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Empirical temporal networks of face-to-face human interactions

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Abstract. The ever increasing adoption of mobile technologies and ubiquitous services allows to sense human behavior at unprecedented level of details and scale. Wearable sensors, in particular, open up a new window on human mobility and proximity in a variety of indoor environments. Here we review stylized facts on the structural and dynamical properties of empirical networks of human face-to-face proximity, measured in three different real-world contexts: an academic conference, a hospital ward, and a museum exhibition. First, we discuss the structure of the aggregated contact networks, that project out the detailed ordering of contact events while preserving temporal heterogeneities in their weights. We show that the structural properties of aggregated networks highlight important differences and unexpected similarities across contexts, and discuss the additional complexity that arises from attributes that are typically associated with nodes in real-world interaction networks, such as role classes in hospitals. We then consider the empirical data at the finest level of detail, i.e., we consider time-dependent networks of face-to-face proximity between individuals. To gain insights on the effects that causal constraints have on spreading processes, we simulate the dynamics of a simple susceptible-infected model over the empirical time-resolved contact data. We show that the spreading pathways for the epidemic process are strongly affected by

the temporal structure of the network data, and that the mere knowledge of static aggregated networks leads to erroneous conclusions about the transmission paths on the corresponding dynamical networks.

1 Introduction

Due to the development of sensors of various types and the use of digital media and computational devices, we increasingly leave digital traces of our daily activities. The scale at which such data can be gathered and analyzed affords a novel, data-driven approach in the investigation of various aspects of human behavior at various scales, from mobility patterns [1–7] to instant messaging or email exchange [8–13]. Proximity patterns [14–18] can also be detected using Bluetooth and Wifi technologies, and even face-to-face copresence of individuals can be resolved with high spatial and temporal resolution [19–22].

In many cases, the corresponding information finds a convenient representation in terms of complex networks and the corresponding "network science" approach has led to many interesting analysis and results [23–30], In this context, the combination of technological advances and of heterogeneous data sources opens new challenges and opportunities, ranging from theoretical to applied issues. In particular, longitudinal data, which have been traditionally scarce in social network analysis [31,32], are becoming more accessible. Thus, a dynamical perspective on interaction networks [33] becomes possible, and many new issues can be investigated, such as the interplay of the network dynamics with dynamical processes taking place on these networks.

In this perspective, we review here stylized facts on the structural and dynamical properties of empirical networks of human face-to-face proximity, measured in three different real-world contexts: an academic conference, a hospital ward, and a museum exhibition. We first describe the corresponding data sets in Sect. 2. In Sect. 3, we describe the structure of the aggregated contact networks, that project out the detailed ordering of contact events while preserving the information about temporal heterogeneities in the duration of contacts. We expose the similarities and differences of these networks across contexts, and discuss the case in which individuals are divided into a priori categories or roles. Section 4 is devoted to the study of a "toy" spreading process acting as a probe of causality constraints of a dynamical network. Finally, we discuss some directions of future work in Sect. 5.

2 Data sets

We consider three data sets gathered in the context of the SocioPatterns project [19]. These data describe the face-to-face proximity of individuals in various contexts, with a temporal resolution of 20 seconds. More precisely, the data collection infrastructure developed by the SocioPatterns project is based on active Radio-Frequency Identification Devices (RFID) that exchange ultra-low power radio packets in a peer-to-peer fashion, as described in Refs. [19–22]. As the human body acts as a RF shield at the carrier frequency used for communication, exchange of radio packets between badges is only possible when two persons are at close range (1 to 1.5 m) and facing each other. Relations of face-to-face proximity (or "contact", as we will refer to it in the following) between the individuals wearing the RFID tags are thus detected, and the operating parameters are such that contacts can be assessed with a probability in excess of 99% over an interval of 20 seconds. Once a contact has been established, it is considered ongoing as long as the involved devices continue to exchange at least one radio packet for every subsequent interval of 20 seconds. Conversely, a contact is