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Interevent time distributions of human multi-level activity in a virtual world

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HIGHLIGHTS

- We use records of player activities in the massive multiplayer online game Pardus over 1238 consecutive days, and analyze dynamical features of sequences of actions of players.
- We show that the interevent time distributions of actions in the Pardus universe follow highly non-trivial distribution functions from which we extract action-type specific characteristics.
- This study of multi-level human activity can be seen as a dynamic counterpart of static multiplex network analysis.

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ABSTRACT

Studying human behavior in virtual environments provides extraordinary opportunities for a quantitative analysis of social phenomena with levels of accuracy that approach those of the natural sciences. In this paper we use records of player activities in the massive multiplayer online game *Pardus* over 1238 consecutive days, and analyze dynamical features of sequences of actions of players. We build on previous work where temporal structures of human actions of the same type were quantified, and provide an empirical understanding of human actions of different types. This study of multi-level human activity can be seen as a dynamic counterpart of static multiplex network analysis. We show that the interevent time distributions of actions in the *Pardus* universe follow highly non-trivial distribution functions, from which we extract action-type specific characteristic "decay constants". We discuss characteristic features of interevent time distributions, including periodic patterns on different time scales, bursty dynamics, and various functional forms on different time scales. We comment on gender differences of players in emotional actions, and find that while males and females act similarly when performing some positive actions, females are slightly faster for negative actions. We also observe effects on the age of players: more experienced players are generally faster in making decisions about engaging in and terminating enmity and friendship, respectively.

1. Introduction

The life of humans can be viewed as a sequence of different actions that are carried out from birth to death. Some of these actions are carried out with high regularity on various timescales (circadian, yearly, etc.), others have significant stochastic

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Player 146 ... AAAAAACTT EEX FTTTTTX CCCTTTTT AC ...
Player 199 ... CCA BBCAAAAATTA AACCCCCBX CFFFF ...
Player 701 ... CCCCTTTT TCTCT FF CXXTT CCCCC TTT ...
Player 171 ... AAAACC CCC C CCC AA TTT FCC EED ...

Fig. 1. Short segment of action sequences, performed by four *Pardus* players. Different actions are shown by different letters as explained in Section 2. The detailed analysis of time sequences of these multi-level action streams is the main goal this paper.

components. By now it is well established that distribution functions characterizing sequences of human actions over time are highly non-trivial [1–12], and their origins remain largely unclear.

The very fact that distributions of human actions over time, such as distributions of phone calls, follow statistical laws was known since the beginning of the last century [13], and triggered the origin of queueing theory [14]. Early attempts to understand human action sequences were based on the assumption that actions are carried out homogeneously in time with constant rates, which then lead to Poisson processes [15]. This led to the conclusion that times between consecutive actions of the same individual should be distributed exponentially. Models to describe human dynamics that are based on Poisson processes are still widely used [16,17]. However, the careful analysis of various patterns of human activity provides growing evidence for highly inhomogeneous bursty distributions of human actions in time. Further there is evidence for non-trivial inter-dependencies of actions that influence their (usually power-law dominated) temporal statistics [1–12]. The latter was found both for traditional human actions such as writing letters [3,7], checking out books in libraries, performing financial transactions [4], or writing e-mails [1,2,6], web browsing [4], sending text messages [9], editing Wikipedia pages [10,12], and many more. Different reasons have been suggested to explain their appearance. In particular, the priority queueing model [2] is a possibility to explain the bursty mechanism of human behavior by a decision-based queueing process where individuals perform tasks according to some priority. This may explain the observed correspondence patterns of Darwin and Einstein [3]. Alternatively it has been hypothesized that human correspondence is driven not by responses to others but by the variation in an individual's communication needs over the course of their lifetime [7].

The common feature of the above mentioned observations is that they are based on the analysis of human actions of a single type: *either* writing e-mails, *or* letters, *or* making phone calls, etc. The next step beyond these studies is to consider the much more involved situation where tasks of different types are performed. What is the action dynamics of an individual (or of a group of individuals) that writes *both* e-mails, *and* letters, *and* makes phone calls? Carrying out actions of different types we call *multi-level human activity*. The analysis of multilevel activity encounters obvious difficulties, typically requiring serious efforts on data collection [18]. In this study we circumvent this problem by studying the log-files of all actions performed in a virtual world, where actions of different types are performed by thousands of people [19,20]. The virtual universe of the online game *Pardus* [21] is briefly outlined below.

Pardus is a massive multiplayer online game (MMOG) which is online since 2004. It is an open-ended game with a world-wide player base of more than 400,000 registered players [21,22]. The game has a science fiction setting and features three different universes. All universes have a fixed start date but no scheduled end date. Every player controls one avatar, called the player's character. The characters act within a virtual world making up their own goals and interacting with the self-organized social environment. There are a variety of different activities the characters can participate in, including communication, trade, attack, and other forms of social actions such as establishing or breaking friendships or enmities, see Fig. 1. Since it has been launched, the *Pardus* game served as a unique testing ground to measure different observables that characterize inhabitants of the virtual world and in this way to learn about complex social processes taking place in the real world—"When the same six soldiers take out a dragon in a synthetic world, the dragon is not real but the teamwork is" [23]. Indeed, with a complete record of complete information about millions of actions of different kinds performed by thousands of people during several years from a single source, this setting provides the unique position to achieve a detailed non-intrusive quantitative analysis of complex social behavior [22,24–32]. In particular, the complex network structure of the Pardus society has been exposed and evidence was collected for several social-dynamics hypothesis, including the Granovetter weak ties hypothesis and triadic closure [28]. In this way further evidence has been provided about validity of a model of online communities for human societies, allowing to operate with a precision resembling that of natural sciences [22]. Further analysis of the Pardus society has revealed the network topology of social interactions [24,28], mobility of characters [25], behavioral action sequences [26], gender differences in networking [27], and the functioning of the virtual economy [30].

The main idea of this paper is to analyze the evolution of actions within the *Pardus* universe over time: what are the temporal characteristics of actions taken by players? Is there an action-specific dynamics, and are there some global processes that dominate the dynamics of players in the online world? It is well established by now that a number of features of the virtual society resemble those in the offline society, giving hope to expect that the analysis of the virtual world action dynamics will provide insights into human dynamics that is valid also for real societies. Social systems can be quantified comprehensively by studying the superposition of its constituting socio-economic networks (multiplex networks, see Refs. [33–35]) [24]. The same information is contained in the dynamical behavioral sequences (Fig. 1) of the individuals, however with a focus on temporal aspects of the multi-level activity.

The paper is organized as follows. In Section 2 we describe the database and concentrate on the main observable of interest, the interevent time τ and its statistics. We comment on the bursty dynamics of individual characters.