Multiagent Epidemiologic Inference through Realtime Contact Tracing

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ABSTRACT

This paper addresses an epidemiologic inference problem where, given realtime observation of test results, presence of symptoms, and physical contacts, the most likely infected individuals need to be inferred. The inference problem is modeled as a hidden Markov model where infection probabilities are updated at every time step and evolve between time steps. We suggest a unique inference approach that avoids storing the given observations explicitly. Theoretical justification for the proposed model is provided under specific simplifying assumptions. To complement these theoretical results, a comprehensive experimental study is performed using a custom-built agent-based simulator that models inter-agent contacts. The reported results show the effectiveness of the proposed inference model when considering more realistic scenarios – where the simplifying assumptions do not hold. When pairing the proposed inference model with a simple testing and quarantine policy, promising trends are obtained where the epidemic progression is significantly slowed down while quarantining a bounded number of individuals.

KEYWORDS

Statistical Inference; Hidden Markov Model; Computational Epidemiology; COVID-19

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1 INTRODUCTION

When combating an ongoing epidemic, many authorities attempt to hinder or even halt the disease spread across the community. Several tools are utilized towards achieving this objective. In general, these can be divided into two classes, disease surveillance [12] and containment strategies [23]. Disease surveillance tools commonly use observations such as test results, presence of symptoms, and physical contact patterns along with epidemic models for anticipating the disease progression. Based on the surveillance projection, containment strategies can appropriately be applied. Containment strategies may include individual or collective quarantine orders, enforcing social distancing, closing certain public facilities such as schools or shops, etc. See Walensky and Del-Rio [23] for a survey on such strategies.

Effective combinations between surveillance tools and containment strategies were shown to lead to desirable outcomes w.r.t. epidemic progression [8, 14, 20]. The approaches proposed in these publications, however, rely on simple inference rules regarding individual infection likelihood. For instance, by ranking the infection likelihood based on a weighted combination of observed symptoms [10].

We present a novel approach for infection inference that reports individual infection probabilities per day over the entire population. We show how such an approach, when paired with a simple containment strategy, is highly successful in hindering the epidemic progression in a simulated community.

The proposed inference approach models the problem as a hidden Markov model [9], where every time step is defined by individual infection probabilities (the belief state) and a compressed representation of the physical contact history. At every state a set of observations is provided, namely, test results for a subset of the community, symptom presence for each individual, and physical contacts within the community. Based on these observations and given conditional probabilities (false-positive/negative test and symptoms rates), the individual infection probabilities are updated. Finally, the transition probabilities are defined by the probability of recovering (transitioning from being infected to recovered) per time step.

The inference procedure is justified using a set of simplifying assumptions. In order to compliment these theoretical results, we present a comprehensive experimental study using a custom-built

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