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ON MODELLING URBAN SYSTEMS

20–24 JUNE 2016
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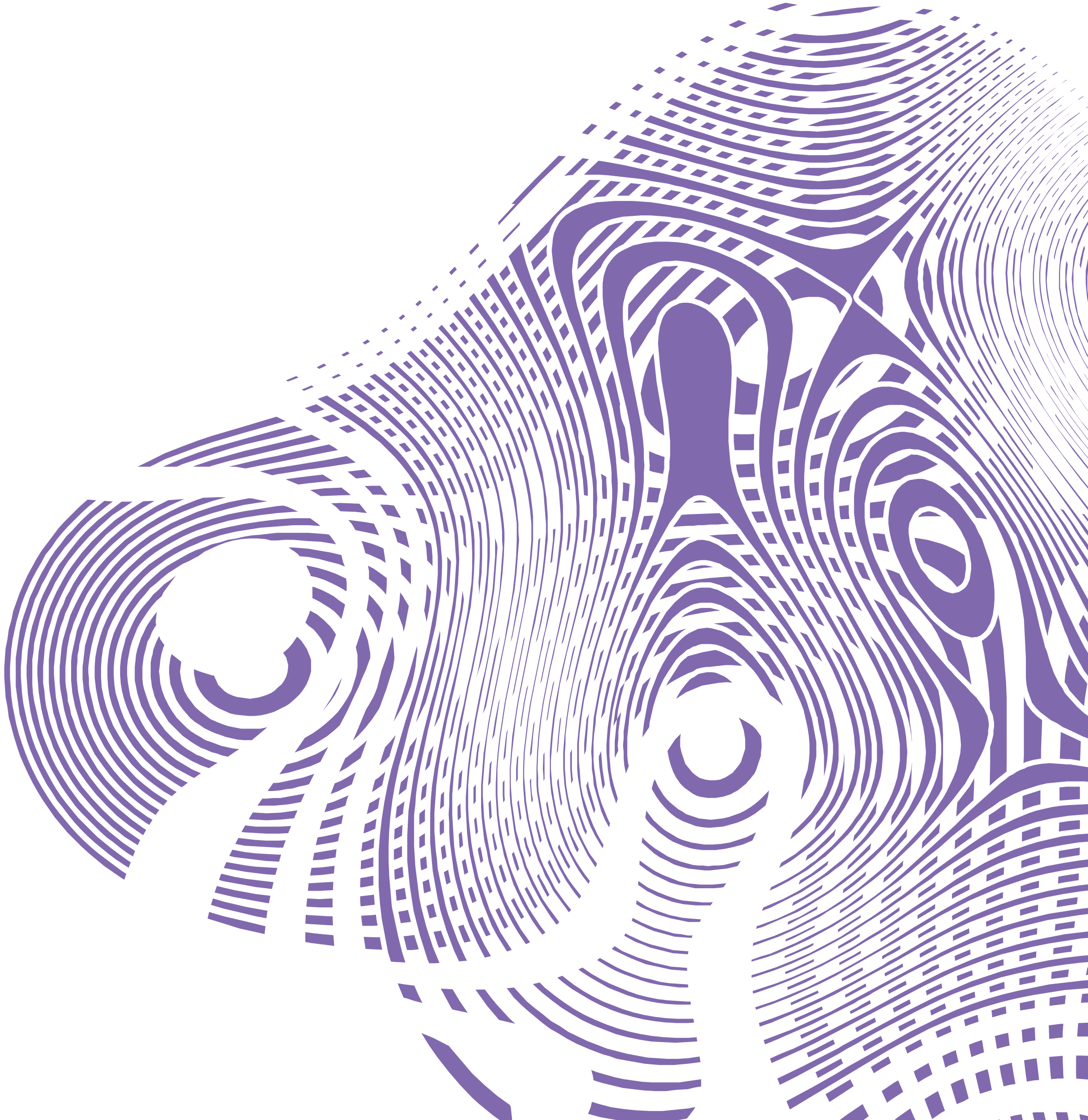
KEYNOTE 02

AGENTS AND MULTIAGENT SYSTEMS IN TRAFFIC AND TRANSPORTATION

ANA BAZZAN

COMPUTER SCIENCE INSTITUTE, UFRG
(UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL), BRAZIL



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Deadline: November 11, 2016

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Agents and Multiagent Systems in Traffic and Transportation

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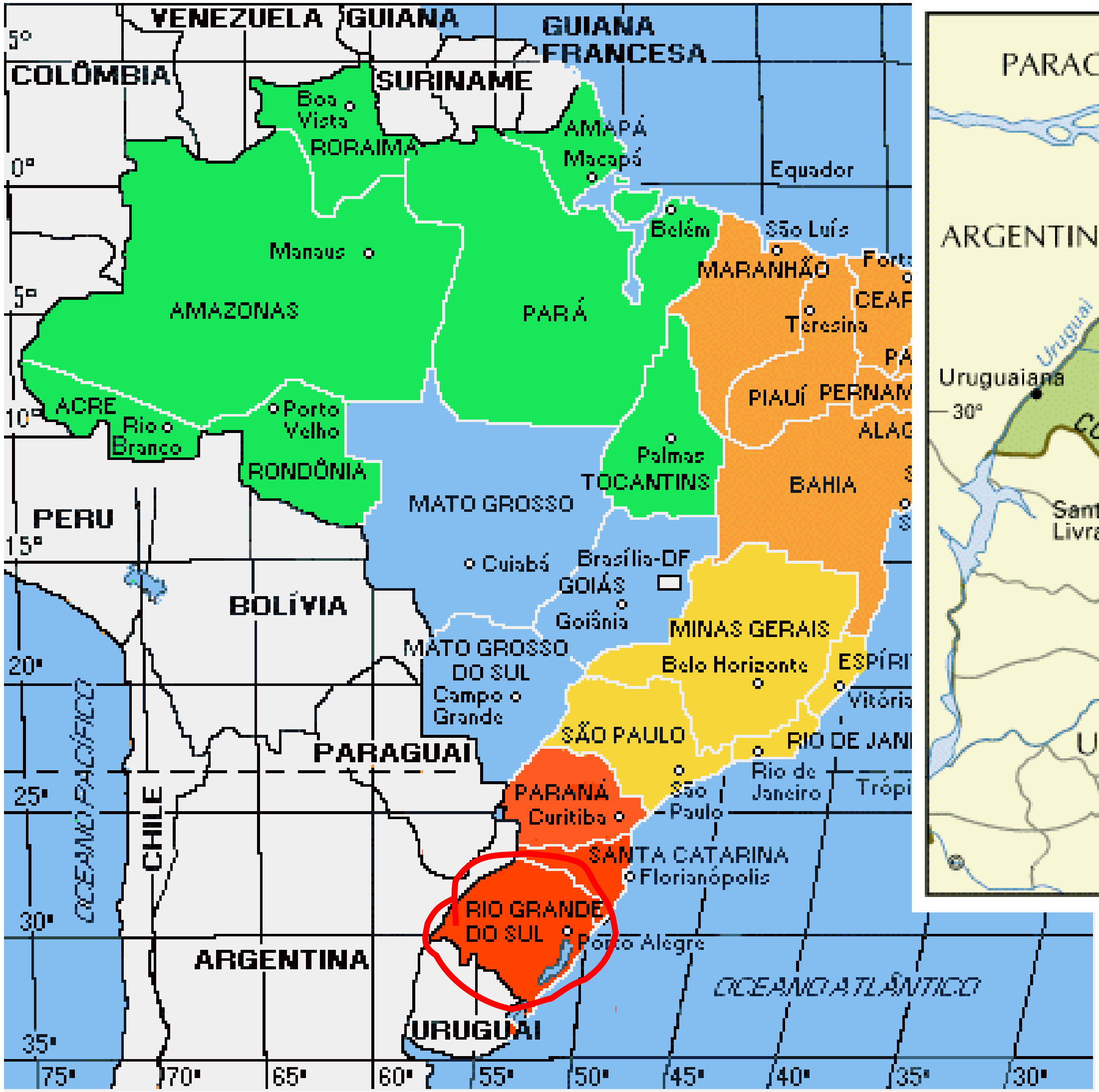
Where?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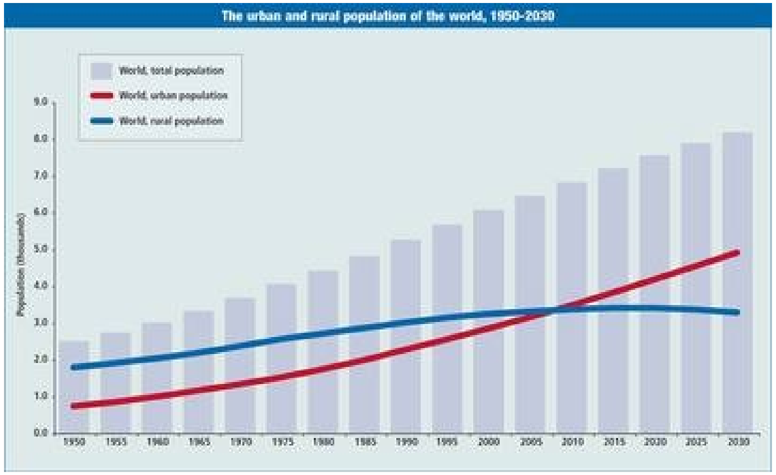
Context



Urban population trends

In 2008, for the first time, half the world's population is living in towns and cities. By 2030, the urban population will reach 5 billion - 60 per cent of the world's population. Nearly all population growth will be in the cities of developing countries, whose population will double to nearly 4 billion by 2030 - about the size of the developing world's total population in 1990.

Context

- Wellington E. Webb
  (former Mayor of Denver, CO):
  - The 19th century: century of **empires**
  - The 20th century: century of **nation states**
  - The 21st century: century of **cities**

Context

- A concept for smart*er* cities:

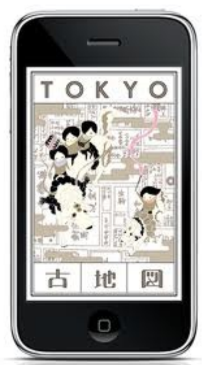
(Participatory) Sensing

Context

- A concept for smart cities:

Context

- In the end... **it's all about people**



Context

- Smart cities: many aspects
  - Here: TRAFFIC

Outline

- Motivation and problem
- 4 facets:
  - Smart modeling
  - Smart information systems
  - Smart control
  - Smart tools/gadgets
- How agents can contribute to make cities smarter
- Current work at UFRGS

Motivation

"...mobility is perhaps the single greatest global force in the quest for equality of opportunity because it plays a role in offering improved access to other services."

Martin Wachs (keynote speaker of the IEEE 2011 forum on integrated sustainable transportation systems)

Motivation

- How to mitigate traffic problems by means of human-centered modeling, simulation, and control
- Human-centered:
  - we are a central part of the system!
  - need to put us in the loop of traffic control and decision-making
  - have us as both targets (or objects) and as active subjects (e.g. as sensors)

Human in the Loop

- Instead of only passively receiving information or passively waiting for the light to turn green, user now has the possibility to interact with the system in various ways
  - most important is the role of providing information, acting as a human sensor
  - thus: changing the user's role of actuator to sensor is a real change in paradigm

Human in the Loop

- … we will revisit this issue later…

Problem

- Mobility patterns have changed drastically
- Congestion is mentioned as one of the major problems in various parts of the world, leading to a significant decrease in the quality of life

Problem: some numbers

- www.its.dot.org:
  - in 2010 there were 32,788 traffic-related deaths in the United States alone
  - mobility is severely impacted with 5.5 billion hours of travel delay (38 hours/person) that put the cost of urban congestion at 121 billion dollars (0.8% of GDP in 2011)
  - costs to the environment (3.9 billion gallons of wasted fuel emissions)
  - average monetary cost (each American commuter, 2011): US$ 818 (more than a threefold increase from 1980, adjusting for inflation)

Problem: some numbers

- Brazil:
  - 30 K fatalities
  - 300 Km record traffic jams in SP city (July 26, 2013, 7:30pm)
  - R$ 27 bi. (lost hours, peak hour) + R$ 6.5 bi (pollution)

Motivation

- NOT a computer network:
  - drivers are autonomous (sometimes irrational !)
  - drivers cannot be routed
  - safety issues: bad policies have far more serious consequences
  - ...

Introduction

- More intelligent solutions:
  - providing information to the citizen (helps trip planning)
- Several technologies
  - generally packed under **ITS** (*Intelligent Transportation Systems*)

Introduction

- Two main components of transportation systems: supply and demand
  - **Supply**: infrastructure (roads, public transportation (transit), etc.)

    environment
  - **Demand**: mobility needs of a population
    - trips that are made at given times from and to different locations, using given transportation modes

      agents
- To know more...

To Know More

The Knowledge Engineering Review

The Knowledge Engineering Review / , *FirstView* Articles, pp 1-29

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DOI: http://dx.doi.org/10.1017/S0269888913000118 (About DOI), Published online: 03 May 2013

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Articles

A review on agent-based technology for traffic and transportation

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Introduction to Intelligent Systems in Traffic and Transportation

Synthesis Lectures on Artificial Intelligence and Machine Learning

December 2013, 137 pages, (doi:10.2200/S00553ED1V01Y201312AIM025)

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Abstract

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Urban mobility is not only one of the pillars of modern economic systems, but also a key issue in the quest for equality of opportunity, once it can improve access to other services. Currently, however, there are a number of negative issues related to traffic, especially in mega-cities, such as economical issues (cost of opportunity caused by delays), environmental (externalities related to

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Introduction

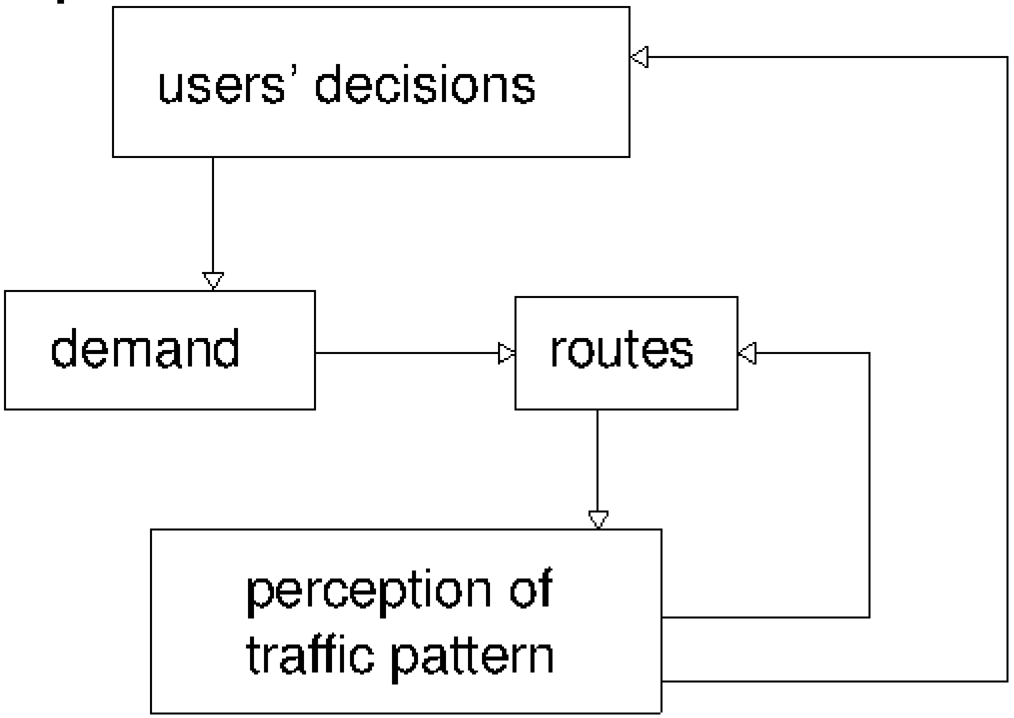
- Supply and demand components are closely related
  - complex systems, multiagent systems

Introduction

- Complex systems:
  - Lots of components
  - Heterogeneous components
  - Highly coupled actions and decisions
  - Feed-back loop

Introduction

- Traffic/transportation systems:
  - Lots of components
  - Heterogeneous components
  - Highly coupled actions and decisions
  - Feed-back loop



Introduction

- Multiagent systems:
  - Lots of agents
  - Autonomous
  - Heterogeneous
  - Highly coupled interactions (actions and decisions)
  - Feed-back loop

Introduction

- Many challenges: 4 main facets
  - Smart modeling
  - Smart information systems
  - Smart control
  - Smart tools/gadgets

Modeling

- Good old problem of how to model the load balance in a network but considering:
  - Costly infrastructure (supply)
  - Heterogeneous, “intelligent” demand
    - Example: traffic stream contains different “particles” (elderly as well as novice drivers, aggressive as well as collaborative decision-makers)

Modeling

- Practical implication:
  - the diversity / heterogeneity in road users' behaviors implies that it is not easy to predict traffic streams
  - "... some models of traffic streams are based on fluid dynamics. However, a flow of water through pipes can be exactly predicted, whereas this is not the case when dealing with road users" (Roess et al.)

Modeling

- Tasks:
  - strategic and tactical planning, feasibility studies, and management of the operation of the system (a real challenge giving the heterogeneity involved)
  - More and more important: designing and fixing smart cities

Modeling

- Particularities:
  - Millions of agents
  - High number of choices (temporal, spatial, modal)
  - Users experimentation and adaptation
    - Price of anarchy !!! (Papadimitrious, Roughgarden and Tardos)

Modeling

- Challenge here:
  - Development of

Microscopic (e.g., agent-based) modelling of large scale systems (millions of individuals) <u>taking the human into account</u>

Information System

- ATIS: advanced traveller information system
  - Provide timely and update information to users of traffic and transportation system
    - Before and during the trip
    - Route guidance
    - etc.

Information System

- Interactive systems where the user may also act as a provider of information
  - so far not the case

Information System

- Once the modeling problem is solved:
  - Need of data
    - Huge amount of data coming from ordinary sensors
    - Even more if we consider humans as sensors (through their smart gadgets for instance)

Information System

- Challenge:
  - **Collecting data from millions of devices (cameras, ordinary sensors, navigation devices, etc.)**
  - **Management of geo-located data**
  - **Processing huge amount of data**
  - **Broadcast of info to mobile devices**
  - **Aggregating info from social networks**

Control

- Aims:
  - maximize capacity of network;
  - maximize capacity of critical routes and intersections;
  - minimize negative impact on environment and on emissions;
  - minimize travel times;
  - increase traffic safety

Control

- Also, modern philosophies:
  - attempt to efficiently manage the communication between driver, vehicle, and roadway components (e.g., traffic signals)

Control

- Conventional concepts are doomed to fail to address unexpected situations
- Example:
  - Church opening in the GRU area (late 2011)
  - Why weren't tweets used to forecast or mitigate the effects?

Control

cotidiano

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01/01/2012 - 19h13

Inauguração de igreja causa 22 km de congestionamento na Dutra

COLABORAÇÃO PARA A **FOLHA**

Recomendar 192 +1 2

A inauguração de um templo da Igreja Mundial do Poder de Deus causa transtornos para os motoristas que passam pela rodovia presidente Dutra durante todo o domingo, na região de Guarulhos. De acordo com a PRF (Polícia Rodoviária Federal), muitas pessoas com destino ao aeroporto internacional de Guarulhos ficaram mais de duas horas paradas na rodovia e perderam seus voos.

- Example:
  - Church opening in the GRU area (late 2011)
  - Why weren't tweets used to forecast or mitigate the effects?

Control

- Particularities:
  - Difficult optimization problems
  - Conflict resolution
  - Social aspects (toll)
  - ...
- Main one: how to align the global (system) utility with local (user) utility???

Control

- Traffic authorities: interested in the system optimum, while the user seeks its own optimum
  - normally different :-(
  - price of anarchy: system optimum is ¾ of user optimum
    (for linear cost functions)

Control by Routing

- Here machine (reinforcement) learning – RL – can be used to:
  - simulate agents' learning to select routes
  - anticipate eventual jams
  - give information to divert a portion of agents to other routes (alignment with system optimum)

Control by Routing

- How RL is useful in routing:
  - drivers compute *k* shortest paths
  - drivers select one of these, drive and collect travel time
  - learning can be used to learn a policy to use the *k* routes
  - can be used to compute the user equilibrium

Control by Routing

- Agent-based perspective to routing is different from that of traffic engineering:
  - Assignment (planner perspective) versus route choice
    (agent perspective)
  - Learning a route versus receiving a route

Control

- Challenges
  - **Intelligent use of the existing infrastructure**
  - **Real time, distributed control**
  - **Pricing and other mechanisms to incentivize certain behaviors (system of credits/debits to use demanded links, congestion toll)**
  - **Use of collective intelligence**

Automation

- Navigation devices becoming ubiquitious
- Little has been investigated about the **effects** of this use
  - Example: which are the effects on travelers whose routes were mostly restricted to local streets?
  - Also: do travel times decrease if navigation devices get widely used?

Automation

- One example:
  - Bazzan and Azzi 2012: driving of thousands of agents is simulated
    - typical question answered with agent-based simulation (different classes of agents)
    - own route is based either on navigation devices or on own mental map of the network
    - what happens?

Automation

- One example (cont.):
  - Intuition: navigation device helps to distribute vehicles in the network
    - global performance: better
    - local streets: bad performance
  - Results support intuition

Automation

- C2C, C2I, and C2X
  - developments in two main directions:
    - autonomous driving and automated vehicles
    - automate highway and road infrastruture

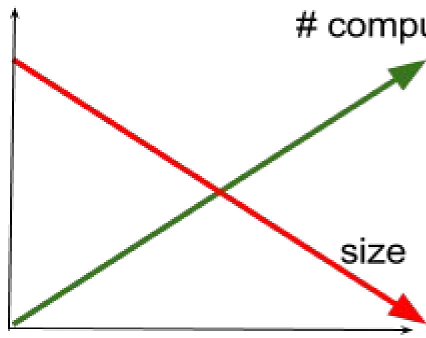
Automation

- Challenges:
  - Engineering of sensors and actuators for C2X (safe ones!!!)
  - Communication protocols for C2X
  - Privacy and dealing with cheating
  - Autonomous driving: **human drivers out of the loop**

Human Drivers Out of Loop

- Autonomous vehicles that might change the way you travel

Putting all Together



- Cities as systems of systems
  - Sub-systems: transportation, leisure, health, education, etc....
  - ... but always: the quest of INFORMATION

Putting all Together

- Solutions...
- ...relate to information gathering
  - Paradigm change:
    - user centered paradigm
    - user as consumer / target of information
    - user also as provider of information
      - smart phones etc. as means to sense / get information

Putting all Together

It is all about people !

Putting all Together

- Typical questions:
  - Best bus line to my destination ?
  - Which are the best routes/schedules for disabled people/passengers?
  - How to avoid jams ?

Putting all Together

- Typical questions:
  - How to prioritize public transportation ?
  - How to adjust signal timing to current traffic network status?

Putting all Together

- Typical scenarios:
  - User sends its location
  - Buses share information

Solutions

- Together with optimization techniques:
  - New technologies (GPS, RFID, ...)
  - Useful and timely information
  - Personalized information (e.g., via cell phone)
  - Distributed computation
    - Sensors network
    - Intelligent agents
    - ...

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Solutions

- AI, agents techniques:
  - Deal with dynamic, distributed and incomplete information
  - How to go fast from A to B ?
    - Typically reasoning with incomplete information
  - How to turn autonomous driving a reality?
  - How to align individual agents and system goals?

Important !

- New information system assumes paradigm change
  - Not only technical systems (e.g., traffic engineering)
  - But also information technology, AI, multiagent systems ...
  - ... and multidisciplinarity (social, cultural contexts)

How Close are We?

- DARPA challenge
  - Autonomous driving

The Urban Challenge

This pimped-up Chevrolet Tahoe is now, officially, the cleverest car in the world. It was the winner of the $2m first prize in the Urban Challenge, a competition held on November 3rd. The challenge, issued by America's Defence Advanced Research Projects Agency, was to design a robot car capable of negotiating urban streets and normal traffic. Although the streets in question were part of an old airforce base in southern California and the "normal" traffic was driven by professional stunt drivers, the test was nevertheless fairly realistic. *Boss*, as the Tahoe was dubbed by the engineers from Carnegie Mellon University who fitted it with the necessary controls and software, managed to travel the 88km (55 mile) course at an average speed of 22kph without hitting anything and without too many infractions of California's traffic regulations.

How Close are We?

What do we (at UFRGS) do?

- RS-SOC project
  - Testbed for new policies (e.g., by city authorities)
  - Microscopic, agent-based simulation (able to consider each individual of the population)
    - Traffic
    - Environment
    - Disaster management

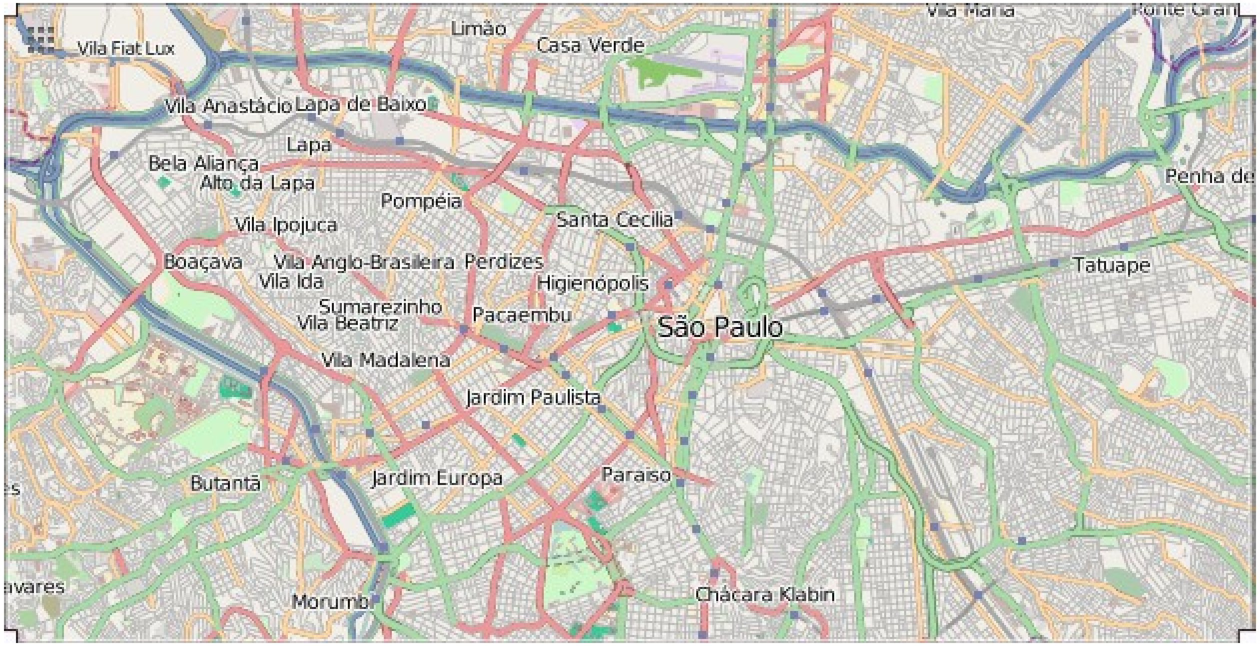
What do we (at UFRGS) do?

- C2C (car to car communication) project
  - Bilateral cooperation with Germany (prof. B. Scheuermann)
  - Saving travel time through C2C communication
    - What kind of information should be communicated?
    - Cheating ?
    - Trust and reputation ?

What do we (at UFRGS) do?

- Information retrieval from Twitter and other web-based sources / social networks
  - Feed traffic simulators
  - Infer origin-destination patterns
  - Infer other patterns

What do we (at UFRGS) do?



XML

origin node	destination node d_1	d_2	d_3	d_4	d_5	$\cdots$	d_m	
o_1	$r_{o_1d_1}$	$r_{o_1d_2}$	$r_{o_1d_3}$	$r_{o_1d_4}$	$r_{o_1d_5}$	$\cdots$	$r_{o_1d_m}$	V_{o_1}
o_2	$r_{o_2d_1}$	$r_{o_2d_2}$	$r_{o_2d_3}$	$r_{o_2d_4}$	$r_{o_2d_5}$	$\cdots$	$r_{o_2d_m}$	V_{o_2}
o_3	$r_{o_3d_1}$	$r_{o_3d_2}$	$r_{o_3d_3}$	$r_{o_3d_4}$	$r_{o_3d_5}$	$\cdots$	$r_{o_3d_m}$	V_{o_3}
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o_n	$r_{o_nd_1}$	$r_{o_nd_2}$	$r_{o_nd_3}$	$r_{o_nd_4}$	$r_{o_nd_5}$	$\cdots$	$r_{o_nd_m}$	V_{o_n}
	U_{d_1}	U_{d_2}	U_{d_3}	U_{d_4}	U_{d_5}	$\cdots$	U_{d_m}	T

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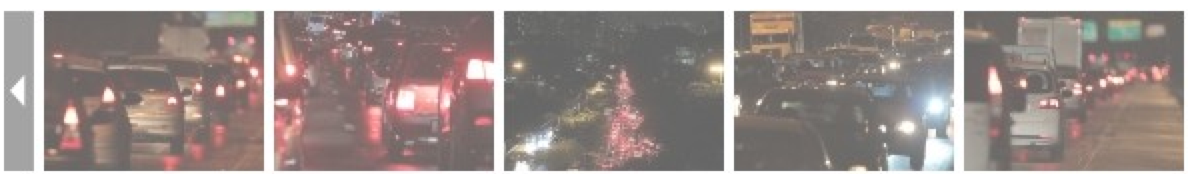
SUMO

What do we (at UFRGS) do?

GERAL 01.junho.2012 06:30:24

TRÂNSITO AGORA: acompanhe o trânsito em São Paulo e o tráfego nas estradas de SP nesta sexta-feira

Mande e receba informações sobre o trânsito na cidade de São Paulo pelo twitter do Estadão, usando a hashtag #transito_estadao e envie para @Estadão. Baixe o aplicativo do trânsito no i tunes.



19h33 – A Rua Clélia tem 2,4 km de morosidade da Pompeia até a Pio Xi.

19h15 – A capital paulista bateu o recorde histórico de trânsito no período da tarde às 19 horas desta sexta-feira, 1°, com 295 km de vias congestionadas. O recorde anterior foi registrado no dia 10 de junho de 2009, com 293 km. Às 18h30 desta sexta, a cidade havia registrado 282 km, superando o recorde anual do período da tarde – às 19 horas do dia 11 de abril a medição da CET apontou 225 km de morosidade. Segundo a Companhia de Engenharia de Tráfego (CET), a marca de hoje é reflexo do acidente que interditou a faixa central da Marginal do Tietê, do excesso de veículos e da chuva que atinge a cidade.

Text

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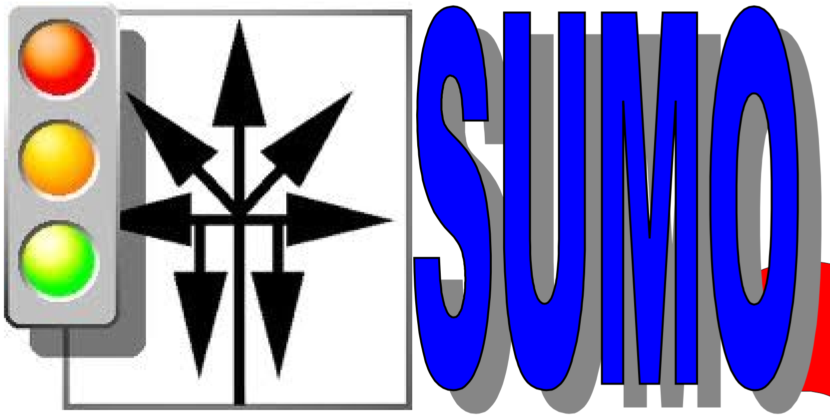

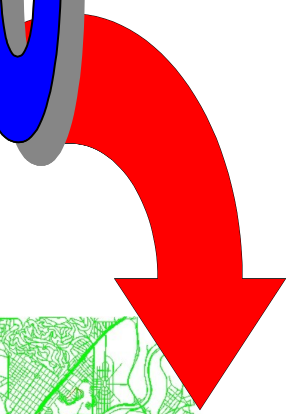

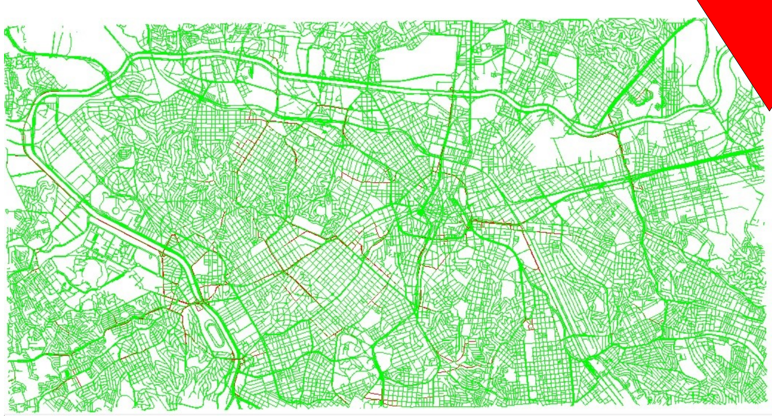

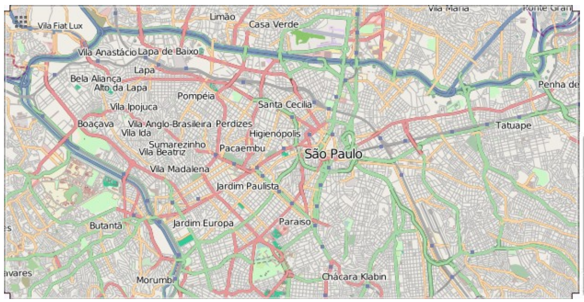

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o_2	$r_{o_2d_1}$	$r_{o_2d_2}$	$r_{o_2d_3}$	$r_{o_2d_4}$	$r_{o_2d_5}$	$\cdots$	$r_{o_2d_m}$	V_{o_2}
o_3	$r_{o_3d_1}$	$r_{o_3d_2}$	$r_{o_3d_3}$	$r_{o_3d_4}$	$r_{o_3d_5}$	$\cdots$	$r_{o_3d_m}$	V_{o_3}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
o_n	$r_{o_nd_1}$	$r_{o_nd_2}$	$r_{o_nd_3}$	$r_{o_nd_4}$	$r_{o_nd_5}$	$\cdots$	$r_{o_nd_m}$	V_{o_n}
	U_{d_1}	U_{d_2}	U_{d_3}	U_{d_4}	U_{d_5}	$\cdots$	U_{d_m}	T

What do we (at UFRGS) do?

- Characterization of transportation networks
- Use of centrality measures (e.g. betweenness) to detect:
  - “central” nodes
  - community of nodes (e.g. for coordination purposes)

What do we (at UFRGS) do?

- Combines OD matrix with network graph
- Calculates betweenness centrality over the weighted edges in the network

	1	2	3	...	10	11	12
1	0	1	0	...	7	2	0
2	2		5	...	0	0	
3		4	0	...	12	0	
...	...	...	...	...	...	...	...
10	10	7	0	...	2	0	10
11	11	19	0	...	0	5	23
12	9	10	0	...	21	14	0

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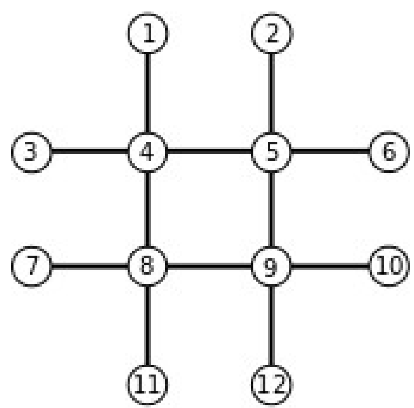

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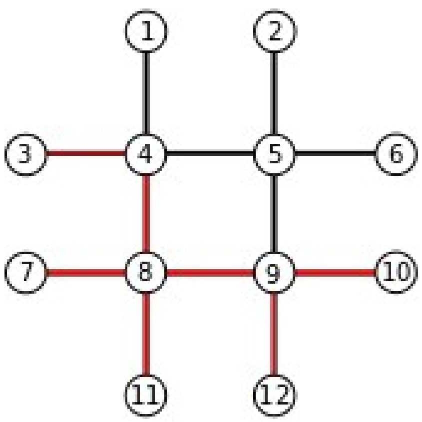
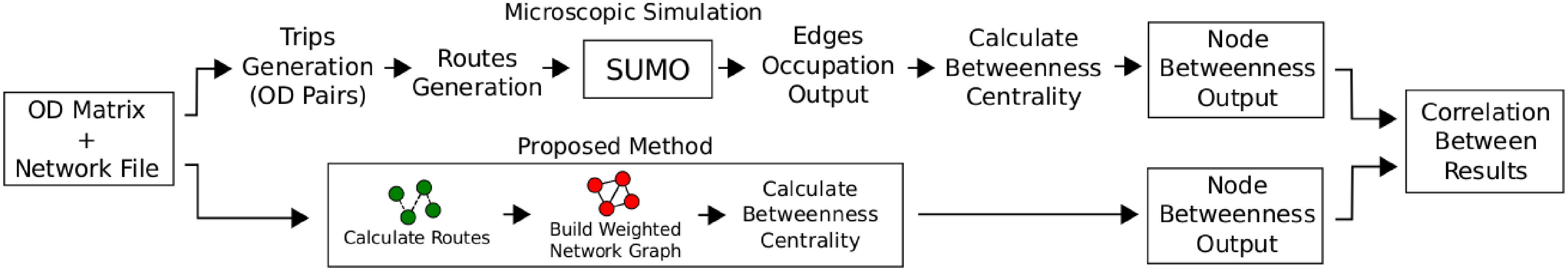


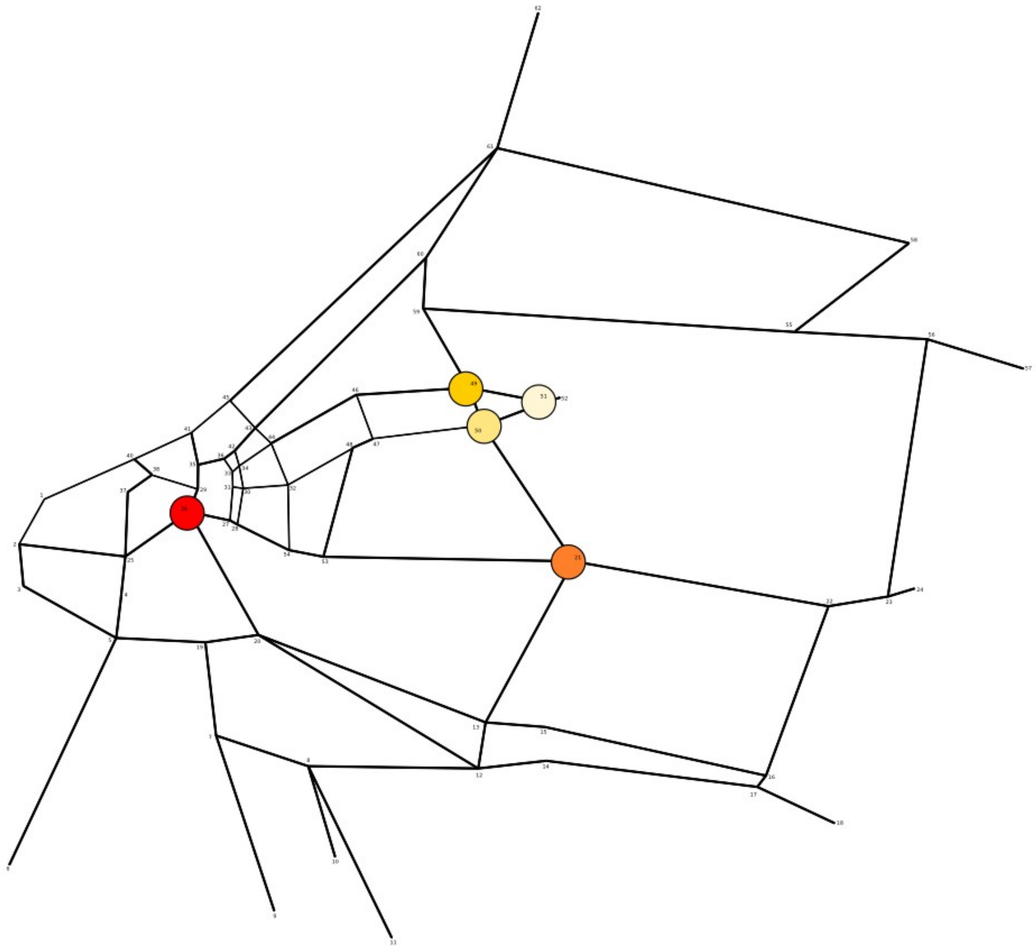
What do we (at UFRGS) do?

- Method:



- Main points:
  - The more routes, the less weight
  - The more central, the less routes

What do we (at UFRGS) do?



Past Work

- Game theoretic modeling for distributed control of traffic lights (PhD thesis)
- Reinforcement learning for control of traffic lights
  - Learning automata
  - Q-learning
- Cellular automata based microscopic traffic simulator (ITSUMO)

Past Work

- Dynamics in binary route choice / modeling as minority game (with M. Schreckenberg's group)
- Swarm intelligence based task allocation for control of traffic lights (with F. Klügl)
- Co-adaptation (with F. Klügl / K. Nagel):
  - Traffic lights adapt to traffic
  - Agents adapt to traffic lights

Past Work

- Pedestrian simulation with cellular automata
- Market-based allocation of personal rapid transit
- Route choice using random Boolean networks
- Route choice and load balance under information

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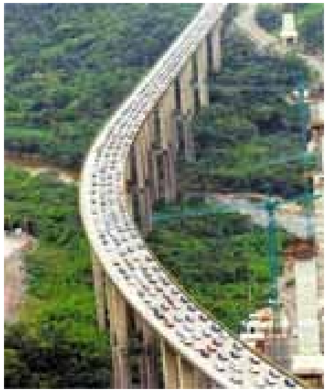
Past Work

- Routing (binary as well as non-binary) and traffic assignment
- Holonic approach to learning by traffic lights (with M. Abdoos)
- Dynamics of route choice:
  - Population game
  - Congestion game

Challenges Ahead

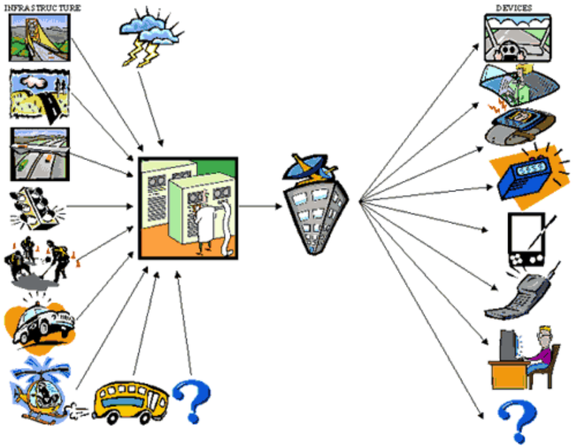
- Out of …

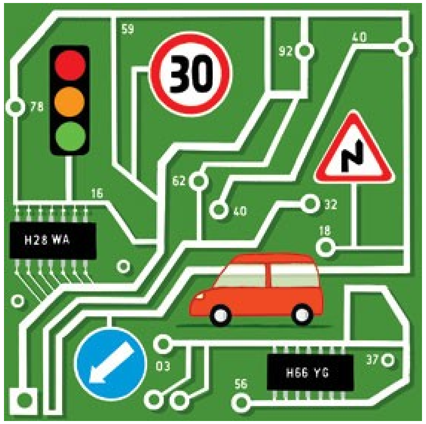



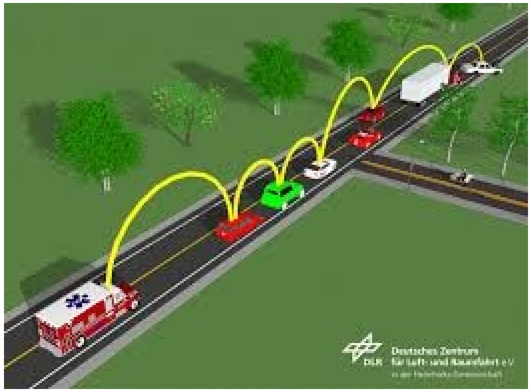


Challenges Ahead

- … into







Summary

- Many issues related to bringing the human user closer to a very technical system (transportation)
- Already reality: users of this system are influencing the system with their increasing coupled behaviors
  - in spite of the will of the managers of these systems
  - why not take advantage of this?

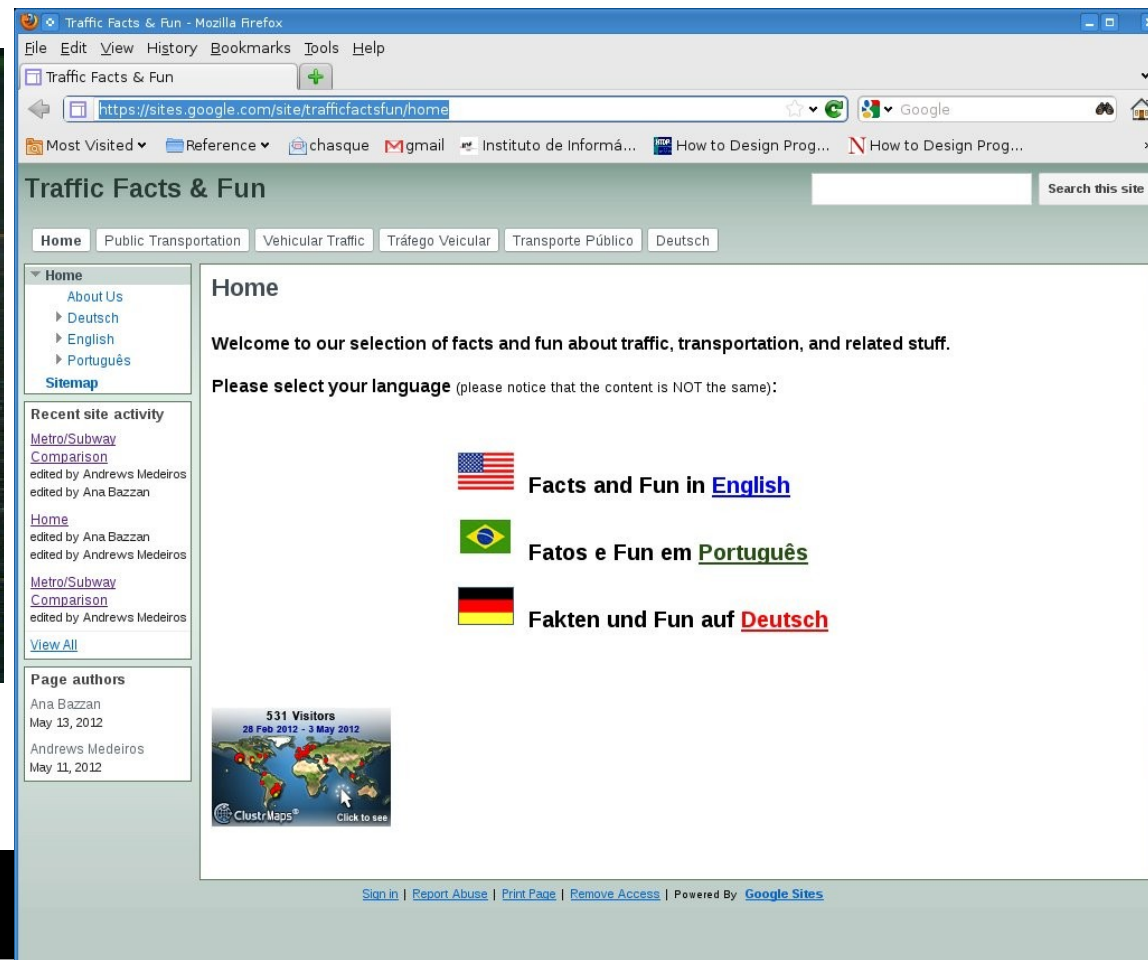
Summary

- Real opportunity for a change in the management paradigm in order to take advantage of multiagent systems and collective intelligence that is present in the real-world system

Credits

- Funding agencies
  - CNPq
  - FAPERGS and CAPES (former projects)
  - Alexander von Humboldt
  - BMBL / DLR
  - Santander

- Visit our web site *traffic facts and fun*
  - https://sites.google.com/site/trafficfactsfun/home



Credits

- (MASLAB) people involved
  - Dr. Andrew Koster, Dr. Jorge Aching
  - PhD student: Gabriel Ramos, Ricardo Grunitzki
  - Master students: Marcelo Souza, Rodrigo Batista
  - Undergrad students
  - Former students

Credits

- Collaborations
  - Prof. Dr. Scheuermann (HU Berlin)
  - Prof. Dr. F. Klügl (Sweden)
  - Univ. of Nice: Prof. Dr. Célia Pereira and Prof. Dr. A. Tettamanzi (BDI model based on possibilistic logic; application on trust of information sources)