map
- Changes in Coverage Map
- Features of 2G/3G/4G technologies
Contribution

• Research of the microscopic road traffic simulator and cellular network technologies to design and model cellular network
• Integration of the cellular network entities into the road traffic simulation software
• Running command-line and visualize traffic simulation with integrated cellular network simulation
Contribution
Contribution: Support programs

- HexagonGen
- Mobility Event Simulation Generator - MESGEN

```xml
<vehicles xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:noNamespaceSchemaLocation="http://sumo.dlr.de/xsd/msevents_file.xsd">
  <vehicle id="0" depart="0.00">
    <mEvents>  
      <mEvent begin="0.00" end="25.00" type="WEB_COMM"/>
      <mEvent begin="100.00" end="116.00" type="CALL_INIT"/>
      <mEvent begin="272.00" end="386.00" type="WEB_COMM"/>
      <mEvent begin="530.00" end="554.00" type="CALL_REC"/>
      <mEvent begin="908.00" end="946.00" type="CALL_REC"/>
    </mEvents>
  </vehicle>
  <vehicle id="1" depart="1.00">
    <mEvents>  
      <mEvent begin="1.00" end="6.00" type="CALL_INIT"/>
      <mEvent begin="112.00" end="132.00" type="CALL_INIT"/>
      <mEvent begin="183.00" end="225.00" type="CALL_INIT"/>
      <mEvent begin="401.00" end="425.00" type="WEB_COMM"/>
      <mEvent begin="472.00" end="583.00" type="CALL_REC"/>
      <mEvent begin="837.00" end="885.00" type="CALL_REC"/>
    </mEvents>
  </vehicle>
  <vehicle id="2" depart="2.00">
    <mEvents>  
      <mEvent begin="2.00" end="2.00" type="SMS_SEND"/>
      <mEvent begin="2.00" end="2.00" type="WEB_COMM"/>
      <mEvent begin="2.00" end="2.00" type="CALL_INIT"/>
      <mEvent begin="2.00" end="2.00" type="WEB_COMM"/>
    </mEvents>
  </vehicle>
</vehicles>
```
Contribution: Classes

- GUI and microsim:
- Cellular antenna
- Signal propagation

\[
P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}
\]

- Cellular tower
- Cellular tower controller
- Mobile and GPS devices
- Mobile Event Data
- Data import and export
Results: GPS

- Mobile mobility logs
  - GPS data

Results: CDR

- Mobile mobility logs
  - CDR-like

- Event types:
  - Call initiation
  - Call receiving
  - SMS sending
  - SMS receiving
  - Web communication

```xml
<mobile-output>
  <vehicle id="16">
    <event timestamp="16.00" eventType="SMS_REC" insl="16" cgl="t-571-1"
          signalStrenght=-27.30" latitude="58.28" longitude="26.52935928" speend="0.0000000000"/>
  </vehicle>
  <vehicle id="91">
    <event timestamp="91.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-24.43858123" latitude="58.27194942" longitude="26.53703835" speend="0.0000000000"/>
    <event timestamp="92.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-24.4892827" latitude="58.27194625" longitude="26.53706002" speend="1.66107110"/>
    <event timestamp="93.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-24.33217660" latitude="58.27193876" longitude="26.53713152" speend="3.93172514"/>
    <event timestamp="94.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-24.22709829" latitude="58.27192817" longitude="26.53722397" speend="5.54970039"/>
    <event timestamp="95.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-24.99187215" latitude="58.27191446" longitude="26.53734378" speend="7.19185444"/>
    <event timestamp="96.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-23.9139039" latitude="58.27189622" longitude="26.53750321" speend="9.57643992"/>
    <event timestamp="97.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-23.9217162" latitude="58.27187303" longitude="26.53770574" speend="12.15771737"/>
    <event timestamp="98.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-23.46158188" latitude="58.27184822" longitude="26.53792255" speend="13.01484487"/>
    <event timestamp="99.00" eventType="CALL_INIT" insl="91" cgl="t-693-2"
          signalStrenght=-23.24320965" latitude="58.27182381" longitude="26.53813582" speend="12.80231273"/>
  </vehicle>
</mobile-output>
Results: GUI

- Visualization:
Road traffic simulation and CO$_2$ Emission

- Road traffic simulation using SUMO Tool
  - Simulating urban mobility dynamic
    - Vehicles
      - Private
      - Public transport
    - Pedestrians
    - Railway
  - Simulating vehicular mobile devices’ interactions
- CO$_2$ Emission Models
  - Handbook of Emission Factors for Road Traffic Model (HBEFA) - Versions 2.1 & 3.1
    - Vehicle category: passenger cars, light duty vehicles, heavy duty vehicles, buses, coaches and motorcycles
    - Pollutants covered - CO$_2$, CO, HC, NO$_x$, PM$_x$
  - Passenger car and Heavy duty Emission Model (PHEMlight)
    - Pollutants covered - CO$_2$, CO, HC, NO$_x$, PM$_x$
SUMO
Tasks ToDo

• Check the readings section in course webpage
• Download and install the right version of sumo on your computer.
• Try to run it to be ready for the lab session