Targets and Shapes Tracking (Advanced Seminar)

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***Abstract*—The topics of tracking moving objects and moving shapes have been extensively researched in multiple communities – from Moving Objects Databases (MOD) and spatio-temporal data management, through image/video processing and traffic management, to environmental and ecology studies. This paper gives a summary of the topics discussed in the advanced seminar on tracking objects and shapes, as well as an overview of its proposed structure. After a brief introduction and motivation-survey of different research fields and societal applications, the first part of the seminar will give a historic survey of the fundamental techniques for tracking mobile objects. The second part will give an overview of the approaches popular in MOD and spatio-temporal data management communities (tracking and querying, streaming data, map-matching, etc.). The third part is the central one – discussing the issues and solutions in distributed tracking of moving objects and shapes: from topological predicates and trends detection, through tracking deformable shapes, to specifics of indoor tracking. The fourth major part is intended to be a "potpourri-style" review of different application contexts and the popular approaches for tracking individual objects and shapes – spanning from collective motion analysis in social networks and animal herds, through toxic elements, pollutants, and geo-processes (landslides), to different approaches for visual analytics in this context. The main objective of this advanced seminar is to provide a cohesive overview of the different perspectives on motion tracking; the corresponding approaches for its effective management; and possibilities for other research directions.**

I. Introduction and Motivation

Given its relevance to multiple applications of extreme societal relevance, the efficient detection and management of location-in-time information has attracted a vast amount of research from multiple arenas. Historically, the first such attempts were motivated by hunting [1]–[3] and military operations [4]. As the human societies evolved, so did the needs for tracking in various applications: logistics and goods along trading routes [5]–[7] and exploratory journeys [8]; tracking of naval fleets [9] and trains on railroads [10], [11].

Starting in the 1960s, the technological advancements of the time generated several possibilities for detecting location of mobile objects on road networks (inductive-loop detectors, magnetometers, video image processors, microwave radar sensors (presence detecting and Doppler) [12], [13] – and brought a new type of problems to the horizon: scalability and query processing over large datasets for the purpose of better traffic regulation. Initial efforts were led by the transportation community, focusing on management of congestion and optimization of traffic routing [14]–[16].

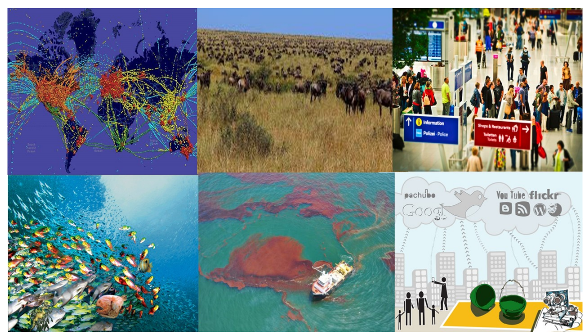

Fig. 1. Objects and Shapes Tracking Application Domains: (in row-major order) Airline Monitoring; Wildlife Herds Tracking; Airports Security; Collective Motion (school of fish); Shapes of Oil-spill in Oceans; Shapes of Pollutants in Urban Environments (Participatory Sensing)

The advancements in satellite technology and the Global Positioning system, which was authorized for public use in the 1990s [17], along with the the Wireless Communications and Public Safety Act of 1999 with the purpose of improving public safety by encouraging and facilitating the prompt deployment of a nationwide, seamless communications infrastructure for emergency services, opened new frontiers for tracking mobile entities. Various applications requiring some form of Location Based Services(LBS) [18] emerged – ranging from route planning and recommendation systems to queries related to motions of the fleet of ships with respect to a range of ports, spreading of the hurricanes and floods with respect to evacuation, routing of emergency vehicles relative to traffic density fluctuations, etc. These, in turn, demanded techniques for managing spatial and temporal data processing, giving rise to the fields of *Spatio-temporal* databases [19] and Moving Objects Databases (MOD) [20]. Supporting time-varying entities necessitated methodologies and tools ranging from management of tracking [21], through types for modelling

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them and means for representing/indexing mechanisms [22], to query constructs and processing algorithms for such data [23], [24], [26] – e.g., *range, (k) Nearest-Neighbor ((k-)NN), skyline, etc.* [27]–[30]. As an illustration of the magnitude of the spatio-temporal dataset and its impact in the BigData world, we note that O(Peta-Bytes) per year of (location,time) data is generated from the GPS-obtained locations of the smart phone users alone. It is projected that the size of that location data could increase up to 400 times if cell-tower locations are included [31], and by 2020 more than 70% of mobile phones will have GPS capability – compared to 20% in 2010 – with similar trends in cars equipped with dashboard GPS devices. These quantities do not include the large volumes of data obtained from sources such as roadside sensors [32], [33] and cellular towers [34], [35].

The next major technological leap came in the early 2000s, due to the advancement in miniaturization of devices that could simultaneously sense/measure particular physical phenomena, perform on-board computation, store and transmit data to its peers – giving rise to the field of Wireless Sensor Networks (WSN) [36]. Initially, the research focused on novel communication, routing, lifetime management and in-network processing approaches [37]–[45]. However, very quickly in the evolution of the WSN paradigm, a problem emerged that is rightfully considered as a canonical one – *tracking* [46]–[57]. At the heart of the different problems arising in the realm of tracking in WSN settings was the quest for balancing:
(a) energy-efficiency – since transmitting data to 1-hop neighbours may drain up to 10^3 more current from the (most often non-replenishable batteries) [46], [51], [58].
(b) accuracy and relative directionality – since objects may move with varying speeds and there may be multiple targets, and the tracking interests may be based on their proximity to, or direction towards, other objects [21], [49], [59]–[62].
(c) timeliness/freshness of the data in the respective sink node/server [57], [63]–[66].

One particular type of problems, previously studied by multiple research communities (e.g., Computational Geometry, Spatial Databases and GIS, graphics, cartography, etc.) [67]–[76] that had a "renaissance" with the development of WSN is the one of managing spatial shapes. One category of research pertains to estimating the boundaries (and holes) of a given WSN [44], [45], [77]–[79]. The other category of research works focused on efficient detection and subsequent tracking of mobile shapes, corresponding to boundaries of a particular physical phenomenon that is being monitored by the underlying WSN [54], [80]–[85].

II. Detailed Seminar Outline

We now present the main portions of the advanced seminar.

A. History, Background and Motivation

The seminar will begin with a brief overview of the various facets of tracking problem throughout the human history – from the ancient times to present-day era [1], [2], [5], [7], [8]. It will also discuss the issues that arise in various application domains (cf. Figure 1) [4], [9], [10].
Expected Duration: 10 minutes

B. Impact of Technologies: Spatial and Spatio-Temporal Data

The second part of the seminar will focus on how different technologies and their availability have affected the capabilities of performing not only a simple tracking in the sense of location-in-time determination, but also: (a) posed the challenge of efficient storage and retrieval of such data [19]–[21], [24], [25], [86]; (b) opened new opportunities for various query-types and mining such data [27]–[30], [87]–[89].
Expected Duration: 25 minutes

C. Sensing and Tracking

This central portion of the seminar will focus on the issues and solutions arising when dealing with the tracking problem in WSN. After a brief overview of the basic WSN features and their impact on location detection and tracking (e.g., energy efficiency, routing structures, coverage etc.) [46], [51], [58], [90], [91], this portion will have two distinct parts:
Part I: Here we will discuss two different scenarios. The first approach involves target tracking when the target moves along a trajectory and some suffix of the trajectory needs to be considered at each sampling interval in order to detect different movement predicates: *moving towards* a POI or *moving along* a given boundary [59], [62]. The second scenario is a tracking cum localization approach where the target moves in a random way, and a number of sensors work collectively to estimate the state (position and velocity) of a target. The problem can be formulated as having n sensors that detect the target at time t and all their measurements, including time stamps, are collected by a leader who then determines the target state using the measurements from time 0 up to time t [57], [58], [92].
Part II: Using a rather broad interpretation of the term *boundary tracking*, we include here the problem of boundary estimation of dynamically changing regions as well the problem of boundary covering [45] where the goal is for the sensors to reach the contour and then trace it. The boundaries may correspond to binary events, for example the boundary between an oil covered locations and oil-free ones [81]. Alternatively boundaries may be derived from threshold-based detection of continuous fields, such as the boundary between locations above a certain temperature and those below it [80], [82]. In both cases, the most interesting work concerns the detection of topological events that cause the underlying regions of the boundaries to change. We will illustrate the topological model introduced in [81], which is based on the inside relation defined on a collection of regions and holes. This relation allows natural interpretation of topological events such as appearance/disappearance, merge/split, etc. Boundary covering is a technique employed when the sensors need to reach the contour in order to take some preventive action such as spraying anti-pollutants. In such a case mobile sensors need to be deployed and to physically move to the contour and trace it [78]. We will discuss heuristics to estimate the directions

sensors need to take in order to move towards the contour as well as how to spread out as they approach the contour.
Expected Duration: 40 minutes

III. Potpourri and Concluding Remarks

The last portion of the seminar will provide an overview of the issues arising when tracking objects in other settings, peculiar to emerging applications, such as: – RFID data [93]; – indoor tracking [94], [95]; – participatory sensing [96], [97]; – tracking in social networks [98], [99]; and other environment-centered applications [100], [101].
Expected Duration: 15 minutes

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