Report from Dagstuhl Seminar 16091

Computational Challenges in Cooperative Intelligent Urban Transport

Edited by

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Abstract

This report documents the talks and group work of Dagstuhl Seminar 16091 "Computational Challenges in Cooperative Intelligent Urban Transport". This interdisciplinary seminar brought researchers together from many fields including computer science, transportation, operations research, mathematics, machine learning and artificial intelligence. The seminar included two formats of talks: several minute research statements and longer overview talks. The talks given are documented here with abstracts. Furthermore, this seminar consisted of significant amounts of group work that is also documented with short abstracts detailing group discussions and planned outcomes.

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1 Executive Summary

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Following the history of two Dagstuhl seminars on Computational Issues in Transportation in 2010 and 2013, the organizers of this follow-up seminar concentrated on upcoming, data-driven challenges in the area of urban transport. In recent years, urban transportation networks have become more diverse, with a growing mix of public and private operators providing disaggregated services and information. The resulting multitude of transportation options includes non-traditional modes and services such as car and bike sharing in addition to established public transport and individual car options. So far, it is challenging to combine detailed operational data automatically arising from these services, since these data are generated both from service operation and from the users of services via crowdsourcing. The seminar aimed to discuss how data sources can be made available for individual planning and system-wide coordination of urban transportation using an approach from distributed computing, i.e., getting all involved parties to cooperate in providing relevant spatial and temporal information in a timely fashion. It was not clear how to derive reliable information for planning and control approaches, or how to adapt optimization methodologies to make urban transportation more cooperative and intelligent.

The aims of the seminar were to extend the existing network in disciplines such as Computational Traffic Science, Optimization, Autonomic Computing and Artificial Intelligence for discussing computational challenges in cooperative intelligent urban transportation, mesh communities by collecting suggestions for (partial) solutions for burning issues in urban transportation and discussing the prerequisites for merging into interdisciplinary approaches, document the state of the art and current computational challenges in cooperative intelligent transportation.

To this end, an interdisciplinary group from areas such as computer science, geography, applied optimization and traffic engineering met at Dagstuhl. The number of attendees was advantageous for group discussions, not too small for breakout groups but also not too large for meaningful discussions in the plenum.

We started on Sunday evening with a game ("Cards Against Urbanity – special issue for this seminar") specifically designed for this event by Ms. Cottrill. The game was a great success as icebreaker and helped bringing together the participants with their various backgrounds. Monday was opened with a keynote by Vonu Thakuriah, who discussed examples, prospects and challenges of emerging forms of data in transportation research and applications. The participants introduced themselves, bringing a significant object describing their relationship with the seminar's topic.

For the remaining seminar time, the participants were asked to contribute to the seminar's content by one of the following options: they could give an overview talk of an emerging area (20 minutes), a research statement on what they have been working on in their particular area (5 minutes), and they were asked to come together in groups that were defined dynamically on Monday afternoon. The resulting abstracts can be found in this report. Based on the participants' interests, groups discussing the topics of online simulation, pedestrian behavior, autonomous transportation, smart cities, and benchmark data emerged. On Wednesday afternoon, the participants went on a 'field trip' to the retail lab by DFKI in St. Wendel, where the future of retail can be explored hands-on. Since there was a significant interest in the provision of benchmark data for urban transport, there was a special session and group work devoted to this topic on Thursday afternoon. Friday morning was meant for collecting the results of the group work and collecting open challenges for future seminars.

Summarizing, the seminar identified computational challenges to cooperative intelligent urban transport, among others notably research on opportunistic groups in public transport (i.e., people sharing tickets and or trajectories in an ad-hoc fashion), freight pods attached to light rail (i.e., mixing of freight and passenger transportation), define a common language for sharing complex knowledge and real-time data in smart cities and creating benchmark datasets for different modelling purposes and at different scales. We think that the seminar was quite successful in extending the existing networks by bringing together researchers from many different disciplines relevant for the future of urban transport. Some of the groups are planning to write proposals for the appropriate EU calls coming out in October, while others have started to work on position papers describing the state of the art as well as resulting future challenges of the field.

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3 Overview of Talks

3.1 Ridesharing and crowdshipping

Niels Agatz (Erasmus University – Rotterdam, NL)

In this presentation I discuss various initiatives that allow people to share rides or ship freight by using journeys that already take place. These systems may provide significant societal and environmental benefits by reducing the number of cars on the road and improving the utilization of available seat capacity. I present the results from several research projects in this area that aim to provide decision support models to match drivers and riders/parcels in different settings.

3.2 Human-centered intelligent transport systems

Ana Lucia Bazzan (Federal University of Rio Grande do Sul, BR)

In this slides I:
- present some motivation for human-centered Int. Transp. Systems
- discuss common issues between multiagent systems, complex systems, and transportation systems
- present an overview of my current projects

3.3 E-Fulfillment for Attended Last-Mile Delivery Services in Metropolitan Areas

Catherine Cleophas (RWTH Aachen, DE)

Our project aims to optimize the final part of a firm's value chain with regard to attended last-mile deliveries. We assume that to be profitable, e-commerce businesses need to maximize the overall value of fulfilled orders (rather than their number), while also limiting costs of delivery. To do so, it is essential to decide which delivery requests to accept and which time windows to offer to which consumers. This is especially relevant for attended deliveries, as delivery fees usually cannot fully compensate costs of delivery given tight delivery time windows. Existing order acceptance techniques often ignore either the order value or the expected costs of delivery.

We present an iterative solution approach: after calculating an approximate transport capacity based on forecasted expected delivery requests and a cost-minimizing routing, actual delivery requests are accepted or rejected aiming to maximize the overall value of orders given the computed transport capacity. With the final set of accepted requests, the routing solution is updated to minimize costs of delivery. The presented solution approach combines well-known methods from revenue management and time-dependent vehicle routing.

References

1 C. Cleophas and J. F. Ehmke *When Are Deliveries Profitable? – Considering Order Value and Transport Capacity in Demand Fulfillment for Last-Mile Deliveries in Metropolitan Areas*. Business & Information Systems Engineering: Vol. 6: Iss. 3, pp. 153–163, 2014.

3.4 Linking urban infrastructure systems: Future smart cities

Sybil Derrible (University of Illinois – Chicago, US)

Transportation systems are but one of the many infrastructure systems that populate cities. Whether it is the water/wastewater systems, the electric grid, the natural gas system, the telecom lines, or even the buildings, all urban infrastructure systems are intrinsically interconnected and interdependent. Computational challenges that the transportation sector have to face are in fact shared across most infrastructure systems. In this research statement, I discuss how urban infrastructure systems are physically and operationally linked and how we can better integrate them in the future, notably by presenting the concept of an integration-decentralization matrix and by giving specific examples. Overall, this research argues for a better coordination and planning of urban infrastructure systems, contributing to the future smart city.

3.5 The Computer Systems Group at Universidade Nova de Lisboa

Cecilia Gomes (New University of Lisbon, PT)

The distributed nature of Computational Transportation Science (CTS) and its requirements for large-scale data management and intensive computing raise a set of problems matching the area of Computer Systems. Cooperative Intelligent Transport Systems (CITS), in particular, benefit from novel solutions in mobile technologies and social networks and heavily depend on advances pertaining the big data problem. Namely, data management in all of its dimensions is very present in CITS including data acquisition, data storage and access, data processing and mining, or data dissemination and sharing.

Data acquisition is increasingly made from multiple heterogeneous data sources like vehicle and infrastructure sensors, satellite sources, user's mobile devices, services supported by transport companies and authority entities, etc.

The generated data may range from raw/unprocessed data in real time to off-line data generated by simulations building an historic view of a particular transport system. Such diverse data at different levels of the Intelligent Transport System (ITS) infrastructure may need to be accessed at different times or together requiring flexible forms of data access and uniformization in order to allow related information extraction. For instance, deployed networks of wireless sensors for weather conditions with restricted autonomy may be accessed only for severe weather conditions to be combined with traffic flow data (including from users) in a increasingly congested area. Moreover, CITS require support for data integrity, reliability and security, to guarantee that the acquired data is in fact dependable and not permeable to malicious information injection or extraction.

Such huge amount of produced data requires hence efficient, affordable, and secure ways of data storing, access, and processing. This includes traditional ones like proprietary data centers, to more recent private and hybrid Clouds or public Clouds' upscale solutions in a pay as you need model. Whereas local authorities and established urban transport networks traditionally rely on private centralized systems for data processing and mining, novel transport applications in logistics or car sharing/hiring benefit from novel forms of dependable distributed processing supported by a combination of mobile devices with cost effective Cloud solutions. In the former case, data processing requires traditional high performance computing solutions but also, for instance, easy forms of applications' portability to novel parallel architectures. Computer nodes composed of CPUs and GPU nodes are increasingly present in diverse computational platforms offering economies of scale but still demanding substantial effort on application's deployment.

In the latter case, data processing may be done on transit exploring mobile devices' capabilities but requiring efficient mechanisms on distributed data consistency and security and on using Cloud services whenever necessary (e.g. to locate a novel transportation application's service and its state).

As for data dissemination and sharing, CITS depend on timely data distribution to support decentralized information and service provision. Additionally, they will also increasingly need to explore forms of data sharing and dissemination (e.g. building common contexts like in social networks) among different urban transportation networks and users. For instance, internet and mobile companies may explore the information on travelers' location in order to use efficient broadcast for data dissemination for a particular area or application instead of more inefficient point to point/client-server interaction models. Likewise, different transportation networks may agree on sharing information (e.g. public transports and logistics operators with pre-defined schedules) whenever that may be economical viable.

Towards the above requirements in CITS, the Computer Systems Group at the New University of Lisbon, Portugal, is researching a set of topics that may contribute to this area. The mission of the group is to make the computer systems that surrounds us in our daily lives more reliable, trustworthy, dependable, and better performing following a principled engineering approach. This encompasses designing new algorithms for building systems that address practical needs and using formal methods to reason about that design, and implementing software prototypes for experimentally evaluating those systems. Some of the research areas are Highly-scalable Adaptable Data Dissemination, Decentralized Data Processing, Secure Data Management, Structured Parallel Programming.

In popular applications it is expected that a huge number of users a) Contribute with sensor data, e.g. via their mobile phones, and b) request information from the system. In this scenario, scalability of data processing (streams) becomes a major issue. Namely, a single server is insufficient to process all data and reply to all queries, but data processing may be partitioned among the nodes. The proposed solution, named C4S (Cloud for Sensing) provides a system for supporting participatory sensing applications that leverages cluster or cloud infrastructures to provide a scalable data processing infrastructure. Several decentralized processing strategies for data processing based on geographic partitioning are offered providing different tradeoffs on reliability and processing latency.

Following an increasing trend on moving processing the network edge, the group is also exploring other solutions combining mobile computing and edge Clouds for collaborative computations on mobile devices. The research encompasses forms of mobile to mobile device collaboration where no access to the Cloud is available with computations offloaded to the Cloud when possible. The solution minimizes network usage and significantly reduces latency, building systems that are fast when possible and consistent when needed.

Abstract-Gossip, or epidemic, protocols have emerged as a highly scalable and resilient approach to implement several application level services such as reliable multicast, data aggregation, publish-subscribe, among others. All these protocols organize nodes in an unstructured random overlay network. The goal of this work is to support the decentralized management of these networks supporting high churn tolerance and high scalability, while guaranteeing an efficient, robust and collaborative data dissemination among the nodes. Applications relying either on mobile networks or vehicular networks (e.g. autonomic vehicles in a city or groups of vehicle/user combination of computational devices) may benefit from these type of protocols for efficient and flexible data dissemination.

The group also addresses reliability and privacy-preserving of data via secure data management solutions. Low overhead solutions are being developed that offer secure data search on the cloud since they operate over encrypted data. They provide decentralized data sharing over an high number of replicas and rely on pairwise synchronization, and may be applied to sensitive information like medical data or to perform search over multimedia data repositories. Such secure solution may hence be a good contribution to transportation data processing whenever privacy concerns have to be addressed.

Finally, concerning the need to simplify the programming of the novel computational infrastructures composed of heterogeneous components (multi-core and many-core) the group is contributing to the area of structured (i.e. pattern-based) parallel programming. This area tackles a software engineering approach for (parallel/distributed) applications' development that aims to reuse expert knowledge on programming distributed and parallel applications via pattern abstractions. The goal is to increase the productivity of non-experts in those areas by promoting application portability and reusability in a simpler way.

Relevant publications:

- Scalable Data Processing for Community Sensing Applications. S. Duarte, et al. MONET 2013.
- Pixida: Optimizing Data Parallel Jobs in Wide-Area Data Analytics. K. Kloudas, et al. VLDB'16.
- HyParView: a membership protocol for reliable gossip-based broadcast. J. Leitão, J. Pereira and L. Rodrigues, DSN'07.
- X-BOT: A Protocol for Resilient Optimization of Unstructured Overlay Networks. J.
- Leitão, J. P. Marques, J. Pereira, and L. Rodrigues, IEEE TPDS 2012. Privacy-Preserving Content-Based Image Retrieval in the Cloud. B. Ferreira, J. Rodrigues, J. Leitão, and H. Domingos. SRDS'15.
- Extending Grid-Based Workflow Tools With Patterns/Operators. M.C. Gomes, O.F. Rana, J.C. Cunha. IJHPCA 22(3) (2008)
- Evaluating Novel Parallel Programming Models in the Context of Digital Breast Tomosynthesis. P. Somsen, P. Ferreira, N. Matela, P. Medeiros, and M.C. Gomes. (under submission)

3.6 Population-level filtering of abundant data

Benjamin Heydecker (University College London, GB)

We work in an era when data of one kind or another are abundant. However, the sources and quality of the data are often different from what we would have chosen. Issues that arise include implicitly selective sampling, incomplete observations and erroneous measurements. If we are to use data with these characteristics, then recognising them in our analysis and usage is potentially important.

This presentation will show how analysis of abundant datasets can lead to probabilistic identification and treatment of spurious data. This establishes an approach to filtering data that takes advantage of the volume of data available. The result of this is a probabilistic classification of individual observations as relevant or not, and a consequent approach to filtering information at the population rather than the individual level. An example application to travel time data derived automatically from matched number plate readings shows how this approach can be used to estimate a distribution of travel times under normal conditions alongside a distinct distribution of together with those under adverse conditions. A separate component distribution is estimated for spurious observations, which is taken into account when estimating travel times and when classifying individual observations.

The approach presented is applicable to data streams that are so abundant that detailed analysis of individual observations is impractical.

3.7 Enhancing environmental awareness using Participatory Sensing and the Social Web

Andreas Hotho (Universität Würzburg, DE)

The Social Web allows millions of users to share and exchange information about their daily activities. Smartphones are one way to do this. Even more they become a device to sense the environment and to inform users about the current situation. Thus, subjective data like human perceptions and impressions expressed in the Social Web can easily be combined with additional low cost sensor information, which is an important next step on the way towards establishing the ubiquitous web. The active contribution of everyone carrying such devices as a sensor is known as participatory sensing and allows for the collection of huge masses of new kinds of sensing data, especially as the data most often contains location information. Combining those with Social Web information adds additional value to it and researchers, especially from machine learning, data mining, and social network analysis, are interested in such data. They work on novel methods to understand the underlying human relationship, perception and interactions with the environment.

In the Everyaware project, we made a first steps towards turning a smartphone into a sensor for noise and air pollution measurements. Particularly we combined it with effective low cost air quality sensors which enables everyone to measure the black carbon concentration. More specifically, the developed box allows to determine the personal BC exposure in an urban environment by measuring indicator gases. Additionally users are able to react to the presented measurements using typical social web channels but also simple keyword or hashtags. As time and spatial information are connected with each measurement, the data can be used as a basis for a collective view on the urban environment. Results can be shown in an aggregated form on maps which allows for better insights into the current noise and air pollution situation. In several case studies we collected a lot of measurements alongside with subjective impressions. This data demonstrates the power of the approach and give insights into temporal and spatial distribution of both the noise and the black carbon concentration. The added personal feedback of the users show their perception of the measured environment and their learning behaviour about the perceived perception of their surrounding.

Details about the project results can be found in:

- Sîrbu, A., Becker, M., Caminiti, S., De Baets, B., Elen, B., Francis, L., Gravino, P., Hotho, A., Ingarra, S., Loreto, V., Molino, A., Mueller, J., Peters, J., Ricchiuti, F., Saracino, F., Servedio, V. D. P., Stumme, G., Theunis, J., Tria, F. & Van den Bossche, J. (2015). Participatory Patterns in an International Air Quality Monitoring Initiative. PLoS ONE, 10, e0136763. DOI: 10.1371/journal.pone.0136763
- Becker, M., Caminiti, S., Fiorella, D., Francis, L., Gravino, P., Haklay, M. (M., Hotho, A., Loreto, V., Mueller, J., Ricchiuti, F., Servedio, V. D. P., Sîrbu, A. & Tria, F. (2013). Awareness and Learning in Participatory Noise Sensing. PLoS ONE, 8, e81638. DOi: 10.1371/journal.pone.0081638
- http://cs.everyaware.eu/event/overview
- http://www.everyaware.eu/

3.8 Earliest Arrival Problem of Pedestrians

Tobias Kretz (PTV AG – Karlsruhe, DE)

Problem Formulation

Pedestrians can choose their walking direction continuously. A single pedestrian – undisturbed by other pedestrians – who wants to arrive as early as possible at some given destination would simply walk the shortest path – a poly line that leads around obstacles to destination. If there are other pedestrians around evading these might be required and the actually walked trajectory will deviate from the shortest path. If there is a considerable number of pedestrians around one may adopt a macroscopic perspective and by some given fundamental diagram assign spots continuously an expected walking speed according to the local density. The task is to simulate the behavior of a pedestrian who wants to move in minimum time through such an environment with two continuous spatial dimensions and walking speeds varying over time and space; or – a slightly different task: to find at each moment from continuous 360° the walking direction which momentarily promises the earliest arrival at a given destination.

Solution Idea

To compute estimated remaining travel time to destination one can place a fine (finer than body dimensions) grid over the geometry and assign each grid cell a small estimated time to pass over it. If – beginning from the destination – all these small times are summed up one ends up with a map of estimated remaining travel time to destination. The negative gradients of such a field (resp. map) point into the direction of estimated earliest arrival at destination. Since the normalized gradients are the desired result of the computation and since the normalized gradients are invariant to a global factor of the map of remaining travel times one may arbitrarily define that the estimated time to move over an empty cell of solid ground and even surface be 1. An empty cell with a ground that hinders movement (for example sand) might be 1.5 throughout the simulation. A cell that is occupied by another pedestrian can be chosen to have the value $1 + g$ with g being a parameter that needs calibration. Obviously not all pedestrians pose an equal hindrance for future movement. If some other pedestrian is ahead of "me", but is walking faster than "I" would ideally like to move, then this other pedestrian is not a hindrance. There is no need to begin overtaking. Therefore the "$1 + g$" is extended to the following formula:

$$\frac{1}{f} = 1 + \max\left(0, g\left(1 + h\frac{\vec{v} \cdot \nabla S}{v_0 |\nabla S|}\right)\right).$$

Here h is another parameter for calibration whose value is expected to lie in [0..1]. S is the field of (static) spatial distance to destination. v is the velocity of the pedestrian occupying the spot and v_0 is the desired speed of the pedestrian for whom the field of remaining travel time is to be calculated. Thus, v and v_0 are NOT from the same pedestrian. If the field is calculated to be used by more than one pedestrian v_0 can be chosen to be the average of desired walking speeds.

The resulting $1/f$ is used as right side of the Eikonal Equation

$$|\nabla T(\vec{x})|^2 = \frac{1}{f(\vec{x})^s}.$$

Which then is solved numerically using for example the Fast Marching Method (Kimmel & Sethian, 1998) or the Fast Iterative Method (Jeong & Whitaker, 2007). This mathematical integration is also an integration in the sense that it integrates the effect of all pedestrians as well as the attractive effect of the destination such that the resulting walking direction is no longer a greedy optimization with regard to distance reduction to destination. This implies that adding or taking one single pedestrian to or from a scene may change the effect of all other pedestrians on the one pedestrian under consideration. In social systems "…the properties of any part are determined by its membership in the total functional system." (Sherif, 1936). The desired walking directions can then be computed as

The method as described to this point has been implemented in 2011 and is available in the microscopic simulation PTV Viswalk to make pedestrians walk into the direction of estimated earliest arrival. For this the resulting desired direction is used as direction of the desired velocity in an implementation of the Social Force Model (Johansson, Helbing, & Shukla, 2007).

Computational Challenges

Since the spatial distribution of pedestrians as well as their velocities change within a simulation, the field T has to be computed repeatedly, ideally in each simulation time step. Even if only one field T is computed for all pedestrians heading to a particular destination this is already computationally challenging for typical project size area extent (computation time in this case does not scale with the number of pedestrians, but the area extent covered by T) and current typically available desktop computing power.

As stated ideally each pedestrian would have its own field T which multiplies the effort by the number of pedestrians. As of 2016 this is computationally infeasible to be carried out on typical commercial project size scale.

Another aspect in principle requires a multiple computation time. The gradient of the field S in the first equation has the role of the desired walking direction. However, the desired walking direction is what is intended to be calculated with this method. Thus gradient S is just an approximation to the desired walking direction as input for the method and so T is only an approximation to the field of estimated remaining travel times as output of the method. One could (and ideally would) use the resulting T as input for the same method, replacing S to compute a T_2 and iteratively a T_3, T_4, and so on. Provided the process converges this would be continued until $T_{n+1} - T_n$ is smaller than some given value for all cells.

Further Reading

The solution idea is rolled out in detail in (Kretz, et al., 2011). In (Kretz, 2014) the aspect is discussed that the field T considers the destination and all pedestrians holistically, i.e. that adding one pedestrian may change the effect all other pedestrians have to the pedestrian in focus. The method is used in (Kretz, 2013) to verify the computer implementation of the Social Force Model and itself. In (Kretz, et al., 2011) the parameters of the model are calibrated by means of an immersive virtual reality experiment. Further applications of the method are presented in (Kretz, 2009b) and (Kretz & Große, 2012). Finally in (Kretz, Lehmann, & Hofsäss, 2014) the method is compared to a method which statically computes routing alternatives and distributes pedestrians with an iterative assignment on the routes such that there is an equilibrium of travel times along the routes. A video that animates the mathematical process and shows examples of application can be seen here: https://youtu.be/8SmRBTJ-jeU.

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3.9 Logistics for Shared Mobility

Dirk Christian Mattfeld (TU Braunschweig, DE)

People's mobility budget seems to be bounded to approximately one hour per day. Urban transportation infrastructure determines the distance that can be covered by travelers within this hour. The greater the flexibility of travel modes, the greater the benefit to inhabitants of a conurbation. Only recently, shared mobility systems offer the individual use of vehicles without required ownership of these vehicles. This flexible use allows for inter-modality and multi-modality of people and directly impacts the reach of daily travel.

However, the availability of shared vehicles will be limited to typical daytime dependent flows of travel within a city. For instance, the demand of commuting from a residential area to a business district in the morning will be high resulting in a competition with respect to vehicles of a shared mobility system. This effect can be shown by the fill level of stations of the bike sharing system of London. Cluster analysis with respect to the bike usage in Vienna conducted by the author reveal similar results.

In order to provide a high level of service in terms of the possible pickup of bikes and the possible return of bikes at stations, a relocation of bikes through the transport operator is necessary. Exemplary figures show, that the Barcelona bike sharing system Bicing requires approximately 4 million Euros for the relocation of bikes per year. This amounts to approximately 1/3 of the operations cost of this system providing access to 6000 bikes to the population of Barcelona, Spain. In order to provide cost efficient operations, a proper planning and control of the system is required by means of logistics optimization models. On the strategic level, the system design of a bike sharing system may be supported by covering models. Transportation models may be used to determine relocation flows of bikes between stations pursuing a balancing of bike numbers among stations. In order to support relocation operations, vehicle routing models may be applied.

Additionally, user incentives with respect to the bike usage may be set by dynamic pricing. Revenue management may contribute to this task in future shared mobility systems. Also, maintenance and repair of shared mobility vehicles may be supported by interval or condition based maintenance in the future. All of these optimization models have been formulated in logistics management and need to be tailored to special needs of shared mobility systems. The actual needs strongly depend on the features of the shared mobility system under consideration.

3.10 Automated Planning

Thomas Leo McCluskey (University of Huddersfield, GB)

Automated Planning, from an artificial intelligence point of view, is a research area in which algorithms are developed that output plans which solve goals. Specifically, planning algorithms input knowledge of actions and resources, and knowledge of an application environment, and given a planning problem, synthesis an ordered set of actions which when executed from a current state will solve the given planning problem.

Planning algorithms developed by the research community have been applied in a wide range of applications, including AUV control, narrative generation and workflow management. In the talk we consider some important areas of research in Automated Planning, and its application to road transport management, where it has proven useful in generating traffic light strategies for urban regions.

3.11 Research Statement: Computer Vision

Andrea Prati (University of Parma, IT)

Within the field of Cooperative Urban Transportation, computer vision (CV) should be considered as an enabling technology. Among the different uses which might be helpful for Urban Transportation, CV can be use as a tool for automatic extraction of (real-time) information about objects (people or vehicles) in an urban scenario. Object detection and tracking from different (live) video streams can be achieved using standard CV algorithms. Object re-identification (i.e., the ability to automatically understand whether an object reappears in a new camera view) might also be employed to keep tracks of object movements (and related statistics, such as travel time, queue formation, incident detection, etc.) on larger areas.

Apart from this extraction of real data (to be compared with or added to simulated data), CV enables also new types of applications related to transportation. Among the many, the implementation of CV algorithms on mobile phones (smartphones and tablets), often called “mobile vision”, opens the way to several interesting applications. For example, the automatic place recognition (i.e. the ability to recognize from the camera embedded on the mobile device landmarks in the surroundings) provides a tool for refining the localization of users and vehicles while traveling in a city. An even more innovative application is related to the automatic profiling of users through the use of the frontal-facing embedded camera: mood/emotion, as well as age, gender and ethnicity, could be automatically determined (with a certain accuracy) in order to provide to advanced recommender systems, useful profile information about the user.

Last but not the least relevant, CV algorithms are at the core of autonomous guidance of vehicles, in addition to other sensors.

3.12 Good City Life

Daniele Quercia (NOKIA Bell Labs – Cambridge, GB)

The corporate smart-city rhetoric is about efficiency, predictability, and security. “You’ll get to work on time; no queue when you go shopping, and you are safe because of CCTV cameras around you”. Well, all these things make a city acceptable, but they don’t make a city great. We are launching goodcitylife.org – a global group of like-minded people who are passionate about building technologies whose focus is not necessarily to create a smart city but to give a good life to city dwellers. The future of the city is, first and foremost, about people, and those people are increasingly networked. We will see how a creative use of network-generated data can tackle hitherto unanswered research questions. Can we rethink existing mapping tools [happy-maps]? Is it possible to capture smellscapes of entire cities and celebrate good odors [smelly-maps]?

happy-maps: http://www.ted.com/talks/daniele_quercia_happy_maps
smelly-maps: http://www.di.unito.it/~schifane/smellymaps/project.html

3.13 Overview of Issues/Problems leading to Computational Challenges in Cooperative Intelligent Urban Transport

Jörg-Rüdiger Sack (Carleton University – Ottawa, CA)

In this talk, we set the stage for the seminar by reviewing (see also [1]) some of the main urban transport challenges and identify the resulting tasks:

1. Parking optimization
2. Delivery parking optimization
3. Planning environmentally friendly transport
4. Intelligent city planning
5. Intelligent, cooperative planning of transport mixes
6. Intelligent incorporation of public space
7. Development of software/hardware infrastructure to store, assess, model, plan intelligent infrastructure maintenance, repair, renewal, expansion ...
8. Reduction of accidents on road networks and increase the safety of all participants using cooperative approaches.
9. More and more intelligent city logistics strategies are required taking many environmental factors into consideration: noise, vibration, visual intrusion, ..
10. Develop privacy guaranteeing strategies or clear guideline on extend to which privacy needs to be given up to gain access to services...

We also discuss some of the European Comission work on ITS (see [2]) including the European Union mandates M/45 on C-ITS abd M/453. Finally, we describe some of the obstacles in acceptance of work on C-ITS and an approach how to overcome these.

A proposal we made to TomTom based on work carried out at an earlier Dagstuhl seminar is described. This work is based on an exact algorithm for shortest path in time-dependent

FIFO networks developed by the author and collaborators (former Ph.D. student M. Omran and F. Dehne, Carleton University) and practical approximation algorithms (see [4]).

Task 8 on accidents and safety might benefit from [5], where we describe how to find k "shortest paths" between s and d with the minimum number of shared edges. Distributing traffic between two nodes of the road network is this fashion could result in a better road utilization, reduce traffic and thus accident while having a small additional cost when compared to the cost of an optimal route.

Finally, the important topic of privacy is discussed which is of importance throughout the remainder of the seminar. The question is raised if cooperation is a means to, or an automatic loss of, privacy. Work by the author [**?**] generalizing k-privacy to (i, j)-privacy might be usable to determine if certain information to be shared with others needs to be delayed prior to its sending. We wish to guarantee that even multiple sharing of information along a route taken does not lead to a loss of location privacy.

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3.14 How does real-time information change the behaviour of traffic, and can cooperation emerge with intention sharing? (The online routing game model)

Laszlo Zsolt Varga (Eötvös Lorand University – Budapest, HU)

Active participants (agents) of urban transport are embedded in their environment. They perceive the current state of the traffic and make decisions which action to perform, e.g. which means of transportation to take, which route to follow, etc. If each subsequent agent reactively optimizes its trip, based on the real-time data of the current state of the whole traffic network, then in some situations the traffic may start to fluctuate, and sometimes the agents may be worse off with real-time data than without real-time data. This was observed by traffic engineers and multi-agent researchers both in real world and in simulations, and it was formally underpinned recently, using the novel online routing game model. Researchers proposed to add proactive flavour to the actions of the agents with anticipatory techniques, where the future state of the traffic is predicted from the current intentions of the agents.

Simulation results indicated, that these anticipatory techniques improve the properties of the traffic.

I am planning to present the online routing game model and how the model can be used to investigate these issues.

3.15 Spatio-temporal Search for Transportation Resources

Ouri E. Wolfson (University of Illinois – Chicago, US)

This talk will focus on the problem of spatio-temporal resource search and its application to transportation as in vehicular parking. Spatio-temporal resource search consists of two sub-problems: the location-detection of spatial resources, and the competition among mobile agents for capturing them. I will describe a crowdsourcing approach for the first, and a game theoretic approach for the second. I will discuss the implementation of the results in a new smartphone app that helps drivers locate open street-parking slots and capture them in competitive scenarios. In this sense, the app extends the car-navigation-system concept to parking.

4 Working groups

4.1 Benchmarking

Caitlin Doyle Cottrill (University of Aberdeen, GB), Ana Lucia Bazzan (Federal University of Rio Grande do Sul, BR), Andreas Hotho (Universität Würzburg, DE), Kevin Tierney (Universität Paderborn, DE), and Ronald Van Katwijk (TNO Telecom – Delft, NL)

In our first small group discussion, we reviewed the concept of benchmark data. In the discussion, it emerged that we all find that the concept of benchmark data is a good thing. Having a standard set of data that can be used for comparing processes and programs, perhaps particularly in the areas of model calibration and paper writing and reviewing, was viewed as a useful goal to pursue. It was also agreed, however, that establishing benchmark data is a complex process. Issues such as the following can negatively impact upon the potential for creating useful, standardized benchmark data sets:

- defining the standard the data needs to meet (good enough or gold standard),
- having access to adequate data (via sensors, surveys, etc.),
- defining the scenario(s) for which the data should correspond (i.e. timeliness, dispersion, context, etc.).

The ensuing discussion focused on both the potential for collecting benchmark data, as well as the purposes for which they could be used. Given the diversity of interests represented around the table (from freight to behaviour), it was quickly evident that no one data set could function in a similar fashion for all interests. There was discussion around the potential for creating (or identifying) a 'model city', which would be used for purposes of creating a 'perfect' synthetic or real dataset by instrumenting all aspects of infrastructure and behaviour. Ensuing discussion, however, revealed that this, too, would be in question. For instance, while it might be viewed as relatively simple to create a representative O-D matrix using a combination of in-road sensors, smartphones, and cameras, there would still likely be aspects (such as trajectory) lost in the process. Such discussions revealed both the interest in and relevance of the topic, while highlighting the myriad concerns evident in the construction and/or creation. The group broke up after this meeting; however, the underlying discussion and concerns were brought forward in ensuing discussions among the Dagstuhl participants.

4.2 Collaborative Travel in Public Transportation

Ivana Dusparic (University College Dublin, IE), Franziska Klügl (University of Örebro, SE), Marco Mamei (University of Modena, IT), Andrea Prati (University of Parma, IT), Jörg-Rüdiger Sack (Carleton University – Ottawa, CA), and Laszlo Zsolt Varga (Eötvös Lorand University – Budapest, HU)

Increasing proliferation of real-time travel information and travel planners as well as change in vehicle ownership rates are giving rise to novel transport models such as car-sharing, car-pooling, on-demand public transport, and provision of multi-modal transport as a service. One area that is still relatively unexplored is ad-hoc group travel in public transport, with the goal of obtaining significant group travel discounts transport companies offer to travellers, but also to provide more inclusive travel options to those who require additional help using the public transport (e.g., elderly, disabled, those who do not speak the local language etc). Transport providers would further benefit from such a model, by gaining new customers who would otherwise not be able to afford the travel, as well as from more fine-grained transport demand and preference information that groups formation would offer.

Self-organizing collaborative group formation for group public transport travel raises several challenges such as identification of suitable groups and group members based not only on constraints on source, destination and times of travel but also on group member preferences (e.g., which travel mode a user prefers, and what profile of group members does he or she prefer travelling with), appropriate group sizes sufficient to avail of discounts, re-organizing of the groups in case of cancellations, real-time delay updates (especially in the cases of connecting modes of transport), incorporating feedback on traveller reliability, and privacy of the travellers. In order to implement such a model, advances will need to be made in a number of research areas such as privacy, real-time demand prediction and simulation, learning of user preferences, and theoretical analysis of group formation. Impact of legal issues and regulations will also have to investigated and addressed.

Privacy: Questions on privacy falls into at least three different levels:
1. to the booking service,
2. to the assembled group and
3. to the travel provider.

Subscribers using such systems are willing to sacrifice some amount of privacy, in particular, when they are meeting face-to-face for travel in the assembled group (where/if joint travel is required). However, they may wish keep many aspects of their identity to themselves; these may include: exact locations of origin and destination and name (except for payment details and ticket verification). Obfuscation of exact locations, or techniques to ensure k privacy may be required while still allowing efficient group formation. These techniques need to be studied w.r.t. the requirements of the system and possibly new techniques may need to be developed in particular since privacy is here multi-level.

Learning of user preferences: Users might have multiple objectives and constraints on meeting those objectives when availing of public transport and group formation in particular. User preferences need to be captured, explicitly or implicitly, and their relative importance determined depending on the current context of the user. (e.g., users might prefer later train but are willing to change travel time within x minutes, for y amount of discount, but only if the weather is nice and they are not a personal and not business trip, and are alone rather than with a co-worker or a child). Implicit capturing of user preferences might include to access to sensory data, e.g. from the mobile phone of the user, while keeping in mind privacy issues. Suitable learning techniques will need to be identified and extended to deal with dynamically changing preferences and trade-offs between multiple objectives travel plans need to be optimized for.

We propose to perform a proof of concept study of such a system in public transport system (trains primarily) in Netherlands.

4.3 Online Data and Simulation

Franziska Klügl (University of Örebro, SE), Catherine Cleophas (RWTH Aachen, DE), Piyushimita Vonu Thakuriah (University of Glasgow, GB), and Laszlo Zsolt Varga (Eötvös Lorand University – Budapest, HU)

The title of the working leaves room for interpretation. During the seminar, we have seen that online web data is a valuable resource for many questions related to urban systems. For example, Twitter messages can be classified whether it contains a positive comment on public transportation or a comment about its safety. The term "prediction" is hereby used for predicting future classifications. Twitter messages like these could be used in a simulation model related to route choice. Data generated from online channels can be actually used for simulation like any other data source. The alternative to interpret the topic is the idea to feed data into a running simulation "online" – in contrast to offline, that means before the simulation or after the experiments for validation of simulation output. Thus approaches are also subsumed under the term dynamic data-driven simulation. Hereby, feeding-in data is associated with real-time data processing. Assuming that a simulation produces output y from input data x simulating a function like $y = a \cdot x + b$. Hereby, x is some form of input value, determines the output value of the simulation, a and b are parameters. We identified four approaches to feed in data during a running simulation.

1. The initial situation $x0$ may be directly connected to a real simulation. A simulation faster than real-time could illustrate how the world would develop starting from the current situation. An example would be the illustration of effects of climate change.
2. Online infusion of input data. There is an ongoing connection between real-world sensors and a continually running simulation. Sensor events are fed into the simulation. An

example is the OLSIM Simulation which connects a simulation-based extrapolation of traffic state of the highway network of North-Rhine Westphalia (Germany) to sensors that register vehicles moving on and off ramps.
3. Online calibration would address adaptation of parameters such as a or b so that the current simulation is better aligned to the real world.
4. Model adaptation means a data-driven alignment of a running simulation to the real-world by not just adapting parameter, but changing the structure of the model. In the example that means the way how the input values and parameters are combined, the $*$ or $+$.

Whether such a dynamic data-driven approach could work depends on the temporal resolution of model dynamics with respect to granularity of incoming sensor data and the time frame of predictions that the model could provide:

- Short time appears to be quite clearly related: the simulation could provide forecasts of travel time given the current real-world traffic state.
- Mid-term would relate to daily activities, mode choice models; Real people's choices can be clearly observed and extrapolated into the future.
- Longer-terms like simulations for finding the optimal headway of busses or adaptation of infrastructure appear to be harder.

Based on that discussion, we identified interesting application ideas:

- Simulating the urban metabolism consisting of different sub-systems with different data needs aligned to the real world. One could identify locations at which there might be a big crowd in an hour. Based on those predictions – if done reliably – actions could be triggered such as send more busses than originally planned.
- Knowing that a fitness app tells a person to drop of the bus now for satisfying the daily goals of number of steps, could be fed into the prediction of travel time for the person that drops off, but also for the complete system.
- Predicting whether future connections would work given number of travelers who intend to go to destination and would due to their numbers further delay the connections at other places.
- Simulation for predicting my information needs about an activity before I actually fully planned the activity. As a result of this discussions, we decided to continue with personalized travel information also involving simulation-based predictions.

4.4 hello... Situation Aware Systems Integration (SASI)

Thomas Leo McCluskey (University of Huddersfield, GB), Sybil Derrible (University of Illinois – Chicago, US), Cecilia Gomes (New University of Lisbon, PT), Jörn Schlingensiepen (TH Ingolstadt, DE), Piyushimita Vonu Thakuriah (University of Glasgow, GB), and Ronald Van Katwijk (TNO Telecom – Delft, NL)

Cities have gained tremendous complexity since the industrial revolution, forcing the separation of responsibilities across multiple "departments" (e.g. transport, water resources, utilities). This directly contrasts with older paradigms of planning that were led by central authorities (Figure 1), what Lewis Mumford (1961, p. 172) describes as "regimenters of human functions and urban space" and perhaps best illustrated by Baron Haussmann for

Paris and Ildefons Cerdà for Barcelona. Beyond the substantial benefits, this decentralization has come at a cost, and nowadays, departments rarely communicate with one another, acting as distinct silos. What is more, the situation is likely to be exacerbated by the predicted rise in urban population through this century. Letting departments develop vertically leads to interference of services (perhaps discovered in operation), lack of coordination when facing urban-wide challenges and emergencies, and inherent inefficiencies in the whole urban system. While there has been work in service / department co-ordination for example in the area of disaster recovery, by and large these developments tend to be ad hoc.

While many argue for a breaking down of the silos, there are two ways that this can occur. One way is to re-centralize responsibilities. This is unlikely, however, since cities are complex systems, and it is not reasonable to assume that one entity can successfully plan and coordinate all activities of a city. A more preferable paradigm is to encourage communication between departments, as illustrated on the right-hand-side of Figure 2. To this end, the main goal of this project is to enhance department-to-department (D2D) cooperation and coordination, via improved D2D communication and data exchange, through a common formal semantic vocabulary. This is particularly useful for data acquisition purposes. For instance, the transportation department will be able to communicate with other departments and share services and data for the benefit of the city; e.g., the transportation department will easily be able to acquire urban emission data from the environmental department. To some extent "smart cities" initiatives are aimed at such improvements, but up to now the focus of smart cities has been on sharing data through enhanced ICT infrastructure. Little work has focused on investigating the requirements on and functions of departments (utilities) with the aim of considering these together with the aims of coordination, cooperation and synchronization.

To illustrate the problem, we detail two "examples" of how a city with isolated functions/ utilities might fail: (1) urban emissions, and (2) urban flooding.

Example 1: Transport, energy generation and construction are three "departments" within a City that manage functions which generate urban emissions as a side effect. Currently there is no (as far we know) communication or co-ordinating control between them. It is well known that cities regularly break air pollution limits, even in Europe. It may be possible for "Transport" to adjust regional traffic flows to alleviate this pollution, but this takes no account of the other ca. 50% of pollution which is generated by other utilities. Currently it is not known how these departments can communicate and combine together to produce a holistic solution to the problem. In fact, there is likely to be little shared knowledge between them. Enabling D2D communication on a shared vocabulary, could significantly tackle this challenge.

Example 2: Flooding has become a significant threat in cities. The impervious surfaces created by buildings and roads force storm water systems to handle large flows of surface runoffs during heavy rains. Runoffs access storm water sewers through grates at street curbs that can easily be obstructed by debris, causing flooding. This problem is likely to be amplified in the future as extreme weather events are not only increasing in frequency but also in number, thus making cities particularly vulnerable to flooding. At the moment, municipal crews drive around neighborhoods before and during rain events, and try to detect obstructed grates. This information could easily be collected by other parties, however, from being crowd-sourced by responsible citizens or police patrols, to being detected by smart streetlights (that can detect when flooding when equipped with sensors). Although water departments could implement their own monitoring system (e.g., in the form of 311 calls such as in Chicago)), the goal here is to offer a common language and make it easy to share information across departments, beyond implementing an ad hoc system that purely fits this particular case. A similar process can be imagined for many other problems, from pothole detection to sag in distribution lines, which could easily be reported by non-responsible parties.

Methodology

Since the interaction of different stakeholders in this field is too complex to drive this development in a top-down-way, we propose to uses an approach inspired by functional design. The main idea is to describe current and future demands in a solution-independent way in order to free the mind in order to think about the solution in new ways. The main aspect is to give a value to provide functions but also allow identifying advantages in coupling different functions / services in cities. We aim to capture the requirements of the example systems in a formal way, and hence capturing the semantics of the functions and services, and the semantics of the data flowing between them, independent of our interpretation. Data sets could be annotated with ontologies which will underpin the sharing of data. Additionally, this will enable the use of tools to look for inconsistencies and interference between requirements. (For example, we would be able to check whether, with the addition of some services requirements, safety conditions on some existing service are compromised). More generally, it would allow us to simulate the behavior of these systems defined by the requirements. It will also facilitate the modular addition of the requirements of further services in the future. The expression of these requirement will rely on the use of a fundamental commitment to some common language convention, such as first order logic, using a controlled but extensible vocabulary.

Since data acquisition is a big cost factor in providing smart services the focus is on identifying data that can be shared or data that is demanded by one service solution that is already generated by another. To achieve this we propose to focus on coupling two or three current services resp. their providers in the first step.

Intersection (re-)design

Intersections are locations where many people meet that are in transit. In this case we are focusing on locations where different modes of transport, often with different speeds, meet. Currently the merits of one solution over the other is made by quantifying only one or two criteria, which are mostly internal to the transport system. Solutions also affect the city in other important ways, which are at best taken into account only qualitatively.

Key performance indicators:

- Safety (both objective (crashes) and subjective (social safety),
- Fairness (with respect to waiting times),
- Efficiency (with respect to energy use, throughput),
- Aesthetically pleasing
- Attractiveness of nearby housing and shops
- Healthy (emissions and emissions)

Known (partial) solutions

Shared space, spatial segregation of different travel modes (vertically by means of underpasses and overpasses or horizontally by providing separate infrastructure), signalization, roundabouts, speed harmonization

Data requirements:

- Expected) traffic demand for the intersection split out for
- the different modes of transport: motorized traffic, bicycles (electric and manual), pedestrians,
- The different (types) of users of the intersection (elderly, schoolchildren, shoppers, etc.)
- How demand could be affected by the chosen solution both locally and elsewhere in the network
- The available resources (time, space and money)
- Number of residents and merchants effected economically or health-wise (emissions and emmisions)

Some informative sources:

- http://www.eltis.org/guidelines/introduction
- https://en.wikipedia.org/wiki/Shared_space
- http://www.pps.org/reference/shared-space/
- https://mitpress.mit.edu/sites/default/files/titles/content/9780262012195_sch_0001.pdf
- http://nacto.org/publication/urban-street-design-guide/intersections/intersection-design-principles/

Contribution of Maria Cecilia

The idea of Cloud Computing was preceded by the idea of Grid computing (similar to the power Grid), i.e. having computational power everywhere, you just have to "plug your computer". Since big enterprises like Amazon and Google had big data centers, they started offering storage and computational resources as a service., leading to the basics of Cloud computing – IaaS (Infrastructure as a Service) PaaS (Platform as a S), SaaS (Software as a Service). So the Cloud computing is already making the cities smarter, and helping transportation by avoiding transportation, but mostly by providing resources in a transparent and distributed way, as with a cost model "pay as you need".

Cloud computing is hence providing services for:

- people
- commercial enterprises
- transport domain (private and public)
- authorities (e-city)
- entertainment enterprises

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4.5 COllaborative Flexible Freight for Eco-Efficient Delivery (COFFEE-D)

Kevin Tierney (Universität Paderborn, DE), Catherine Cleophas (RWTH Aachen, DE), Caitlin Doyle Cottrill (University of Aberdeen, GB), Jan Fabian Ehmke (Freie Universität Berlin, DE), and Benjamin Kickhöfer (TU Berlin, DE)

This group addressed the topic of collaborative freight transportation in urban environments. Urbanization has been steadily increasing since the industrial revolution and sees no signs of abating. As more and more people relocate to cities, the challenges for urban governments and authorities are becoming larger and more difficult to overcome. Pollution, noise, and traffic congestion are several key problems in urban areas requiring action to avoid negative consequences for the health and well being of city inhabitants. With residents demanding a higher quality of life in their neighborhoods, innovative solutions are required to address the downsides of city growth.

As cities expand, so does the amount of freight shipped in to, out of and within urban areas. Freight carrying trucks are key contributors to lower air quality, noise, and congestion of streets both in terms of parking and traffic flow. However, truck traffic in cities is unavoidable according to current freight transportation paradigms. Large cities consume and produce many tons of goods and require constant traffic in and out of the city. An innovative transportation solution would therefore reduce truck traffic within cities while continuing to support the freight demands of a city's inhabitants.

We propose utilizing existing light rail infrastructure to transport goods from transshipment hubs located outside of a city to stations within the city. Receivers of goods would either pick up their goods in package stations located along light rail lines or would engage third party last mile services to bring packages to their doorstep. The system would support shipments from and to anybody inside of a city, meaning unlike previous light rail-based freight systems, it would also be able to offer last mile services normally provided by the post or package companies like DHL, UPS or Fed-Ex. Since the entire system would run on light rail, it would be clean and not detract from the city's air quality. And it would also run independently from road traffic.

The COFFEE-D system would use a set of stackable containers in various sizes that can be palletized as well as carried on hand trucks or by a single person. Goods destined for locations within the city would be placed into these containers at their place of production or packing, loaded into trucks and brought to transshipment hubs at the border of a city. Automated systems would quickly load the containers into a buffer at the hub and await a freight pod to carry containers into the city. Freight pods could be fully automated, semi-automated, or towed and would directly interface with package stations at selected stops.

The outcome of our proposed system will be cleaner cities with less traffic and parking congestion. We plan to submit a grant in a Horizon 2020 EU call to further explore the COFFEE-D system.

4.6 Modelling Pedestrian Behaviour

Sabine Timpf (Universität Augsburg, DE), Benjamin Heydecker (University College London, GB), Andreas Hotho (Universität Würzburg, DE), Tobias Kretz (PTV AG – Karlsruhe, DE), Daniele Quercia (NOKIA Bell Labs – Cambridge, GB), and Giuseppe Vizzari (University of Milano-Bicocca, IT)

The reason to model pedestrian behaviour within the context of CTS is to gain an understanding of this behaviour and to test hypotheses on behaviour. One motivation for this modeling might be to inform the design of pedestrian systems; this is especially true in event planning where issues for investigation need to be identified. Offline simulations and analysis of results may improve key performance indicators (Level Of Service, travelling times, densities, etc.); faster-than-realtime simulations may be used for short term predictions (e.g. in systems supporting crowd managers / operators) or to inform individual pedestrians as a basis for a decision-support system or for a cooperative system. Modelling pedestrian behaviour is a multi-perspective endeavour, which means that planners, architects, urban and landscape designers, transportation engineers and managers need to bring their own issues and questions in order for a satisfactory model to emerge. Bringing together this many disciplines remains a challenge even through the intermediary of models. In a modelling framework many influences on pedestrian behaviour need to be considered: in general the spatial cognition of pedestrians, their situational awareness, their objective(s), their knowledge of routes and areas, and their culture. Within the model run the objectives of activity need to be taken into account, the information levels, the development of knowledge of time, the proximity and the physical contact with others need to be modelled. Apart from these parameters we are very much interested in defining and deriving the influence of cooperation among pedestrians.

Cooperative Pedestrians

Cooperation can happen at several levels, with increasing prospective benefits to participants individually and the community as a whole. Cooperation might be positive and voluntary, but also forced (i.e. through social norms or rules) or triggered by incentives. Cooperation is founded on communication of data and information of various kinds. One possible classification of levels of communication, with increasing prospects for cooperation, is as follows:

- Sharing data (or information) about current state (position, speed, instantaneous properties)
- Sharing knowledge of individual decisions that have been made, based on individual information and information from others
- Sharing intentions (e.g., intended destination - both location and schedule)
- Making joint decisions based on shared information and knowledge of intentions.This seems to be collaboration, which goes beyond cooperation

First try at making a definition

Cooperative Pedestrians share the same space but they generally have different goals leading to potentially conflicting use of the shared space. Cooperative behavior arises when individual actions are not optimal (from a personal perspective) but improve the general welfare (e.g. improve the overall flow). The individual tendency for cooperative behavior must be there or must be enforced. The basis for cooperative behavior seems to be the sharing of information with resulting shared intentions/objectives.

Examples of ways of cooperating

1. Pedestrians cooperating among themselves:
   - avoid moving between perceived members of a group
   - groups can be:
     - 2 peers (friends, partners)
     - parent+child or similar hierarchical pair with clearly defined leader
     - group with a leader (think tourists with a guide)
     - unguided group of peers (consider a party of friends)
   - changing behavior to account for density, i.e. forming lanes with your own people
   - cooperation in panic situations, people also help each other (we're better off if we stick together), research on influence of expectation of behavior needed
2. Ped cooperating with management system, taking escalator up, but walking down stairs
3. Ped sharing the same goal
4. Ped coming towards each other
5. Ped standing on right and walking on left on escalator

The altruistic pedestrian who, finding no space on the right where they wish to stand, walks up on the left when they do not wish to walk but does so for the benefit of those walking up on the left behind them.

Examples of (possibly) cooperating pedestrians

1. Alighting and boarding tube train
2. Themepark with different queues
3. Pop-concert with different stages
4. Marathon runners turning the corner
5. Fans approaching a stadium
6. Cordon of cleaners coordinating to also clear an arena of people (walking in formation)

Models

Among the different approaches to modeling pedestrian behaviour there is a need to compare microsimulation models with agent-based simulation and with physics-based models. It is not clear how to setup such a comparison or how to validate these models. Measures for validation are also needed.

Data

This type of research requires empirical evidences characterizing pedestrian behavior: this kind of information may be gathered by means of controlled experiments or observations under natural conditions. Both approaches have advantages and issues, for instance the possibility to generalize the acquired results in different contexts (e.g. cultural differences, motivations of participants or observed pedestrians), so generally both are necessary. As of this moment, although there is a growing interest in both large scale experiments and observations, but there are no guidelines on how to conduct these activities. In case of analyses carried out through video recording, post processing should employ state of the art or innovative computer vision tools to reduce the necessary effort. Moreover, although there are efforts towards the definition of a shared standard way to validate simulation models (e.g.

NIST Technical Note 1822), also this kind of activity could benefit from additional reflection, possibly involving different disciplinary perspectives.

Different pedestrians move differently and one and the same pedestrian may move differently at different times. This roots in the motivation for movement. Motivation in turn depends on external properties (e.g. air temperature) and internal properties which can be goal oriented (hurry to reach a store before it closes for the day) or internally enforced (keep different distance to different types of others as a consequence of social norms). All this implies that a seemingly simple property like "free speed" in fact already is a difficult theoretical concept and subject to temporal variations and influences which are not necessarily reflected by models. To come up with proper models one needs to analyze not only the observable properties like speed or trajectories but also the more general goals and preferences which can be gathered by controlled experiments.

Dimensions of analysis

Among the dimensions of analysis in transport, we are interested in the following: The first dimension concerns cargo versus persons: we are interested only in persons. The second dimension deals with system design versus operation support. We believe that pedestrian behavior models will be of benefit to both in the form of offline simulations which support design and planning, whereas the gathering and sharing of data (maybe with some elaborations) supports operations. Within the third dimension (individual vs many) we are interested in the many, first, because they produce data, but they also are provided with awareness information to support their decisions. The move from individual decision to collaborative decision is not clear and needs further investigation. As for the fourth dimension (centralized vs decentralized control); the term control is probably inappropriate: the system provides information that can support cooperative behaviors, however, "control" is decentralized. This also need further research. Within the dimension descriptive vs prescriptive our main focus lies on descriptive modelling, but this can ultimately be used to generate prescriptive advice to pedestrians, to managers and to designers.

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