A Knowledge Sharing Approach to Foster Interdisciplinary Pedestrian Dynamics and Epidemiological Modeling Research and Practice

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Abstract. A significant challenge to interdisciplinary computational science arises from the difficulty of using models from diverse domains. We show that combining the concepts of knowledge sharing – a component of knowledge management – and recommender systems, which have traditionally been viewed as separate undertakings, can help address the above limitation. In particular, we describe the VIPRA Recommender System (VRS), which enables transformative inter-disciplinary science using pedestrian dynamics for epidemiological modeling. VRS provides a venue through which researchers can share capabilities of modeling systems and practitioners can receive assistance in identifying and using systems that meet their modeling needs, such as recommendations of suitable models and their input parameters. We present a usability study to establish its usefulness as a tool to empower interdisciplinary science using models from a variety of domains.

Keywords: knowledge sharing, recommender systems, pedestrian dynamics, epidemiological modeling, decision support.

1 Introduction

Science-based solutions to problems at societal scales, such as suitable interventions to mitigate an epidemic, require interdisciplinary contributions from a variety of domains. Each domain typically provides a variety of computational or mathematical models, each having its own parameters and targeting specific contexts. It is challenging for researchers from a specific domain to choose the right models and parameters from other domains in order to solve a problem. For example, we focus on the use of pedestrian dynamics in infections modeling applications, from local to global scales. The use of the right combination of pedestrian dynamics and infection spread models is essential to designing interventions that are effective in reducing infection spread. However, researchers and policy makers typically lack expertise in both domains.

Suitable knowledge sharing of scientific models by their developers and recommendations on models to use and their parameters for specific problem contexts can alleviate the above problem. Although some preliminary attempts have been made to integrate knowledge sharing and recommender systems [20], these fields have traditionally been viewed as separate undertakings, especially in the context of scientific applications. Knowledge sharing has been couched as occurring either within the confines of the firm where trade secrets, proprietary processes, and institutional memory are viewed as strategic assets or in academia where improved knowledge sharing could foster more rapid advances in a given field. Recommender systems have traditionally been based upon creation of implicit or explicit user profiles and filtering of large datasets in service of e-commerce.

The current work seeks to exploit principles at the intersection of knowledge sharing and recommender systems to foster advances in interdisciplinary research as well as to enhance the opportunity for that research to be employed in practice. We consider the application of pedestrian dynamics to infection spread or epidemic modeling. Pedestrian dynamics is used to simulate pedestrian flows in defined geometric spaces. Pedestrian trajectories output from these simulations provide information on human proximity and mixing patterns, which are important drivers of disease spread. For example, recent experiences with COVID-19 demonstrate that capabilities to model disease spread by superimposing an epidemiological model on a pedestrian dynamics model has important applications [24, 25].

A variety of approaches to pedestrian dynamics modeling have been identified, each with its own strengths and weaknesses for specific problem and resource contexts. The choice of model and model parameters depends on the situation being studied, the computational resources available, and goals of the study. Broadening the use of pedestrian dynamics to a wider range of researchers and end users requires an assistive tool. End users ranging from scientists in academia to public health professionals, could benefit greatly from support with the identification and use of such modeling tools. Furthermore, such users might seek background knowledge on the workings of such modeling capabilities and why certain models and parameters are appropriate for a given scenario.

In previous work, we have developed pedestrian dynamics models that accurately predict pathogen spread in a variety of settings in airports and for airplane boarding and deplaning [1, 2]. The goal of the current work is to pioneer an effort to democratize this type of modeling science by creating a repository for researchers and end users to describe and support selection of a suitable model and parameters for decision making. VIPRA Recommender System (VRS) is a Web-based beta-level software program designed to lend such support. In addition to basic modeling support, the system provides links to scientific literature and other resources so that provenance and suitability of the models are clear to scientists from a variety of disciplines. Such ideas can be generalized to other scientific domains.

The remainder of this paper contains descriptions of the current work on VRS. Section 2 describes related literature. Section 3 includes a description of basic VRS features, the user interface, various ways the software can be used, and the range of recommendations the system can produce. Section 4 contains a description of a usability study on the current system. Section 5 provides a discussion of the usability results, and Section 6 describes conclusions and future work.

2 Literature on Knowledge Sharing and Recommender Systems

VRS seeks to afford capabilities both to share general knowledge on pedestrian dynamics and disease spread modeling capabilities and to provide recommendations regarding how to use these modeling capabilities. In the following sections, literature pertaining to knowledge sharing and recommender systems is presented.

2.1 Knowledge Sharing Literature

The corpus of literature on knowledge sharing is large. This review will seek to elucidate relevant highlights. Boh [3] discusses the relative benefits to communities of practice in sharing knowledge via repositories versus discussion forums. Boh found that both sharing modes provide opportunities to link knowledge seekers to knowledge providers. Boh states that knowledge repositories help to create linkages that both allow individuals access to the knowledge codified by a knowledge provider and to provide the opportunity for individuals to follow-up with knowledge provider contact information for further clarification, and discussion.

White and Lutters [4] describe expertise recommender and organizational memory systems (ER-OMS) which are a type of knowledge sharing repository. They site limitations of such systems that only capture in-house expertise for individual organizations. They describe the use of ontologies to categorize knowledge contained in such systems, and state that ontological frameworks routinely evolve as knowledge expands.

Alotaibi, Crowder, and Wills [5] describe knowledge sharing with Web Technologies. They explored why, where, and when academics share knowledge. They identified important issues including intrinsic and extrinsic motivations to share or consume knowledge, how well potential users perceive and accept the system used to share knowledge, social pressures to share, and organizational culture as impacts on the utility of Web-based knowledge sharing systems.

Alsaleh and Haron [6] identified requirements for knowledge sharing systems in academic settings. They state that knowledge sharing is both synchronous and asynchronous. They state that systems of knowledge sharing should have functional requirements including alerts for new knowledge, efficient search, effective categorization, the ability to provide information regarding relevant experts, and provision for consultations. They identify non-functional requirements that include multi-media support, accessibility, reliability, ease of use, and multi-level organization.

Lilleorg, Tammets, Evert and Ley [7] described social media tools used for knowledge sharing and barriers to knowledge sharing that must be overcome. They found that general-purpose social media tools such as Wikis and Facebook, while playing a role, were used less frequently than dedicated websites and email. The authors identified several barriers to knowledge sharing including those related to culture, motivation, trust, and organizational development.

Almujally and Joy [8] studied why potential participants accept or reject use of knowledge sharing systems in an academic setting. They state that no unified theory exists regarding adoption of knowledge sharing systems. They refer to a unified theory of acceptance and use of technology (UTAUT) which does not specifically address knowledge sharing systems, and task-technology fit (TTF) theory, a second broad measure of the capability of a technology to foster successful completion of a task. They propose a conceptual model that considers individual motivation, technology acceptance, social influences, and organizational culture impacts on predisposition to contribute to or utilize knowledge sharing capabilities.

2.2 Recommender System Literature

This review of recommender system literature elucidates the range of recommender systems and issues associated with them. Recommender systems typically help users navigate the huge collections of content on recommendation platforms utilizing various filtering methods [9]. Recommendation systems were originally based upon two basic methods of sifting through large quantities of data, content-based filtering and collaborative filtering [10].

Content-based filtering employs user profiles that can be constructed explicitly by asking users questions about preferences, or implicitly, by tracking user choices and making recommendations of things that are similar to previously selected items. Collaborative filtering [11] exploits historical data regarding user interactions with items represented in a user-item interaction matrix. Similar users might be grouped to create user stereotypes. The associations among other users deemed similar to the current user and choices made by those users are used to make suggestions to the current user.

Next item recommendations [12] are based upon interests and needs, as reflected in users' purchasing history or other interests. A potential problem of such systems is the multiple interest problem: multiple interests are more difficult to capture in a single representation. A way to deal with this problem is to construct interest graphs based on the historical and current behavior sequences of users.

In [13] the authors describe problems for recommender systems including the problem of data sparsity, the related cold start problem, and the long tail problem. Bandit algorithms have found increasing application in recommender systems [14]. The multi-armed bandit problem models an agent that simultaneously attempts to acquire new knowledge (exploration) and optimize its decisions based on existing knowledge (exploitation). Bandit algorithms seek to balance these two competing goals and are applicable to recommender systems.

Modern recommender systems employ a variety of machine learning techniques to create user models from browsing and search data [15]. Algorithm-based recommender systems can provide useful and effective recommendations. However, their algorithmic design commonly neglects underlying psychological mechanisms that shape user preferences and behavior. Current systems attempt to mimic human cognitive processes, personality, and affective cues.

Some preliminary work has been done on attempts to incorporate recommender systems into personal knowledge management systems [21,22]. In [21], Zhen, Song, and He described incorporation of a recommender system as an add-on to a knowledge query system. Skrzypczyk et al [22] cite the success of recommender systems in e-business and e-commerce settings and describe conceptually how recommender systems might facilitate learning if coupled with personal knowledge management tools.

The authors of a workshop on recommenders geared toward health improvement [16] wrote that recommender systems might help people by providing individually devised suggestions regarding ways to improve health. This work, which overlaps the health-related aspects of the current work, suggests that not all recommender systems are based upon filtering large amounts of data, but might be built from expert knowledge. A new category recommender system based upon expert knowledge seems necessary to support proper use of specialized tools across research communities. VRS is such a tool, and it is described in the next section.

3 The VIPRA Recommender System

Our current work seeks to combine a knowledge sharing system with a recommender system with the explicit goal of broadening the use of pedestrian dynamics and epidemiological modeling across scientific domains. The idea behind the current work is to create a support tool to enable users ranging from academicians to public health officials both to contribute to the corpus of identified systems and to identify modeling software systems for a particular task, needed input parameters and recommended parameter values to meet modeling needs. The following sections contain descriptions of the system's features, navigation structure, and currently realized capabilities.

3.1 Features

The software provides a variety of features to support the addition of new modeling capabilities and to provide recommendations pertaining to categories of simulation software, recommendations for parameters that are needed to carry out a study, and a variety of other resources. VRS provides a framework in which both local and global modeling capabilities may be described. In the category of local modeling (at the scale of a single structure, group of structures, or somewhat larger outdoor space), several different approaches to modeling are currently addressed including social force, queue-based, agent-based, and cellular automata. Global modeling currently contains descriptions of two modeling capabilities. VRS allows the addition of other modeling approaches as they are identified.

Each modeling approach has its own strengths and weaknesses. It is a goal of VRS to help the user understand these strengths and weaknesses, to determine an appropriate model or models for a given study type, and to determine parameter ranges that will provide realistic simulations. The system also contains a special section on local to global modeling which is essentially a placeholder for future work.

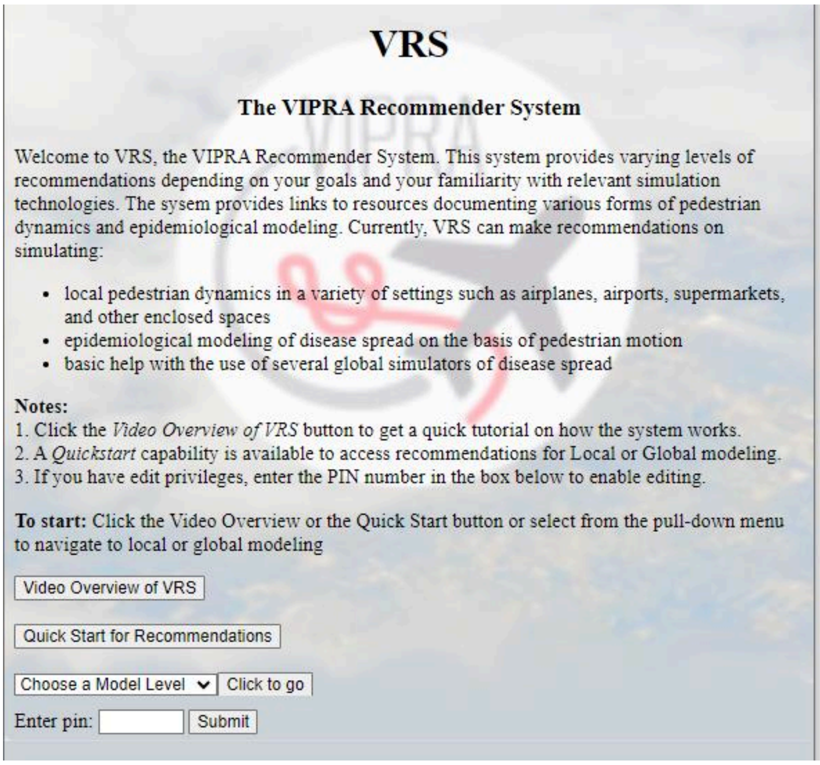

Fig. 1. The VRS homepage.

3.2 Navigation

As seen in Figure 1, the landing page of VRS provides a video overview of the app, a quick start capability for those who want to identify capabilities for a specific modeling scenario, and navigation to the various model levels available: local models for pedestrian dynamics and disease spread, local-to-global models and global epidemiological models. Navigation in VRS is based upon a hierarchical structure. Figure 2 shows the current overall navigation structure of the app. The Web browser headers have been removed from the UI graphics to conserve space.

The landing page also contains pin-protected access to edit privileges for the app. Users who do not have the pin number can access all recommendations of models and parameters, and they can view all supporting documentation (research papers describing modeling capabilities and verification results, URLs with descriptions of how to use the models, contact information for model creators, etc.). They also have access to the quick start capability that allows them to select inputs and desired outputs of a study and to specify the level of compute capabilities they have, in order to get immediate recommendations regarding models and parameter values to use. Users who have been granted edit privileges have all the capabilities of the other users. Additionally, they can enter the pin and gain capability to add new models and parameter sets, and to edit and delete existing ones.

Model Level
Local Models
Queue-based
Generic Queue-based Model
Agent-based
Generic Agent-based Model
Social Force
CALM
SPED
Harweg-Bachman-Weichert
Local to Global Models
Generic Local to Global Model
Global Models
ZooPhy
PanViz

Fig. 2. The hierarchical organization and current menu structure of VRS.

If the user selects local modeling, the page in Figure 3 appears. It has several features that are typical of the capabilities afforded at the various model levels and on individual model pages. Clicking the "Quick Start for Local Models" button brings the user to a page where they can select the type of study they want to perform, select various output parameters of interest, and specify the amount of computational power available. On the basis of these attributes, the system recommends models that can fulfill the requirements. In Figure 3, one can also see three sections that appear on all navigation pages except the homepage for the app:

- Navigation
- Recommendations
- Resources/References

The Navigation section in the Local Model page provides a pulldown to navigate to the various categories of local models. In turn, the category page affords navigation to individual models. The Recommendations section provides links to pages that provide more detail on the suitability of a model for a particular use. At the level of Local Models, these recommendations are basic guidelines for selecting a category of modeling capability.

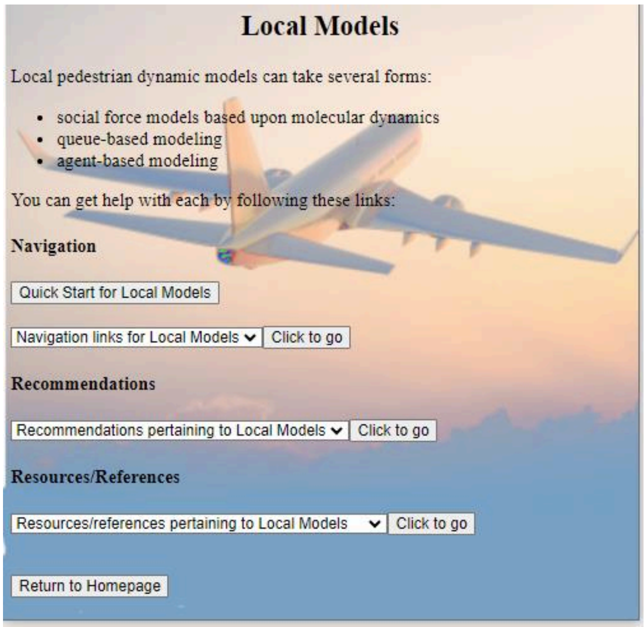

Figure 3. The Local Modeling page with edit capability enabled.

At the homepage for a given model, recommendations link to actual recommendations of individual parameters and suggested values for various scenarios for which the model has been validated, or links to external websites where modeling capabilities are located. When the user has selected a given scenario, the recommendation page populates with suggestions for all needed parameters and recommended values. When the user has reviewed those recommendations and indicated values to use from those recommended, a JSON file is generated with attribute-value pairs. The

Resources/References section permits addition of links to documents that may be uploaded and stored on the VRS server or to URLs on the Internet with resources to delve deeper into the model's characteristics.

3.3 Current Modeling Capabilities

The current system has six local pedestrian dynamics models, their uses, required parameters, and recommended parameter values for several modeling scenarios. Two modeling capabilities are present at the global modeling scale. All knowledge pertaining to the use of these models was culled from systematic knowledge elicitation initiatives [17]. This approach was necessitated by the fact that no single large corpus of data on verified simulations is available for use in making recommendations-the cold start problem [13].

4 VRS Software Usability

Software usability testing has evolved with time from the use of large numbers of individual users (on the order of 40-50) to smaller numbers of users, sometimes collaboratively using the software [18]. Usability testing may be characterized as formative (an ongoing process as software is being developed) or summative, involving culminating testing before a major release. A formative usability study was performed on VRS. A description of the study and results are reported in the next sections.

4.1 The Usability Study

A usability study was implemented to answer basic questions regarding users' ability to determine an appropriate model and associated parameters to carry out a study. Additionally, the usability study explored users' capabilities to find resources that further described the model at hand such as papers published regarding a particular modeling scheme, modeling results, and contact information for the creators of the models.

Study participants were referred to a Web page that contained links to an overview video that briefly describes the layout of the app. After viewing the video, students were asked to complete several activities including determining a model and parameters for a pedestrian dynamics and disease spread modeling effort, accessing an accompanying resource describing the workings of the model, and determining how to identify the point of contact for the model. After participants completed the tasks, they were asked to perform with the app, they completed a Qualtrics survey based upon the Post Study System Usability Questionnaire (PSSUQ) [19].

The PSSUQ is a verified instrument that can elucidate three factors of usability: System Usefulness, Information Quality, and Interface Quality. For the current study, participants gave 5-point Likert scale ratings (Strongly agree, Agree, Neutral, Disagree, Strongly disagree) to 15 affirmative statements regarding system usability. The survey statements participants rated are presented in Table 1.

Table 1. The Statements participants rated in the Usability Survey.

Statements pertaining to System Usefulness
1. Overall, I am satisfied with how easy it is to use this system.
2. It was simple to use this system.
3. I could effectively complete the tasks and scenarios using this system.
4. I was able to complete the tasks and scenarios quickly using this system.
5. I was able to efficiently complete the tasks and scenarios using this system.
6. I felt comfortable using this system.
7. It was easy to learn to use this system.
8. I believe I could become productive quickly using this system.
Statements pertaining to Information Quality
9. The system gave error messages that clearly told me how to fix problems.
10. When I made a mistake using the system, I could recover easily and quickly.
11. The information provided with this system was clear
12. It was easy to find the information I needed.
13. The information provided for the system was easy to understand
14. Theinformationwaseffectiveinhelpingmecompletethetasksandscenarios.
15. The organization of information on the system screens was clear.

As seen in Table 1, the current study focused on system usefulness and information quality. The first eight questions on the survey pertained to system usefulness. The other seven questions pertained to information quality. Participants for the study were recruited from a senior level undergraduate computer science class conducted by the lead author of this article. A total of nine participants completed all activities in the study, a sufficient number to generate usable data.

Surprisingly, the PSSUQ, which is 20 years old, asks all questions in an affirmative, positive way such as "It was easy to learn to use this system." Current best practice in the use of Likert scales include posing statements with a negative sense such as "It was difficult to learn to use this system." Since all questions were posed in a positive, affirmative way, results reported in the next section simply indicate the degree to which participants agreed or disagreed with questions pertaining to ease of use and information quality.

4.2 Results

As can be seen in Table 1, all statements in the survey were affirmative in nature, such as "It was simple to use this system." and "I could effectively complete the tasks and scenarios using this system." A total of 72 individual responses (eight questions answered by nine participants) were recorded pertaining to system usefulness and 63 responses (seven questions answered by the nine participants) were recorded pertaining to information quality. Aggregated results of those responses are presented in Tables 2.

As can be seen in Table 2, participants rated system usefulness very highly with 87.5% either strongly agreeing or agreeing with the various statements affirming ease of use of the system. No participants in the study disagreed with any of the questions which probed ability to learn the system and complete specified tasks. Information quality was rated somewhat lower than system usefulness, but still rated very highly. For information quality, 71.4% of responses either strongly agreed or agreed with statements affirmatively describing about information quality.

Table 2. Aggregated results across all statements pertaining to System Usefulness and Information Quality.

System Usefulness				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
24	39	9	0	0
Information Quality				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
18	17	16	2	0

Interestingly, the PSSUQ validation data shows that information quality is often rated lower than system usefulness. The PSSUQ paper identifies help in dealing with error conditions generally, and error messages in particular, as a well- known deficiencies in many software systems. The current study confirmed that finding, as the two individual disagreements with the affirmative statements regarding information quality were to the questions: "The system gave error messages that clearly told me how to fix problems" and "Whenever I made a mistake using the system, I could recover easily and quickly."

5 Discussion

It is an ambitious undertaking to attempt to demonstrate a system that can foster sharing of knowledge in a given domain and to make recommendations regarding how to use that knowledge to practitioners who might benefit from its use. The system described here seeks to broaden traditional knowledge management notions that are proscribed by constraints on sharing outside a firm, and to make very specific recommendations regarding how to use that knowledge.

Knowledge sharing is viewed as a knowledge modeling activity [23] which attempts to organize knowledge in an easily accessible manner, and to provide accompanying resources that elucidate the knowledge. Following from Boh's observation that repositories have benefits over discussion boards [3] VRS is implemented as a dedicated application/repository. The hierarchical organization of the knowledge contained in VRS creates an easily navigable taxonomy of modeling approaches that can be utilized by knowledgeable users. The quick start capabilities present at all levels in VRS provide scaffolding for users who are less well acquainted with the knowledge domain, addressing Alsaleh and Haron's [6] ease of use concerns. The ability to link accompanying resources and references to the description of a model enables the model developer to share deep knowledge of the workings of the model, and the user to delve into those details as deeply as desired.

The inclusion of a recommender system greatly enhances the capabilities of the system. However, differences between the included recommender system and traditional recommendation systems are significant. While a very important domain of knowledge, the pedestrian dynamics and epidemiological modeling community is relatively small, research-oriented, and has no large central repository of data on successful modeling efforts to mine. The literature on recommender systems mostly pertains to systems that build implicit user models based upon user preferences and data gleaned from large collections of data documenting many user interactions.

However, other recommender systems such as VRS and the Elsweiler et al. healthcare system [16] are built out by recruiting experts and employing knowledge elicitation techniques to develop content. The bootstrapping process in the absence of significant filterable data is called the cold start problem [13]. For VRS, the cold start problem is being addressed by recruiting experts in pedestrian dynamics and disease spread modeling to contribute to this work. These initiatives are briefly elaborated in the discussion of future work.

The usability study reported here indicates that study participants found the system generally to be highly useable. Some deficiencies, particularly in help with error conditions, are noted and will be rectified. It is important to note that participants were university seniors majoring in computer science and this non-randomly selected group likely has well above average computer skills, presenting a threat to the validity of the usability study results. However, it is anticipated that the target audience for this software likely has exceptional user skills based upon high educational attainment in fields employing significant computer utilization. Additionally, the fact that potential users are seeking software to model pedestrian motion and disease spread further suggests a high level of computer skill among potential VRS users.

6 Conclusions and Future Work

The current system is a step toward democratizing the use of important modeling capabilities across research domains from academic researchers to public health officials. VRS creates a space where researchers in pedestrian dynamics and disease spread modeling can make their academic work more widely available and useful to practitioners in the field. VRS provides a proof of concept for the integration of knowledge sharing systems and recommender systems, and to a broader view of recommender systems beyond those that filter large bodies of content.

VRS provides support for the identification of a range of modeling capabilities including local modeling, local to global modeling (an important area of research with many open issues) and global modeling. The current prototype system is up and running and has several modeling capabilities already available, with more to come. The currently available capabilities pertain both to local and global models. While having identified some areas needing improvement, the results of a usability study are overall quite encouraging. Future work will involve adding additional models to the system. This end will be achieved by identifying collaborating experts who will describe their models, elaborate potential uses, and identify accompanying resources that may be brought to bear to explain model workings. We expect VRS to become a clearinghouse for tools and resources that can be used to model pedestrian flow and disease spread across a wide range of contexts.

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