Towards Specification of Requirements for COVID-19 Mitigation Strategies

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1 INTRODUCTION

COVID-19 has influenced virtually all aspects of our lives. Across the world, countries applied wildly varying mitigation strategies for the epidemic, ranging from minimal intrusion to imposing severe lockdowns. It seems clear at the first glance what all those measures are trying to achieve, and what the criteria of success are. But is it really that clear? Quoting an oft-repeated phrase, with COVID-19 we fight *an unprecedented threat to health and economic stability* [39]. While fighting it, we must *protect privacy, equality and fairness* [33] and *do a coordinated assessment of usefulness, effectiveness, technological readiness, cyber security risks and threats to fundamental freedoms and human rights* [40]. Taken together, this is hardly a straightforward set of goals and requirements. Thus, paraphrasing [40], one may ask:

What problem does a COVID mitigation strategy solve exactly?

Even a quick survey of news articles, manifestos, and research papers published since the beginning of the pandemic reveals a diverse landscape of postulates and opinions. Some authors focus on medical goals, some on technological requirements; others are concerned by the economic, social, or political impact of a containment strategy. We propose that the field of multi-agent systems can offer a common platform to study all the relevant properties, due to its interdisciplinary nature [38, 42] and a wealth of formal methods for specification and verification [18, 22, 38].

This still leaves the question of how to gather the *actual* goals and requirements for a COVID-19 mitigation strategy. One way to achieve it is to look at what is considered relevant by the general public, and referred to in the media. To this end, we collected a number of news quotes on the topic, ordered them thematically and with respect to the type of concern, and distilled a comprehensive list of goals, requirements, and most relevant risks. The news clips and the full list of requirements are available in the technical reports [23, 25]. Here, we present some of the requirements (in Section 2). In Section 3, we make the first step towards a formalization of the properties by formulas of multi-agent logics.

Besides potential input to the design of anti-COVID-19 strategies, the main contribution of this paper is methodological: we demonstrate how to obtain a comprehensive and relatively unbiased specification of properties for complex MAS by searching for hints in the public space.

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2 EXTRACTING GOALS AND REQUIREMENTS FROM NEWS CLIPS

Specification of properties is probably the most neglected part of formal verification for MAS. The tools come with examples of how to model the behavior of a system [7, 10, 26, 28, 31], but writing the input formulas is generally considered easy. The big question, however, is: *Where do the formulas come from?*

Mitigating COVID-19 illustrates the point well. Research on mitigation measures is typically characterized by: (a) strong focus on the native domain of the authors, and (b) focus on the details, rather than the general picture. In order to avoid "overlooking the forest for the trees," we came up with a different methodology. We looked for relevant phrases that appeared in the media, with no particular method of source selection [25]. Then, we extracted the properties, sorted them thematically, and divided into 3 categories: *goals*, additional *requirements*, and potential *risks and threats*.

By way of example, the requirements related to epidemiological aspects are presented below. The full list is available in [23].

2.1 Epidemiological Goals

The goal of the mitigation strategy in general, and digital measures in particular, is to:

(i) provide an *epidemic response* [39]
(ii) *bring the pandemic under control* [33]
(iii) *slow the spread of the virus* [2, 3, 11, 21, 39, 43]
(iv) *prevent deaths* [5]
(v) *reduce the reproduction rate* of the virus [5].

The specific goals of digital measures are to:

(i) *trace the spread of the virus* and *identify Covid-19 clusters* [21]
(ii) *find potential new infections* [41]
(iii) *register contacts between potential carriers* [21]
(iv) *deter people from breaking quarantine* [17]

Requirements:

(1) The efforts must meet *public health needs* best [21, 39].
(2) Digital measures should *complement* traditional ones [39, 41]
(3) They should be designed to *help the health authorities* [3].

2.2 Effectiveness of Epidemic Response

Requirements:

(1) The strategy should be *effective* [39, 40]
(2) It should *make a difference* [15].

Risks and threats:

(a) *Inaccurate detection* of carriers and infected people [39]
(b) Specifically, this may *adversely impact easing of lockdowns* [43]
(c) Misguided *assurance* that going out is safe [39].

2.3 Information Flow Requirements

The strategy should allow:

(1) to *identify people who might have been exposed to the virus* [44]
(2) to *alert those people* [1, 3, 33, 41].
(3) The identification and notification must be *rapid* [33, 44].

2.4 Monitoring

The containment strategy should enable:

(1) *monitoring the state of the pandemic*, e.g., the outbreaks and the spread of the virus [1, 20]
(2) *monitoring the behavior of people*, in particular if they are following the rules [37]
(3) to *monitor the effectiveness of the strategy* [19].

3 TOWARDS FORMAL SPECIFICATION

Here, we briefly show how the requirements presented in Section 2 can be rewritten in a more formal way. To this end, we use *modal logics for distributed and multi-agent systems* that have been in constant development for over 40 years. Note that the following specifications are only *semi*-formal, as we do not fix the models nor give the precise semantics of the logical operators. We leave that step for the future work.

3.1 Temporal and Epistemic Properties

The simplest kind of requirements are those that refer to achievement or maintenance of a particular state of affairs. For example, goal (ii) in Section 2.1 can be tentatively rewritten as the **CTL*** formula $\mathrm{AF}\,\mathsf{control\text{-}pandemic},$ saying that, for all possible execution paths, $\mathsf{control\text{-}pandemic}$ must eventually hold.[1] Similarly, goal (iii) can be expressed as $\forall n\,.\,(\mathsf{R0{=}n}) \rightarrow \mathrm{AF}\,(\mathsf{R0{<}n})$. Moreover, goal (iv) can be captured by $\mathrm{AG}\,(\mathsf{\#deaths{<}k})$, for a reasonably chosen k.

The identification and monitoring aspects can be expressed by a combination of **CTL*** with epistemic operators $K_a\varphi$ (*"a knows that φ"*). For example, the information flow requirement (1) in Section 2.3 can be transcribed as $\mathsf{exposed}_i \rightarrow \mathrm{AF}\,K_a\mathsf{exposed}_i$, where a is the name of the agent (or authority) supposed to identify the vulnerable people. A more faithful transcription can be obtained using the past-time operator F^{-1} (*sometime in the past*) [30] with $exp_i \rightarrow \mathrm{AF}\,K_a exp_i,$ where $exp_i \equiv \mathrm{F}^{-1}\mathsf{exposed}_i,$ saying that if $\mathsf{exposed}_i$ held at some point, then a will eventually know about it. Likewise, requirement (2) can be captured by $K_a exp_i \rightarrow \mathrm{AF}\,K_i exp_i$.

3.2 Strategic Requirements

The above patterns can be refined by replacing path quantifiers A, E with strategic operators $\langle\!\langle A\rangle\!\rangle$ of the logic **ATL*** [8, 14], where $\langle\!\langle A\rangle\!\rangle\varphi$ says that *"the agents in A can bring about φ"*. For example, the information flow requirement 2.3.(2) can be rewritten as $K_a(\mathrm{F}^{-1}\mathsf{exposed}_i) \rightarrow \langle\!\langle a\rangle\!\rangle\mathrm{F}\,\langle\!\langle i\rangle\!\rangle\mathrm{F}\,K_i(\mathrm{F}^{-1}\mathsf{exposed}_i),$ saying that if the health authority a knows that i was exposed, then a can provide i with the information sufficient to realize that. Strategic operators are also useful for the monitoring requirements in Section 2.4, e.g., $\langle\!\langle a\rangle\!\rangle\mathrm{G}\,(K_a\mathsf{outbreak} \vee K_a\neg\mathsf{outbreak})$ can be used for requirement 2.4.(1).

This should be sometimes combined with bounds on the execution time [27, 35], mental complexity [24], and/or resources needed to accomplish the tasks [6, 13]. For example, the notification requirement 2.3.(2) can be refined as: $\langle\!\langle a\rangle\!\rangle\mathrm{F}^{\,t\le 10}\langle\!\langle i\rangle\!\rangle^{compl\le 5}\mathrm{F}\,K_i(\mathrm{F}^{-1}\mathsf{exposed}_i),$ based on the assumption that a should notify i in at most 10 time units, and i should have a strategy of complexity at most 5 to infer the relevant knowledge from the notification.

3.3 Probabilistic Extensions

Many events have probabilistic execution, e.g., actions may fail with some probability. Probabilistic scenarios can be modeled by variants of Markov decision processes, and their properties can be specified by a probabilistic variant of **CTL*** [9] or **ATL*** [16]. For instance, formula $\langle\!\langle a\rangle\!\rangle^{P\ge 0.99}\mathrm{F}^{\,t\le 10}\langle\!\langle i\rangle\!\rangle^{compl\le 5}\mathrm{F}\,K_i(\mathrm{F}^{-1}\mathsf{exposed}_i),$ refines the previous specification by demanding that the authority can successfully notify i with probability at least 99%.

3.4 Towards Formal Analysis

Ideally, one would like to automatically evaluate COVID-19 strategies with respect to the requirements, and choose the best one. In the future, we plan to use model checking tools, such as MCMAS [31], Uppaal [10], PRISM [29], or STV [28] to formally verify our formulas over micro-level models created to simulate and predict the progress of the pandemic [4, 12, 32, 34]. As we already pointed out, different requirements may be in partial conflict. Thus, selecting an optimal mitigation strategy may require solving a multicriterial optimization problem [36, 45], e.g., by identifying the Pareto frontier and choosing a criterion to select a point on the frontier.

4 CONCLUSIONS

In this paper, we make the first step towards a systematic analysis of strategies for effective and trustworthy mitigation of the current pandemic. The strategies may incorporate medical, social, economic, as well as technological measures. Consequently, there is a large number of medical, social, economic, and technological requirements that must be taken into account. For computer scientists, the latter kind of requirements is most natural, which is exactly the pitfall that computer scientists must avoid. The goals are much more diverse, and we must consciously choose a solution that satisfies the multiple criteria to a reasonable degree. We suggest that formal methods for MAS provide an excellent framework for that. We also propose a methodology to collect preliminary requirements while avoiding the usual bias of research papers.

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[1] In fact, a better specification is given by $\mathrm{AF}\,\mathrm{G}\,\mathsf{control\text{-}pandemic}$, saying that the pandemic is not only brought, but also kept under control from some point on.

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