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Digital geographies of the bug: A case study of China's contact tracing systems in the COVID-19

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ABSTRACT

The COVID-19 pandemic has radically expanded the role of algorithmic governance in everyday mobility. In China, urban and provincial governments have introduced health codes app as a national contract tracing and quarantine enforcement method to restrict the movements of "risky" individuals through malls, subways, railways, as well as between regions. Yet the health codes have been implemented with uneven efficacy and unexpected consequences. Drawing on glitch politics, we read these unintended consequences as "bugs" emerging from the introduction of platform-based management into everyday life. These bugs mediated individuals' lived experiences of the digital app and the hybrid space constituted by population governance, individual digital navigation, and technology. Drawing on a database of posts scraped from Zhihu, a popular Chinese question-and-answer site, we examine three dimensions of the bug: the algorithmic bug, the territorial bug, and the corporeal bug. This paper sheds light on the significance of end-user experiences in digital infrastructure and contributes to our understanding of the digital geographies of bugs in algorithmic governance and platform urbanism.

1. Introduction

On May 6, 2020, the "health code" mobile app for the city of Hangzhou, China crashed. China's health code apps (健康码 *jiankang ma*) are a key component of the new digital infrastructure that was rapidly developed and deployed in China during the COVID-19 pandemic to conduct contact tracing and enforce quarantine measures. After downloading the app and entering their biometric data, the app then automatically generates a colored Quick Response (QR) code for users: either green, indicating healthy status and free mobilities, or amber or red, indicating that user must be quarantined for potential exposure to SARS-CoV-2 virus. These health codes are checked at the doors of restaurants, grocery stores, malls, hospitals, and all sorts of other public spaces, so when the app crashed, it impacted many areas of public life. However, it was in the transit system that the impact of the crash became most apparent. Stations quickly became crowded with people whose health code apps did not function properly, as a health code is a prerequisite for having access to the public transportation. At Hangzhou's airport, people huddled around boarding gates, repeatedly refreshing their mobile app, unable to display the green QR code required to board. Even though the app was fixed in just 30 min, for that half hour, significant portions of the city's public infrastructure ceased to function as infrastructure.

The May 6 outage illustrates the unprecedented extent to which health code apps have transformed Chinese urban space into code/space, a space where "software and the spatiality of everyday life become mutually constituted" to such an extent that without the code, the spaces cannot function (Kitchin & Dodge, 2011, pp. 16-17). The health codes build on and substantially advance the Chinese state's longstanding interest in using "smart" systems to govern in collaboration with digital platforms like Alibaba and Tencent. As it has spread from its municipal and provincial origins to encompass the entire country, the health code app has become infrastructural: not merely in the technical sense of being integrated with physical infrastructure, but in the social sense of becoming an indispensable part of the background of everyday life (Star, 1999).

Yet the outage also illustrates that these systems are prone to malfunctioning, either directly through errors and other technological issues, or indirectly through unintended adverse effects. In contrast to the dramatic but transient May 6 outage, other malfunctions have led to the inadvertent confinement, continuous frictions for commuters, and isolation for the elderly. These malfunctions disrupt mobility on an

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idiosyncratic, individual level, trapping people in apartments, gated compounds, or provinces, and excluding them from subways, hotels, and even their own homes. These "bugs," as we term them in this paper, are by definition undesirable and unintended. In this paper we theorize bugs as emerging out of three gaps within the health code system: *algorithmic* errors shrouded in the unintended consequences of code, *territorial* seams between health code apps and spatial formations, such as administrative boundaries among cities and provinces, and *corporeal* mismatches between actual users and the health code apps' normative assumptions about its users.

To investigate the societal and spatial consequences of bugs in the health code apps, we drew together a body of scholarship on malfunctions in algorithmic governance (Mattern, 2020; Dalton, 2020; Perng and Kitchen, 2018) and breakdowns in infrastructure (Star, 1999; Kaika, 2005; Chu, 2014). This literature theorizes points of failure as openings, both to a deeper analysis of the system's internal function and to alternative understandings of society and the algorithm or infrastructure's role within it. Feminist digital geography has engaged with "glitch politics" to theorize how glitches in digital platforms offer unexpected and radically open possibilities within what appear to closed, determinate systems (Elwood, 2021; Leszczyski, 2020). Here, we build on glitch politics by asking what consequences do specific bugs have for users, and how do they disrupt public space?

The objective of this paper is to examine the bugs of China's health code app system and its mediation of the spaces of everyday life. We first review the literature on algorithmic governance to show the increasing infrastructuralization of digital platforms, which makes the platforms' malfunctions an urgent social issue and a site of theoretical importance. China's health code infrastructure implements a digital algorithm at the urban scale to control circulations within and between urban areas. Drawing on user accounts of their everyday experiences with the health code apps, we investigate different forms of bugs. Some bugs result from the intrinsic limitations of algorithmic classification, while others emerge from mismatches between the code and territorialization, and others from between the code and the bodily capacities of users. This paper sheds light on the new spaces sparked by bugs in everyday life and on how they are navigated, endured, hacked, and solved.

2. the bug in the machine: theorizing malfunctions in algorithmic governance

The significance of China's health code app system is not simply its scale or autonomy[1] but its link to state power: individuals must use the health code apps, and their determinations are enforced by the government. The health code apps thus exemplify "governance by algorithm," the reliance on automated digital systems to regulate society. The apps are also infrastructural, both in their infiltration of mobility infrastructures and in their rapid integration into the backdrop of everyday life. Simultaneously governmental and infrastructural, the health code exerts a pervasive capacity to shape the spaces of everyday life in urban China. By the same token, its shortcomings—conceived here as "bugs"—can limit and deform individuals' mobility in profound ways.

3. Algorithmic governance

The emergence of algorithmic governance constitutes a qualitative shift in how states perceive and manage space and population. While the gathering and processing of large data sets have been at the core of governance since the origin of the modern bureaucratic state (Foucault, 2009), more recent developments such as ubiquitous computing and the rise of big data have enabled automation and analysis at an unprecedented speed and scale (Kitchin, 2018). For nation-states, algorithmic analysis of travelers' bodies has come to constitute a "biometric border" of anticipatory risk calculation (Amoore, 2006; Adey, 2009) powered by commercial machine learning techniques (Amoore & de Goede, 2008). These risks mainly refer to national security risks (Amoore, 2006) and public health risks (Warren, 2013).

At the urban scale, smart city technologies promise new governmental capacity to know and manage urban flows (Klauser et al., 2014; Luque-Ayala & Marvin, 2016) or to rework the rhythms of urban living (Coletta & Kitchin, 2017). At the intersection of smart cities and platform capitalism, platform urbanism creates new social and material relationships within urban systems mediated through new digitally-enabled socio-technological assemblages. i.e. the platform (Caprotti et al., 2022). Platform urbanism "radically transformed the capitalist extraction of value (Rossi, 2020, page 7)". While promising utopias of efficiency and opportunity, urban platforms nonetheless seem to reproduce systemic biases, social inequities, and existing public values (Riemens et al., 2021; Webster & Zhang, 2021; Boeing et al., 2021). Platforms intermediate urban social interactions precisely by remaining unaccountable, simultaneously embedded and disembedded from the city context (Graham, 2020). Meanwhile, the "blackbox" opacity of urban platforms is crucial in understanding human life (Fields et al., 2020). On the one hand, blackbox is created by algorithm to certain population in that not every-one has the knowledge in understanding algorithms. Second, some algorithm itself is opaque in that its mathmatical equation requires tuning, which to many programmer, is an outcome of accidental trial, instead of logical reasoning.

Yet prior to acting in the world, algorithms must render it calculable, categorizing a complex material world in ways that make it legible and manipulable (Amoore & Piotukh, 2016). But this process is not purely passive collection—rather, it involves altering things in the world. The rise of algorithmic governance was made possible by the prior rise of the machine-readable world: the proliferation of identification codes, from personal identification numbers (PINs) to radio frequency identifications (RFIDs) to barcodes to QR codes (Dodge and Kitchin, 2005b). China's health code apps couple a machine-readable QR code with a human-readable color code. Users are both the readers and the text as they move through the code/space of the contemporary Chinese city.

While the human labor of users is essential to the function of the health code, the core determination—whether one is free to move or condemned to isolation—happens out of view. Even as algorithmic governance expands the capacities of the state, it renders its activities increasingly opaque. Algorithms, particularly those produced by machine learning, "blackbox" the mechanisms of calculation away from subject and operator alike (Latour, 1987). In one sense, this opacity is central to the discursive role the algorithm plays in legitimating the state; it shrouds politics in scientistic claims of objectivity and neutrality (Introna, 2016; McQuillan, 2016, p. 8). In this respect, algorithmic governance recapitulates the logic of what Scott described as "high modernism" (1998), which underpinned the grandiose plans to render populations and spaces legible to the 20th-century state. At the same time, the unknowability of the algorithm leaves an interpretive vacuum. Users develop theories of the algorithms that govern their lives, theories which reflect the anxiety and paranoia the algorithms instill (Leszczynski, 2015; McQuillan, 2016). These theories emerge to no small degree through how the algorithm goes awry: people develop their understandings of the algorithm from personal encounters with the algorithm's glitches.

Such glitches are plentiful. Contrary to the claims of technologists, the city is not a computer (Mattern, 2020), and algorithms never work precisely as intended. When algorithmic "false hits" can lead to detainment and deportation (Amoore, 2006), understanding why and how these bugs manifest becomes a matter of pressing concern, especially for human geography where the boundary between the virtual and reality become blurred with the increasing invovment of digital apps participating social life. As algorithms are woven deeper into the fabric

[1] Autonomous in that the system assigns individual health QR code, which involves no human intervention.

of cities and entire countries, these slippages and disjunctures are harder to dismiss as growing pains. Seen through an infrastructural lens, the problems of malfunction and failure signify something essential about the limitations and unintended consequences of algorithmic governance projects like the Chinese health code system.

4. Infrastructure and breakdown

Looking at China's health code app system as infrastructure sheds light on the politics lurking within algorithm and on the role of breakdown in rendering those politics visible to scholars and to users. Critical infrastructure studies has come to understand infrastructure as including not just its technical, tangible elements, but also the human communities by and for whom infrastructure works (Star, 1999; Graham & Marvin, 2002; Edwards et al., 2009; Brady, 2021). Infrastructure is not just "matter that enables the movement of other matter" but "a kind of mentality and way of living in the world" as well (Larkin, 2013, p. 329, 331).

Infrastructure tends to fade into the background even—especially—for those who rely on it every day (Star, 1999), but this naturalization is limited. Visibility is a matter of perspective (Abel & Coleman, 2020, pp. xi–xiii). As Star notes, stairs may be invisible infrastructure to pedestrians, but never to wheel-chair users (1999, p. 380). Moments of failure, however, render infrastructure abruptly and uncannily visible for entire communities (Chu, 2014; Graham, 2009; Graham & Thrift, 2007; Kaika, 2005), offering an epistemological opening into the nature of infrastructure. Chu (2014) argues that in China, the state's strategy of "infrastructuralizing" power in order to render it invisible and therefore uncontestable is disrupted by disrepair. Through encounters with breakdown, citizens become attuned to "invisible" flows of infrastructural power (Chu, 2014). This suggests a politics of infrastructural visibility: infrastructure offers political actors the power to render fraught decisions fait accompli, and also the radical potential for excavating and re-politicizing buried power relations (Anand, 2011; Anand et al., 2018; Addie, 2021).

Infrastructural approaches have proven fruitful for scholars of the digital. On the one hand, a focus on the concrete infrastructure of dark fiber and data centers has demystified the seemingly immaterial "cloud" or "cybersphere" by tracing the deeply unequal power relations they obfuscate and naturalize (Amoore, 2018; Pickren, 2018). On the other hand, scholars have also examined how digital technologies—particularly platforms such as Facebook or WeChat—increasingly play an infrastructure-like background role in underpinning everyday life, commerce, and politics at the global (Plantin et al., 2018), national (Plantin & de Seta, 2019), and urban scales (Barns, 2020). For example, people uses wechat in everyday communication, and one important payment method. Facebook has mediated people's political preference and e-commerce shopping with precisely targeted advertisement. The politics of visibility have been particularly central for the smart city (Brighenti & Pavoni, 2020; Caprotti, 2019). More a means for seeing than being seen, smart or platform urbanism largely lacks the spectacular dimension of past, high-modernist urban infrastructures, which hinders its role as utopian symbol but shields it from pushback.

Thus, while infrastructure studies is conscious of infrastructure's power to re-order social life, it is also keenly aware of its many failures and unintended consequences. Bringing an infrastructural lens to digital platforms and algorithmic governance directs our attention toward these points of failure, not by negating these platforms' hegemonic impact, but by illuminating their limits and revealing unexpected spaces for political and epistemological contestation. For users, the frustrating, liberating limits of digital infrastructure manifest most sharply in the form of the "bug.".

5. Digital geographies of the bug

"It's not a bug, it's a feature" - programmer aphorism, c. 1970 s.

Bugs are a ubiquitous element of the digital experience, "at once notorious and yet also largely accepted as a routine dimension" (Kitchin & Dodge, 2011, p. 37). A bug occurs when code goes wrong: yet what constitutes a "bug" is a surprisingly tricky onto-epistemological question. For Uber drivers, a platform-based labor model that atomizes workers and limits the cultivation of solidarity is a bug; for Uber it is a feature (Attoh et al., 2019). Accordingly, identifying something as a bug is a form of situated knowledge (Haraway, 1988) that indicates a particular point of view on what the apps ought to do. Traditionally, bugs have existed mainly as computational artifacts, yet as code has evolved into a mediating means through which we humans experience, explore, and make sense of the world, bugs now have a direct impact on our perception of space (Kitchin & Dodge, 2011). In this paper we examine an onto-epistemological space murkier than that covered in Dodge and Kitchin (2005a)'s work on how crashes affect code/space. Perng and Kitchen (2018) examine how "frictions" form sites of encounter across difference; while we touch on the creative responses that bugs in China's health code system have evoked, our main concern is how bugs shape space. We thus use the term "friction" simply to mark the lack of the "smooth" or "effortless" user experience that smart systems and urban platforms promise.

Our conception of the bug builds on—but critically differs from—the "glitch." Glitch feminism, as manifested by Legacy Russell (2020), uses the "glitches" caused by queer, black, and femme bodies that refuse to be neatly categorized as an opening to inquire into how categories such as the gender binary are the product and the tool of oppression. The glitch is an opening, potentially an error (a malfunction or failure) but also possibly an erratum (a correction to a system). Leszczynski (2020) draws on glitch politics to move beyond the typical platform capitalism narratives towards an understanding that is "open to opportunities for tactical maneuvers rooted in everyday digital praxes that remake, unmake, and make differently platform/city interfaces" (p. 201). Similarly, Elwood (2021) engages with glitch politics to disrupt a critical theoretical tendency to read for hegemony: even within hegemonic structures, glitches hint at a far more open ontological space (Ash et al., 2018) wherein digital systems "always contain possibilities for unanticipated forms of agency, subjectivity, or sociospatial relations" (Elwood, 2021, p. 211).

If the "glitch" is an opening of the possibility that the world might be otherwise, then the "bug" is a closure: this is an error. Glitches jar us out of assuming away the device and the code that allow us to chat with friends, order groceries, or navigate a journey. No longer background, digital infrastructure itself becomes the topic of concern and of judgment. Bugs are an interpretation of a glitch: a claim, situated in personal experience, about where the fault lies. Bug, as it interacts with digital geographies, can be considered as a unique instantiation of GIS where a fault appears. The humanistic approach to GIS argues that GIS, positioned between user and environment, appears differently to each (Zhao, 2022). The nature and functionality of the bug is determined by its position with its code, user, or/and the emplaced environment.

This approach resonates with the findings of research on the workers and users whose bodies put the platforms to work; for example, studies of how ride-share and food delivery drivers' experiences generate alienation (Attoh et al., 2019) and pragmatic strategies of mitigation (Sun, 2019). This paper, however, attends to particular bugs and how they emerge from the collision of the algorithms with the rest of society. The health code apps' bugs are distinctly spatial. Kitchin and Dodge (2011) argue that as code permeates daily life, it goes from an element within a space to a constitutive element of space. When code creates space, then bugs create space(s) as well, fracturing and deforming the space the code makes possible.

China's health code app system pervades public space and is backed by the power of the state. Yet following Leszczynski (2020), our theory of bugs avoids approaching this hegemony as a totalizing structure. It is not a dystopia. The health code app system was developed not only through the negotiations that took place among hegemonic stakeholders in the public and private sectors, but was also structured through the experiences, understandings, and responses generated by users across variegated spaces. In theorizing the bug, we seek to empirically examine the ways users are already theorizing algorithmic governance through its mismatches and frictions.

Building on the literature on glitch politics, crashes in code/space and humanistic GIS, we describe the role of bugs in co-producing with the health code app system a variety of hybrid spaces. This hybrid space moves beyond code/space in that it simultaneous involved territorial, algorithmic, and corporeal space, which are interrelated. We break health code bugs into three categories—the *algorithmic* bug, the *territorial* bug, and the *corporeal* bug—not to imply any absolute distinction, but to highlight the origin point of the malfunction which shapes the spaces of the health code app system. Code/space is always simultaneously algorithmic, territorial, and corporeal. The *algorithmic* bug emerges from malfunctions within the code itself, where users cannot identify any other cause for their difficulties. The *territorial* bug is a part of geographical environment that appears from mismatches between code and the sociopolitical arrangement of space. For example, different administrative regions might not recognize the code generated by each other's health code app, which creates barriers to inter-region mobility. Lastly, the *corporeal* bug refers to the bugs that emerge out of users' embodied interactions with the health code apps. Caused by mismatches between the assumed and actual capacities of users, these bugs offer the clearest opening for critiquing the power-laden logic of inclusion and exclusion embedded in the health code app system. With the blurred boundary between the virtual and the reality, algorithmic, territorial, and corporeal bugs are not separated and have spatial deployment on the ground. This spatiality brought by these bugs adds more complexity to our understanding of how glitch politics shape algorithmic governance and the spaces it create.

6. Health code app system: From algorithm to infrastructure

The rapid rise of China's health code app system was made possible by two distinctive elements in China's existing platform economy and algorithmic governance. First, digital infrastructure is already deeply woven into urbanization and financialization (Wagner, 2021). Particularly striking is the ubiquity of digital payment: smartphone-based payment apps have already become a seamless part of urban life in China, accepted by major retailers and street vendors alike. The dominant payment platforms are WePay, a QR code payment service and Alipay, maintained by Alibaba (Plantin & de Seta, 2019). WePay made the QR code, an all-but-abandoned digital standard, into a pervasive element of Chinese public space (Stevens, 2019).

Second, China's digital platforms have strong and enduring connections with the state. China's tech giants (Baidu, Alibaba, and Tencent, abbreviated as BAT) emerged as "national champions" in a vacuum created by the state's exclusion of foreign platforms like Facebook and Google (Plantin & de Seta, 2019). Moreover, the Chinese state has long harbored ambitious e-governance plans: while the mid-90 s "Golden Projects[2]" largely fizzled, newer endeavors like the social credit system reflect the construction of a substantial infrastructure of algorithmic governance, with the support and collaboration of the BAT platforms (Liang et al., 2018).

At the municipal level, Alibaba has collaborated with Hangzhou's city government on smart city initiatives like its City Brain platform (Caprotti & Liu, 2020a; Caprotti & Liu, 2020b). City Brain 1.0 applied smart sensors to address the city's traffic problems, and further iterations incorporated police and disaster response, and venture into industrial management, aviation, health and environment (Caprotti & Liu, 2020b). Hangzhou thus exemplifies the hybrid public–private trajectory of China's smart urbanist development. Given the national focus on smart urbanism, City Brain and similar technologies promise enormous financial and political dividends for Alibaba and 'entrepreneurial' city officials (Chien, 2013), but glitchy rollouts pose risks as well. Justified on technical metrics of efficiency, City Brain's 'success' has justified its exportation to 15 other Chinese cities and Kuala Lumpur (Caprotti & Liu, 2020a).

Thus, when Alibaba released the first health code app in Hangzhou—and when Tencent released their competing mini-app—they were building on not just an established public–private partnership but on an entire infrastructure. It is important, here, to think of this infrastructure as not just comprising the app's code and the material infrastructure of the information and communications technology (ICT) involved, but the habits and practices of the app's extensive user-base, already accustomed to the technological and bodily practices of smartphone life (Star, 1999). That already-existing infrastructure is what made the health code app system's rapid uptake possible, but its limitation, including the digital infrastructure and its required digital literacy, continue to shape how the health codes are used, and how they fail.

The algorithm that assigns people their individual health code remains a blackbox. Take Hainan and Beijing as examples (see Fig. 1 on health QR code in Beijing). After installation, the Hainan health code app asks users to enter their name, address, and to report daily-five possible COVID-19 symptoms: fever, fatigue, cough, stuffy nose, and diarrhea. Instead of requiring information input, the health code app in Beijing only requires a national identification card number and facial recognition data. In practice, users are required to use the app to scan a printed QR code at each location they visit, such as hospitals. By scanning the code, the individual's green colored QR code is revealed, and his or her footprints are recorded.

Although the specific classification algorithm of the health code apps are unknown, users have a variety of guesses about how the algorithm works (See Abidin, 2020 on guestimation). Fig. 2 is the author's guestimation of the health QR code's algorithm. The majority of China's health code apps classify people based on two components. The first component includes possible COVID-19 symptoms gathered during sign-up or daily check-in. Based on the questions asked of users, the variables shown in Fig. 3 might be used in the classification algorithm.

This set of health information and travel history data can then be used to train a classification algorithm to predict and classify people into the high/medium/low categories. Popular classification algorithms include but are not limited to logistic regression, naive bayes, K-Nearest Neighbors, Decision Tree, and Support Vector Machines. For example, the decision tree algorithm might classify the population based on certain "rational/scientific" logics (see Fig. 3). Second, the Beijing health code app reveals how geospatial data can also play a role in the classification algorithm. Contact tracing is performed based on the digital footprint generated through scanning locational QR codes: when confirmed COVID-19 cases were present around the same time in the same location, the health code app can identify individuals as "potential close contacts." As a result, the person who was in the same space as a confirmed COVID-19 case could have their health code turn red or yellow, which would then deny them entrance to public spaces and the use of public services.

7. Research method

To investigate users' interpretations of their experiences using the health code apps, we analyzed posts and comments published on Zhihu in the early days of the pandemic. Zhihu (知乎) is a leading Chinese language question-and-answer site that incorporates user-generated content alongside professional knowledge shared by experts (Li & Zheng, 2020). Zhihu draws disproportionately from the educated urban population, with 80 % of users possessing a bachelor's degree or above (Zhang, 2020). As a platform that encourages robust exchanges, Zhihu has become a de facto arena for civic engagement in the Chinese internet

[2] The Golden Projects refers to the Chinese government's top-down initiatives in establishing IT infrastructures.

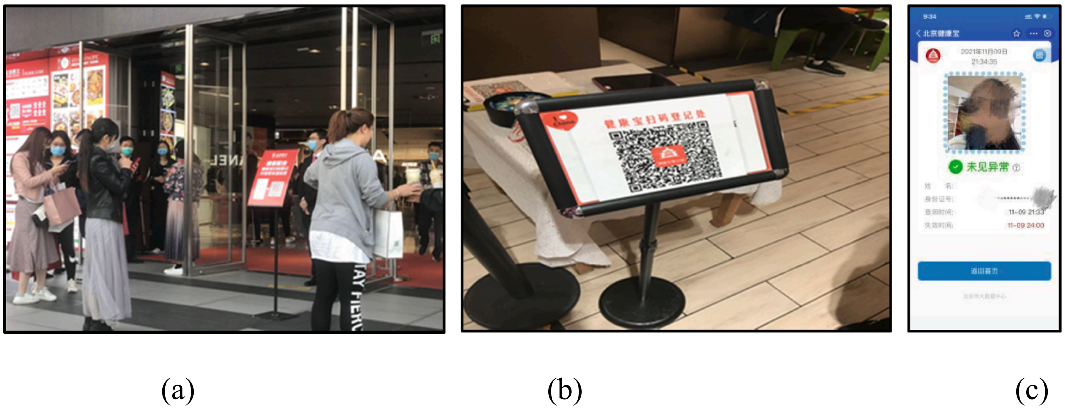

Fig. 1. (a) people stopping to scan the health code; (b) a QR location-tracking code that people must scan to enter; and (c) an example Beijing health code app.

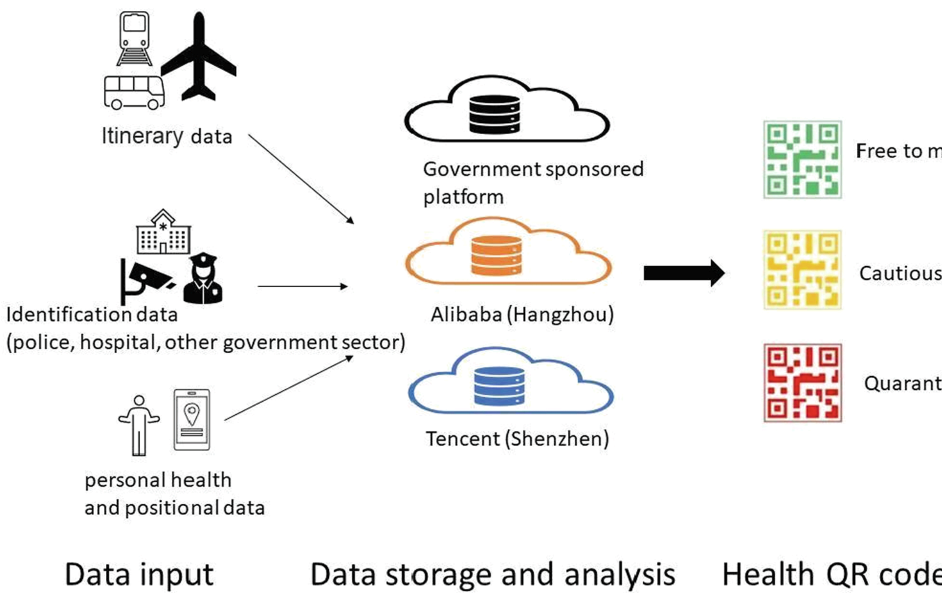

Fig. 2. The contact tracing system: data input; data storage and analysis; and data usage.

ecosystem (Peng et al., 2020).

Data for this study were collected by a Python web crawler, using the Chinese language search keyword "health code (健康码)" on April 20, 2021, just over a year since the health codes were rolled out. The initial search yielded 507 articles, which were qualitatively analyzed. The type of thematic analysis adopted in this research is reflexive: the leading author conducted an inductive coding process where she generated codes through closely reading the text data. The following themes emerged: Access to public infrastructure, bugs due to the app, digital divide, privacy concerns, individual resistance to health code, surveillance, algorithm guestimation, health QR code efficiency, public security vs private responsibility, frictions among regions. We have specifically targeted and engaged with the following four themes in this paper: algorithmic bug in the app, digital divide, algorithm guestimation, and frictions among regions.

Some answers came from self-identified "insider" experts, such as software engineers who had participated in the health code apps' development or code administration employees who monitor the color of the health codes generated by the apps in the backend. However, anyone can post on Zhihu, and it is a public forum that allows any discussion to take place as long as it does not violate the law or other regulations. While many questions and answers describe the function of the health code apps, as well as their underlying principles and organization, our ability to verify the accuracy of the information was limited.

However our analysis focused on the bulk of the comments and answers which came from people who navigate the health codes as part of their work, such as a nurse tasked with checking the QR codes of those entering the hospital, and individuals who encountered the health codes as part of their everyday life. We assume the questions and answers on Zhihu over-represent the extremes, particularly the frustrations of those who have come face to face with the bugs and inefficiencies of the health code platforms. These factors, combined with Zhihu's young and urban demographics, makes it clear that our data does not offer a representative sample of the public opinion in China. Accordingly, we interpret our findings not as a dispositive account of how the health code app system works, but as a type of folk knowledge, a bottom-up account of how it works (or does not work) for those whose lives are shaped by it.

8. the bugs of China's health code infrastructure

In this section, we analyze how bugs within the coded infrastructure of the health code apps shape the experiences of users in unintended ways, giving rise to alternate understandings. Here, we examine the bug from three vantage points: the *algorithmic* bug, the *territorial* bug, and the *corporeal* bug.

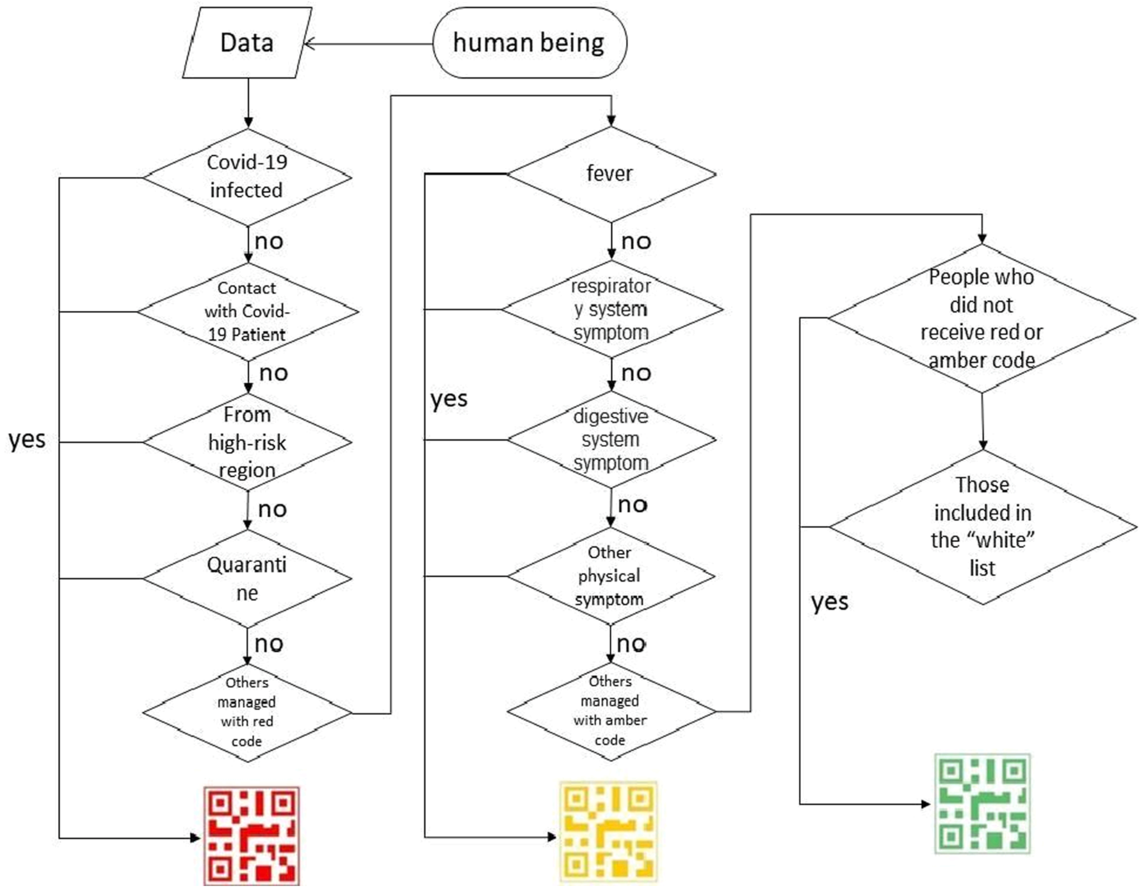

Fig. 3. Potential flowchart of health code classification algorithm.

9. the algorithmic bug: misclassification in the blackbox

Big data's claim to authority rests on, among other things, high levels of accuracy. However, a model always has an inaccuracy rate. As Amoore (2017) notes, algorithms judge via thresholds of satisfaction; within the health code apps, each misclassification has a massive impact: it thrusts individuals into inexplicable quarantine, excludes students from their own campuses, or strands people far from home. Each misclassification interrupts mobility through public spaces that has long been taken for granted. Hence, small percentages matter. A tiny percentage of model inaccuracy impacts millions of people, forcing each person to try and understand what is going on. As one Zhihu user who ran afoul of the algorithm early on put it:

> People outside of Hangzhou don't use the codes and only see the glamourous exterior and fancy "big data" propaganda. Over 90 % percent of users hold green codes. They don't see any problem. But that means more than 300,000 have red codes, with at least 200,000 of them in dispute, and their voices are drowned out…. I wonder if so many people really need to be quarantined for 14 days. As of yesterday afternoon, already more than 30,000 have appealed their red QR code, and all sorts of other problems about changing colors have emerged. There are also many problems regarding the changing color of the health code. Implemented for the whole of Hangzhou, an error rate of only 1 % would impact almost 100,000 people's right to normal mobility. Extended to the whole country, it is hard to imagine.

When the health code app was initially implemented in Hangzhou, more than 300,000 red codes were assigned, which created anxiety about the accuracy of the health code app. Yet bugs also enabled users to guess the function of the algorithm behind the health codes. For example, one user understood precisely why he had received the red code: chronic rhinitis. When he filled out the symptom survey, he was honest and reported his stuffy nose. Given almost twenty days in self-quarantine to contemplate his regrettable honesty, he emerged with a deep skepticism of big data's reliability:

> How can big data know whether I have a stuffy nose, or whether I have diarrhea today at home? How can they judge the veracity of the information that individuals self-report? I was assigned a red code with no reason given, shut up in my home by so-called "big data." It was simply awful.

This concern over the lack of verification of self-reported user information was a common theme among the health code app critics. Like the user above, many expressed concern that reliance on unverified data compromised the entire health code app.

Another set of algorithmic bugs were generated by misinterpretation of geospatial data. In addition to the inaccuracy involved in the individual assignment of the health codes, misinterpretations of the mobile data is crucial, especially when people's subsequent movement totally depends on it. Users' experiences of automated data collection reveals the system's limitations. A student enjoying their holiday encountered a bug in geospatial positioning along the border between and the mainland and the Macau Special Administrative Region, which was seen at the time as a risky place for becoming infected with COVID-19:

> I traveled to Dong'ao island, Zhuhai last Friday and Saturday. After coming back, I realized my footprint tracking suggests that I have been to Macau, China. I was speechless. None of the three friends I traveled with had this issue. I need to go back to school to prepare for graduation. Having been to Macau would make it impossible to enter the university. I was too scared to sleep that whole night.

The description above suggests that in Guangdong province, the health code app is linked to China Telecom base station for footprint tracing. A misplaced geospatial location would lead to misclassification. These situations are not rare within the Zhihu dataset. For users of health code apps that incorporate geospatial data, simply being close to an administrative border could get one mistakenly labeled as having been to a risky region. This misclassification is due to the location spoofing produced by the contract tracing providers (Zhao & Sui 2017). Most smartphones utilize a hybrid positioning algorithm to locate its user. This hybrid algorithm usually relies upon a few plugged positioning modules (GPS receiver) and communication modules (e.g., Wi-Fi module, Bluetooth module, base station, etc.). The base stations are known for low positional accuracy, with errors occurring up to around 100 m. Meanwhile, GPS and Wi-Fi could have relatively high accuracy. In most cases, if the phone's GPS, Wi-Fi, or Bluetooth has a relatively strong signal, the mobile phone will be accurately located using these methods. However, if the above-mentioned signals are weak, which can occur when, for example, a high building blocks the signal, it would change to the base station positioning method. This would increase the locational error. In health code implementation, it is up to the contact tracing provider to adopt a specific locational method. Many people attributed their misclassification to low geo-locational accuracy, normally resulting from base station location.

The above user was doubly fortunate—not only did they know what the error was in their health code, they were able to resolve it by contacting officials to fix it. More often, users have no idea why they received an amber or red QR code, and thus have no way to fix it. One traveler had his health code mysteriously turned red mid-journey, which led to unpleasant results:

> My travel history was completely normal; I hadn't left Lanzhou, Gansu province when I flew to Tianjin on March 26. I hadn't gotten in close contact with any COVID-19 patients or suspicious cases, and I hadn't been to any high-risk regions. But the day I departed, my health code become red for unknown reasons. I used a paper health certificate to go through the manual check and board the plane … There must be a problem in the system. I called the mayor's hotline over and over, and they told me they would reply in one or two days…. [That night in Tianjin] I was a lone foreigner in a strange land. It was raining and cold. Because of the red QR code, no hotel would accept me. Wherever I went, people threw me out. I spent the whole night on the street. One pitiful person.

This story illustrates the stakes of getting health codes right: when a person is mistakenly given a red health code, it cuts off their access to hotels, grocery stores, and public transportation—nearly every piece of urban public infrastructure travelers and residents rely on to get through their day. These are the spaces of health code bugs, the familiar rendered uncanny (Kaika, 2005): the apartment that become an isolation room, the border that shifts underfoot, and the rainy street or quarantine hotel that become places one is allowed to go in a distant city.

The experience of being misclassified is occasionally traumatic and always inconvenient. It spurs users to question the algorithm and to interrogate the source of its authority. When users contacted officials to figure out what had gone wrong, they found that the government workers administrating the systems knew just as little as they did. While "big data" was marshalled as a source of authority, others criticized the resulting opacity as a "blackbox mechanism." As a blackbox, neither the user nor the administrator has the ability to understand or control it. Here, big data creates its own authority simply by being big data, predicated on a high modernist admiration for "scientific" decision making. The health code app system renders the population legible and governable by inserting itself into the circulations of everyday life (Introna, 2016; McQuillan, 2016). Yet that same power renders the algorithm open to critical analysis. Users who know their own individual situation with a high degree of accuracy may be able to challenge the governing algorithm even if its particularities remain hidden. Misclassifications are unavoidable issues for those who experience them because of their impact on spatiality: when they are trapped in their homes and are excluded from public transit, users come face to face with the algorithm through the deformations in public space its bugs create.

10. the territorial bug: disrupted flows among cities and provinces

The second type of bug emerges less from problems in the code and more from problems of political jurisdiction, manifesting in frictions users experience while trying to move between cities and provinces. Unlike algorithmic bugs, which emerge from inaccuracies within the system's code, territorial bugs are co-constructed by technical infrastructure and administrative boundaries (Misa et al., 2003). The regional scale of the health code apps means that countless journeys within China now require travelers to download or fill out various forms to gain another health code to move through another city or province, resulting in a dramatic rise in inconvenience for travelers. Despite a reputation for monolithic centralization, the Chinese state is jurisdictionally heterogeneous with a significant degree of territorial contestation across scales (Shue & Thornton, 2017; Xu, 2017). The health code app system took these once-distant intra-state rivalries and struggles and placed them in the path of every traveler crossing from the jurisdiction of one health code app to another.

10.1. Inter-provincial

The latitude given to lower levels of government in China made the invention of the health code apps possible, but also meant that the national uptake of the health code apps quickly became a morass of incompatible health code apps with overlapping spatial jurisdictions. When they were first implemented in February and early March, each province had its own health code app that only recognized its own green codes as valid. Travel across jurisdictions was a problem left to individual travelers to solve. Numerous Zhihu posts related users' struggles to return to work or school through a maze of incompatible health codes. Some needed to register with as many as five different health code apps to complete a single trip.

> I am from Xiantao city in Hubei province, waiting for the lockdown to end so I can go back to Suzhou, Taicang for work. Right now, I have to register with the national government health code app, the Suzhou city health code app, the Hubei province health code app, and the Jiangsu province health code app. Today the Xiantao municipal government announced a local health code app. In one day, I got five QR codes.

These intra-provincial issues affected a massive population of travelers. A decades-long build-up of transportation infrastructure, including roads, railways, and air travel, has made long-distance, interprovincial travel a normal part of life for a significant fraction of Chinese citizens. Yet even daily commuters found incompatible health codes quickly became a constant source of friction. In Beijing, for example, many people live in Hebei province and commute daily across what was previously an insignificant administrative border into the city to work. Similarly, people who live in Zhejiang province might commute to Shanghai to work, or residents of the Pearl River Delta, an eleven-city urban conglomeration around Guangzhou, Shenzhen, and Hong Kong, might commute into one of those cities. The province-based health code app may be functional on its own terms, but it constitutes a severe mismatch with the mobility patterns its users actually practice.

10.2. Intra-urban

Even within a single city, health codes caused no end of conflicts with people's mobility needs. In some cities, people needed to fill several forms to acquire several health codes just to travel between neighborhoods.

> I returned to Beijing from Hebei province in early February. I stayed where I live for almost one month before returning to work. I commute by motor-bike. The thing that annoys me with the health code is that I work in Wangjing, but I live in Sunhe neighborhood. The pass issued by the neighborhood community has changed three times! If all of Beijing or the whole Chaoyang district had one consistent system, then it wouldn't be a problem. But it is really annoying to have each location have its own independent system.

Particularly in the early days of the pandemic, various sub-municipal districts and neighborhood-level governments took individual-scale health tracking into their own hands. China's "community grid-style management" system provides the state with a remarkably fine-grained level of surveillance and control at the neighborhood level (Cai, 2018), a capacity that played a central role in pandemic urban governance ("Community Grid System Helps China Fight Virus," 2020). This control often relies on residential committees, so that even gated communities require their own pass for COVID-19 prevention. When cities and provinces introduced local health code apps, they simply added another layer of tracking and verification. Each building, school, or residential gated community has a separate requirement, which can result in some individuals needing more than 10 health codes generated each day.

> I got 10 health codes … The community requires one, the property management company requires one. Where I live and work belongs to two different administration regions, so I filled another two forms to acquire two more health codes … I had to fill another one in the local government business center because I went there to deal with some business. Every day I drive from one district to another district, so I fill out another form required by the transportation department … I don't really know how many forms my husband has to fill out. For all the codes I mentioned above, some require re-filling the form every day, some require me only to re-fill it to complete certain tasks.

Each health code app has essentially the same purpose, and largely relies upon the same set of information. Perversely, each new registration means re-entering the exact same information in a repetitive, mind-numbing cycle. The reason users must constantly re-enter information for different administrative departments is that they do not exchange data. The Chinese state has long implemented nationwide mandates by first trying experimental implementation at the local level, and then by scaling up successful models and re-absorbing institutions deemed unproductive (Lim, 2019). The health code apps reflect both the strengths and the weaknesses of this approach.

Moreover, disconnections between regions are also due to different regional policies for COVID-19 prevention. While, in theory, the health code apps reflect national state policy, in practice, they are implemented by local and provincial governments whose policy judgments are highly dependent on individual assessments of risk and reward. Through late 2020 and all of 2021, China maintained a policy of total suppression of COVID-19, but the stringency of response varied from region to region. When there were small outbreaks in Beijing in 2020 and Guangzhou in 2021, some other regions restricted movement of people and goods from these major hubs. Faced with the risk of being held responsible for any failures in COVID-19 prevention, some provincial or local governments prioritized enforcing their own regulations to protect their local situation with little regard for compatibility with neighboring areas.

As circulation of people and goods returned to pre-pandemic levels, the friction caused by the incompatible, highly-localized health code apps became a growing problem. Hence, to facilitate movement and reduce barriers, some provinces started to collaborate by recognizing each other's health codes. This was mostly limited to adjacent provinces with frequent human, goods, and business traffic. For example, Beijing first recognized the health code issued by Hebei and Tianjin provinces on April 18, 2020[3] because these three provinces have close ties. Similarly, Shanghai first recognized the health code issued by Zhejiang and Jiangsu provinces on March, 6th, 2020. Gradually, with the containment of COVID-19 and the urge to boost the economy, most of the provinces in China started to recognize each other's health code.

The fragmented health code app system renders flow between different provincial and urban jurisdictions buggy: if it is not prevented altogether, then travel is burdened by the need to set up and juggle multiple health codes. But this disruption, while manifested through the technicity of the health code apps, does not emerge from the health code apps themselves but from the political constraints on their implementation. These types of bugs, in other words, are co-constructed by technology and the way people define and seek to control space. The territorial bug reflects the multi-scalar politics of China, and thereby transforms the concerns of wary local officials into tangible barriers to the everyday mobility of individuals.

11. the corporeal bug: intensified social inequality in confronting a public crisis

The third type of bug, the corporeal, emerges from the interactions between humans and the health code technology: specifically, from the mismatch between the assumed capacities of the user and the actual user. Setting up and using a health code app takes multiple skills and capacities. The act of downloading an app, filling out a survey, and scanning QR codes requires a familiarity with smartphones, the ability to read a small screen, and the manual dexterity to accurately type and click buttons on a touch screen—not to mention the ownership of a smartphone to begin with. An acquired intuition about how to use technology, sometimes termed "digital literacy," is a skillset that not every-one possesses. Scholars have shown that as digital technologies proliferate, those who lack digital literacy are increasingly unable to access services provided through smartphones and computers, producing a "digital divide" within society. While China may be a leading market for smartphones, the penetration rate remains middling: only 59.9 % (Newzoo, 2021). Building on Rose et al.'s (2021) point that the users of apps are normally assumed to be able-bodied and value rational and efficient mobility, the health code apps assume that Chinese citizens are all able-bodied, literate, and equipped with a smartphone. This mismatch, within our data, was seen most clearly with the elderly (Wang & Jia, 2021).

As might be predicted from Zhihu's demographics, the discussions concerning the health code apps' new digital divide primarily featured the voices of younger, tech-savvy individuals. Yet there were many posts from users who have older adults at home and have seen the struggles of their older family members using the health code apps, often when one of those older adults come to them for help. Here is a typical post:

> I remember it clearly that one day when I was out shopping, I received a phone call from my grandpa … In an embarrassed voice, he asked me whether I could come to the community gate right now. He said the residential community is issuing health codes, which require a smartphone. To enter the grocery store now requires this health code … When I approached the residential community gate, I heard people arguing loudly about whether elderly people needed to use the health code to enter and leave. The neighborhood committee members said "Yes."

This story captures the distress and inconvenience for both older adults and the younger generation on whom they rely. The introduction of the health code to regulate public space suddenly confined the grandfather to his neighborhood, not because of a mistaken red code, but because of his inability to use a smartphone. The bug in this case is in being the wrong kind of user for the designed app. The transformation of

[3] https://bj.bendibao.com/news/2020418/273227.shtm.

public space into code/space dramatically disrupted the everyday routines of countless older adults. As one user related,

> My grandpa is 91 years old … He has two sons who have lived in Guangzhou for more than 20 years. One lives in Gangding, and one lives in Sanyuanli … My grandpa departs from Gangding every morning and takes the subway to Sanyuanli to his second son's home. After dinner, he then takes the subway back to Gangding. This is the routine he has had for the past decade. However, since March 2020, one cannot even enter the subway without a health code. My grandpa doesn't know how to use a smartphone; he can't even read the characters on the screen—how is he supposed to open WeChat and scan the QR code?"

He was far from alone: the loss of access to public transportation, from city buses to inter-provincial trains, hit older adults particularly hard. Older adults who cannot get around via private transportation or do not have smartphones choose to walk because they have been refused by public transportation for not having the health code. Disability studies have argued that disability, rather than residing in the individual, is socially constructed (Moser, 2006). Because the health code apps now intermediate access to public transit, they have constructed as disabled a new class of people. Nevertheless, the ingenuity of older adults and their families have created workarounds to get past this new digital divide. One common solution is to print paper versions of the health codes:

> After successfully registering for my grandpa, I helped him color-print it, hoping he could move freely into the grocery store and supermarket without me. The next day, my grandpa entered the grocery store with the printed version of the health code. The other day, he happily showed me a card holder where he had a printed version of his health code shrunk to a bank-card size. He told me that all other older adults have these kinds of health certificates for entering the grocery store. He thinks his A4 size printed version is too big. So he got a small size one.

Allowing older adults to use paper version codes has become a de facto policy in many places. The health code, which was supposed to be displayed in real time because it had been produced in a timely manner by the backend algorithm, is instead being used as a static code by older adults.

These corporeal bugs resulted from the mismatch between the users and the health code apps. These bugs illustrate that interactions with the digital are highly individual and depend on socio-economic status, digital literacy, physical capabilities, and whether one is with others or alone (Dodge & Kitchin, 2005a). Our findings resonate with Chung et al. (2020)'s argument about the downscaling of health responsibilities to individuals. While our data highlights in particular the plight of the elderly, they are far from the only population affected by the sudden merger between smartphones and citizenship. The difficulties of managing health codes for children was also a common theme in the Zhihu data. Some disabled populations have limited capacity to use smartphones, and thus they find their disability has been expanded with the implementation of the health code app system. In the Zhihu data, some users advocated designing a more inclusive app, with larger buttons and less text to make it more accessible. These changes would indeed make the health code app more inclusive, but would not alter the essential mismatch between the app's assumed user and the messy and heterogenous population of users that actually exists.

12. Conclusion

The health code app system helps the Chinese government contain COVID-19 by identifying risky bodies, limiting mobility, and tracing contacts. However, when implemented nationwide, it has encountered a series of bugs. In this paper, we targeted three dimensions of these bugs and their mediation of the virtual and real space. Algorithmic bugs shed light on how personal and shared experiences of malfunction shape the end users' perspectives: while the health code apps strive to create a transparent, frictionless space, encountering the friction of bugs renders the opacity of the "blackbox" algorithm viscerally apparent. Territorial bugs reveal complexities of China's multi-scalar governance that are otherwise obscured. Corporeal bugs demonstrate how mismatch between the apps' assumptions and actual users create discrimination between groups. Accounts of these bugs also illuminate how users navigate the divide by drawing on cross-generational familial ties. Understood not as a strict typology but as a set of interlocking phenomena, these bugs provide digital geography and humanist GIS a vocabulary for thinking through and investigating the fractures and deformations of code/space.

This paper further contributes to the literature on digital geographies by using bugs as an entry point to theorize and attend to questions of end-user experience in algorithmic governance and smart/platform urbanism. This paper responds to existing calls in the literature to deconstruct the grand narratives of smart city advocates and platform naysayers; these are only one part of the story. Users' experiences with the health code system generate counter-hegemonic understandings which are just as real as the infrastructure's reshaping of urban space. The heterogeneity of these ontologies moreover reveals the multiplicity inherent in bottom-up understandings of digital infrastructure: as Scott observed of the high-modernist state, simply because rendering space and population legible and governable is the goal does not make it an achievable one. This paper contributes to our understanding actually existing algorithmic governance and its necessary shortcomings.

The Chinese state has long had an abiding faith in the power of technological development to solve social problems. The health code app system represents a new dimension of algorithmic governance in China, both in terms of its rapidity and its ubiquity. As health code-like apps become part of the infrastructure of everyday mobility in China, South Korea, Singapore, and parts of the United States, a dystopian vision of hegemonic smart infrastructure looms. As this research shows, the fine-grained control over individual mobility offered by such digital infrastructures is significant, but far from error-free. Yet in their bugs and inadvertent divides, such infrastructure also makes algorithmic governance unavoidably present in everyday life, rendering hidden technological mechanisms self-apparent and therefore open to criticism.

CRediT authorship contribution statement

Yi Yu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Dylan Brady:** Conceptualization, Writing – original draft, Writing – review & editing. **Bo Zhao:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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