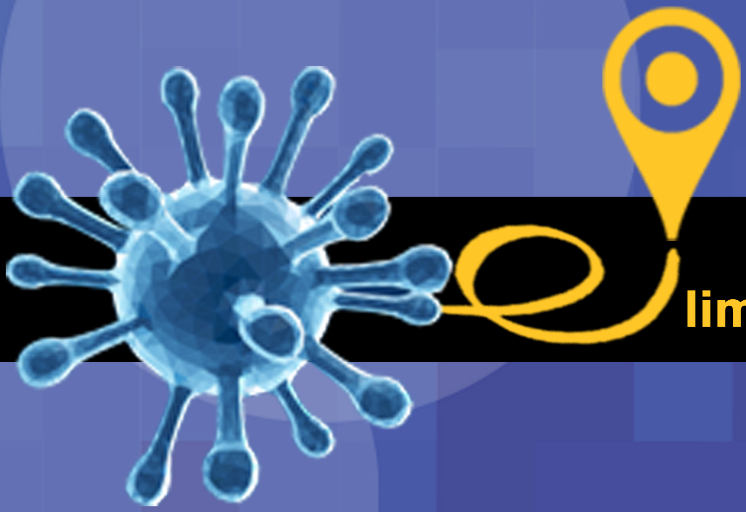
Digital Contact Tracing and Surveillance



Geospatial opportunities, limitations, and research directions

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Executive Summary

As efforts to mitigate and suppress COVID-19 continue, many decision makers are asking if digital contact tracing—a method for determining contact between an infected individual and others using tracking systems commonly based on mobile devices—can help us safely transition from population-wide social distancing to targeted case-based interventions such as individualized self-quarantine. In response, the Spatial Analysis Research Center (SPARC) at Arizona State University organized a panel of national experts to discuss the use of geospatial technologies in digital contact tracing and identify the practical challenges researchers can address to make digital contact tracing as effective as possible. The major themes of the discussion included (i) the capabilities and limitations of geospatial technology, (ii) privacy, and (iii) future research directions. Key takeaways from each of these areas include:

Capabilities and limitations of geospatial technology: There are many geospatial technologies (e.g., GPS, Bluetooth, Cellular, WiFi) embedded in mobile devices that can be leveraged for digital contact tracing (1). However, GPS technology in smartphones lacks accuracy to map interactions in the detailed way one might expect. For instance, the horizontal accuracy of GPS is 15m, and the vertical accuracy is insufficient to pick up which floor of a building a person is on. Indoor accuracy is particularly poor, which is problematic given people spend 87% of their time indoors (2). However, information about the absolute location of an individual may not be as important to digitally tracing epidemiologically meaningful contacts as identifying the types of interactions most likely to result in the spread of the virus. The importance of tracing interactions creates an opportunity to use Bluetooth-based exchange of encrypted keys to record person-to-person contacts that can then be analyzed within the space-time prism framework (3). This approach will not require storing of all individuals' movement data, which will reduce computation complexity. Geotargeted and geotagged social media are useful for tracking transmission between cities or within cities, detecting large gatherings, and helping individuals recall location and contact history during contact tracing interviews. Social media can also provide useful context, such as check-in locations and textual content, to reduce false positives in interactions identified through other forms of digital contact tracing.

Privacy: Digital contact tracing raises numerous privacy concerns. By creating some record of the location history or contacts of an individual, digital contact tracing creates an opportunity to identify an individual without their consent. At present, the privacy implications of digital contact tracing are unclear because these systems have yet to be fully developed or deployed in the US. An evaluation of pros and cons in the existing digital contact tracing plans operating in other countries can inform policy makers on privacy mediation during and after contact tracing. While companies and officials working on this issue have made statements that preserving privacy is an important goal, the details of how privacy will be preserved and the safeguards that will be put in place are not yet available. If any privacy protections are lifted to enable contact tracing, a plan should be put in place to restore protections once the pandemic subsides.

Future Research: To support digital contact tracing and surveillance, several research areas must be advanced. Key technical areas include increasing the accuracy of indoor positioning, developing approaches for reducing false positive of potential exposure (not to be confused with false negatives which are more common in COVID-19 diagnostic test) ensuring a focus on high accuracy in relative positioning, addressing computational complexities, developing group or bubble based approaches to surveillance, and developing a system for the creation and distribution of high resolution risk data and to enable self-determination of the need of quarantine and testing based on possible exposure. Research into how digital contact tracing systems link with existing contact tracing infrastructure and with other digital contact tracing systems also needs to be conducted. The implications of digital contact tracing for society and privacy will emerge along with these systems. Researchers need to study these issues as

they emerge to ensure that we have the ability to hold an informed public debate about the effectiveness and costs of digital contact tracing.

Introduction

As efforts to mitigate and suppress COVID-19 continue, many decision makers are asking if digital contact tracing can help us safely transition from population-wide social distancing to targeted case-based interventions such as individualized self-quarantine. While public health systems already have the ability to conduct manual contact tracing, they do not currently have the capacity to identify and trace infected individuals at the scale or speed needed to respond to the COVID-19 pandemic. To augment the existing manual contact tracing system, public health officials are seeking to use location tracking technologies embedded in mobile devices (e.g., smart phones), to trace people's movement and person-to-person interactions. From these digitally collected location and contact histories, officials then hope to reconstruct potential COVID-19 transmissions and identify locations where transmissions may cluster in space and time. Knowing when, where, and with whom a COVID-19 positive individual has interacted is key to notifying those potentially exposed, providing early testing, and using individualized quarantines to mitigate the further spread of COVID-19. This chain of contact tracing, early detection, and isolation is particularly important for COVID-19 because individuals are contagious prior to symptom onset.

Given the critical need for contact tracing, numerous public and private organizations are developing needed infrastructures. Several states have been rapidly expanding their contact tracing workforce by hiring additional tracers and intensifying training efforts. The Johns Hopkins Center for Health Security estimates that at least 100,000 contact tracers will be needed if the United States is to successfully manage the spread of COVID-19 until a vaccine is developed (4). At the same time, numerous organizations are rapidly developing the digital infrastructure needed to automate some parts of the contact tracing workflow. A collaboration by Apple and Google is scheduled to release an application programming interface in May that will serve as the foundation for contact tracing applications developed by public health agencies and other third parties. South Korea and Singapore have already released contact tracing applications, and Germany, France, and other European countries are set to do so soon. As these technologies become part of public life, numerous questions emerge. Which technologies should we support, develop, and deploy? What technologies can achieve the best results in the fastest time? How can we use these technologies to mitigate COVID-19 while also protecting individual privacy? And, what might be the unintended consequences of implementing widespread digital contact tracing technologies?

Geospatial scientists have been using global navigation satellite systems (GNSS), social media data, satellite imagery, and a host of other technologies to track movement for decades. As a community, geographers and geospatial scientists have a wealth of experience in tracking, mapping, and interpreting individual movement and interactions in space. As a discipline we have a responsibility to use this knowledge to understand which technologies will be most effective and how they will impact our society, to help decision makers determine which digital contact tracing technologies to support, to educate the public on how their lives and privacy may be impacted, and to lead our scientific community in identifying critical technical and social research needs.

Panel Discussion - Watch Now

To meet this need, the Spatial Analysis Research Center (SPARC) at Arizona State University organized an expert panel discussion, held on April 24th, 2020, to (i) discuss the use of geospatial technologies in digital contact tracing and (ii) identify the practical challenges researchers can address to make digital contact tracing as effective as possible. This white paper is the result of that panel discussion. The 10 geospatial experts discussed these topics and answered questions from public health professionals regarding the use of geospatial technology for digital contact tracing. The panelists were asked to address at least one of three questions.

- What are the technical capabilities and limitations of the geospatial technologies likely to be used in digital contract tracing?
- How might digital contact tracing impact privacy?
- What geospatial research is needed in order to develop and deploy effective and ethical digital contact tracing in the United States?

Following a discussion of these questions, a set of additional questions posed by the over 230 virtual attendees was discussed. A summary of this question and answer period is provided in Appendix A. In the remainder of this white paper, we summarize panelist perspectives on geospatial technology opportunities and issues and privacy concerns surrounding digital contact tracing. To conclude we focus on recommendations for next steps in geospatial research that aims to help manage COVID-19 by developing and deploying tools for early detection of asymptomatic cases of COVID-19.

Background concepts

Throughout the panel discussion, several organizing concepts emerged. These concepts are introduced here:

1. *Accuracy versus Precision:* Accuracy refers to the closeness of a measured value to the real value. In the case of location, spatial accuracy refers to how close a measured location is to the exact location in reality. In contrast, precision refers to the level of detail in the reporting of a specific measurement. Typically, locations derived from cell phone GPS are reported with the precision of one meter, even though those location measurements are usually only accurate to within 20 m.
2. *Relative versus Absolute Location:* Measuring the absolute location of an individual identifies where that person is on the globe. Measuring the relative location of an individual identifies where that person is in relation to another object or individual. For many geospatial applications, we aim to have highly accurate absolute locations. However, effective digital contract tracing may be achievable with accurate relative location alone. The community transmission of COVID-19 appears to be most likely to occur when people in close contact, which suggests that accurately recording human interactions may be sufficient for effective contact tracing. Nonetheless, knowing the absolute location history of COVID-19 positive individuals will also be useful for contact tracing efforts, as health officials can use this information to identify the locations that may serve as transmission centers, or to jog the memories of infected individuals attempting to recall their interactions during contact tracing interviews.
3. *Tracing versus Tracking:* We differentiate between *tracing* the movement of individuals and *tracking* the movements of individuals. Tracing focuses on recording relative locations and interactions, which does not require storage of detailed individual movement information. In tracing efforts, movement is just a breadcrumb that helps identify interaction. In contrast, tracking occurs when all of the detailed movement information (i.e., semantic trajectories) associated with an individual is stored. Tracing versus tracking has important implications when it comes to location privacy.
4. *False Positives versus False Negatives:* In the context of digital contact tracing, a false positive occurs when an individual is identified and notified as having been exposed to COVID-19 when they, in fact, have not. A false negative occurs when an individual did come into contact with a COVID-19 positive person and was exposed, but was not identified or notified. Given the spatial accuracy and precision of geospatial technologies, both false positives and false negatives are likely to occur during

digital contact tracing. Both situations have important implications for the deployment of public health interventions and public responsiveness to these systems.

What are the technical capabilities and limitations of the geospatial technologies likely to be used in digital contact tracing?

While the geospatial technologies embedded in mobile devices can be used to trace or track the location and interaction histories of individuals, the current capabilities of these technologies are limited in ways that may impact the effectiveness of digital contact tracing.

Spatial Accuracy

To be effective, digital contact tracing systems must have the capability to identify either (i) epidemiologically meaningful interactions between individuals, or (ii) the location history of COVID-19 positive individuals. There are at least five technologies embedded in the majority of cellular devices that can be used in contact tracing – cellular technology, global navigation satellite systems (GNSS; e.g., GPS), WiFi, Bluetooth, and QR Code scanners (1). However, the spatial accuracy of each of these technologies is imperfect and varies across locations.

Generally, locations derived from cell towers are not precise enough (within 1-5 km) to identify meaningful contacts, particularly in rural areas with fewer towers. Locations derived using device GNSS have widely varying horizontal accuracies from perhaps less than 1 m to 20 m (5-7) and a vertical accuracy of around 20 m, which means they can potentially be used to identify contacts. However, GNSS is not accurate enough to identify high risk interactions between individuals. Moreover, GNSS accuracy varies with the physical environment (e.g., overhead coverage, urban canyons) and is less effective indoors (8). WiFi network access points can be used to infer both indoor and outdoor locations from device scans (9). Combining GNSS and WiFi data can improve location accuracy to <5m, but this also depends on obstructions and network density. Spatial interpolation and geoprocessing of WiFi signals can help improve the indoor positioning and tracking accuracy (10).

QR code is another technology that is being used to construct location histories. In this case, individuals will scan QR codes located at building or room entrances. While this system has high locational accuracy, the lack of automated detection can cause problems if users do not regularly scan codes. Failures to log codes can lead to extensive false negatives.

Many digital contact tracing plans intend to use the exchange of encrypted keys through Bluetooth to anonymously record the relative location of individuals. Bluetooth signals typically extend approximately 10-100 m around a device (11), and can produce accuracies of better than 1 m. However, Bluetooth-based tracing also creates the potential for false positives as devices as much as 100 m apart may exchange keys. Crucially, the performance of all of these location tracking technologies is impacted by environmental factors, which means that their ability to serve contact tracing objectives will vary with the geographic context in which they are deployed.

Indoor Locations

Americans spend about 87% of their time inside (2). Unfortunately, geolocation works best in an open field where there is a clear view of the sky, and indoor location technologies are more limited in both horizontal and vertical accuracy. Technology used for indoor mapping includes WiFi, Bluetooth, and cellular as well as embedded sensors (i.e., dead reckoning, magnetic matching, image matching, flickering LED, ultrasonic). However, with accuracy still limited, more research is needed into fusion techniques that leverage multiple data sources and ambient sensors (e.g. temperature, pressure, humidity, magnetism, illuminance, and audio) to obtain accurate locations (12). In some cases, these technologies may log individuals located on different floors of a building or in different rooms as interacting. Depending on transmission dynamics, these accuracy limitations may result in false positives, if the virus is being passed through close conversation, or false negatives, if the virus is being recirculated through an air exchange system.

Rapid Identification of Proximity or Interactions

Beyond the technical accuracy of locational measurement, there are several challenges to successfully deploying geospatial technology for digital contact tracing and COVID-19 management. First, if the intent of digital contact tracing is to catalog and monitor the interactions of n individuals in the system across time, the computational complexity and requirements to convert digital location data into interactions will be massive (on the order of n^2 for a single point in time). Even in a case where the contact tracing systems will be queried for the recent contacts of a COVID-19 positive individual, system outputs must be integrated into existing manual contact tracing systems. Second, because there is a need to minimize the delay in isolating suspected cases, the emergence of numerous state-run contact tracing systems operating in parallel may pose a challenge. As individuals resume normal travel patterns, many are likely to cross state borders and contact individuals from other states. If those contacts are recorded in isolated state systems, many potentially important contacts may be missed. Third, adoption will similarly be critical for success. Recent model-based research suggests that with appropriate levels of adoption, digital contact tracing can mitigate the spread of COVID-19 (13), but empirical evidence is needed to determine what percentage of the population needs to adopt a contact tracing system and what percentage of cases need to be successfully traced and quarantined. As such, technical solutions must be paired with health and social services for intervention when suspected cases are detected. Finally, there is a cost to false positives as repeatedly 'sounding the alarm' may lead individuals to ignore warnings and public health recommendations. Taking trip purpose and context into account may help reduce the false positives.

Social Media

One of the many additional sources of geospatial data that can be used to augment and improve the results of digital contact tracing is geotagged social media. Although Twitter announced the removal of precise geotagging in June 2019, general geotagging remains available, which allows Twitter users to tag a tweet with a related place, such as a restaurant, a neighborhood, or a city. In addition. Twitter users can continue assigning precise location coordinates to tweets in photo-focused tweets or by using third-party apps like Instagram to share locations. The challenges with using social media for digital contact tracing include that (i) very few percentage of tweets are geotagged (less than 1%); (ii). Twitter users do not represent the entire population and that most of the content is generated by a small percentage of high intensity users - 1% of Twitter users create 16% of tweets (14); (iii). social media also contains a high proportion of data that are not useful - 29.42% of Twitter data are noise (14). Still, social media has been shown to be useful for syndromic surveillance and could be a good approach for tracking city-to-city or neighborhood-to-neighborhood spread. Social media is also useful for early detection of crowd formation and could be leveraged to remove false positives by contextualizing suspected interactions detected from GNSS or Bluetooth.

Space-Time Prisms:

Geographic information science also offers several frameworks to integrate and make use of these many data streams. Perhaps the most useful framework for digital contact tracing is the space-time prism (3). A space-time prism identifies all possible travel paths between two locations that are constrained across space and time. Originally, space-time prisms were used to identify the space-time activity extent of an individual or potential space-time range for interactions among individuals, but the same concept can be used to partition mobility data and detect space-time interactions between people. One key research question for geospatial researchers is "does effective decision making have to rely on the finest granular data at an individual level?" In another words, is there a 'better' scale and resolution for us to make informed decisions without intruding upon user privacy? Space-time prisms can allow us to only look at possible interactions and do not require storage of all individual movement.

How Might Digital Contact Tracing Impact Privacy?

The privacy concerns raised by mobile location tracking technologies are well-documented in the literature (15-19), and the study of the privacy of digital contact tracing is now beginning (20, 21). However, numerous questions remain unanswered because digital contact tracing has not yet been widely introduced in the U.S. (22), and further research into their operational details is needed before their privacy implications can be fully understood.

Privacy concerns related to digital contact tracing revolve around issues of (i) notice-and-consent to location data collection and (ii) the risk of revealing the identity of an individual through their location history. Providing notice to an individual that their location data will be collected and receiving their affirmative consent to do so are at the center of protections of location privacy in the United States (23, 24). Mirroring notice-and-consent, Onsrud et al. (25) introduced eight principles related to the privacy and handling of geospatial data. These principles are similarly reflected in the GIS Code of Ethics (26). More recently, these principles can be seen in rights-based approaches to privacy like the signal code of Greenwood et al. (27), which focuses on crisis situations and argues that data privacy and security, data agency, and regress and rectification are fundamental rights that also facilitate crisis response.

It is unclear to what extent these principles will be adhered to by digital contact tracing systems that are still in development. At the moment, it appears that the download and use of contact tracing applications will be an individual choice. However, how contact data will be stored, transferred, shared, used, and combined with other data is not clear. Part of an individual's location privacy is understanding how their data will be used, and being notified when that use changes or new policies are put into place.

Even in situations where the majority of these privacy principles are maintained, the risk of identifying individuals remains. To preserve privacy, location data must be de-identified and are often aggregated in time and space. However, location data is difficult to fully anonymize. Even if an individual's identifying information (e.g., name, sex) is removed from the data, but their spatial information is left unaltered, it is often very easy to identify an individual. Research suggests that a small number of spatial-temporal locations is needed to identify a large portion of the U.S. population (28). Even when data are spatially aggregated, it is often possible to identify individuals. Golle and Partridge (29) suggest that when location data are aggregated to census tracts, but work and home locations can be inferred, half of the population can be identified as one of ten individuals. Incorporating demographic information can narrow this set to one. Digital contact tracing that focuses on relative location may remove some of these issues but at the same time may raise other concerns. Rather than knowing an individual's precise location in space, systems based on relative location have the potential to place that individual within their social network.

These issues raise a series of questions about the details of digital contact tracing. Questions related to data collection include: What type of data will a contact tracing application collect? What is the spatial accuracy of the data being captured by the application? How will location data be anonymized and spatially/temporally aggregated? Once collected, who will store and have access to the data? How will the data be used? And what are the limitations, if any, on the use of the data? Answering these questions will be key to assessing the privacy implications of contact tracing applications. Finally, questions about the lifecycle of location data will emerge. Will systems designed for pandemic response extend beyond the immediate timeframe? How will these systems be decommissioned once the pandemic has passed? Presently, there are few comprehensive answers to these questions.

What geospatial research is needed to develop and deploy effective and ethical digital contact tracing in the United States?

To create digital contact tracing systems that are both effective and ethical, further research is needed in a number of areas:

Indoor Positioning: Given the amount of time people spend indoors, it is essential that we develop technologies to map indoor movement so we can identify interactions between individuals in malls, office buildings, and retail stores. The way forward is to build on existing geolocating technologies and to fuse multiple sources of data. Spatial analysis methods and machine learning approaches can also be employed for improving positioning and tracing accuracy.

Reducing False Positives in contact tracing: The implications of identifying false positives and false negatives through contact tracing can be very high. While there exists a clear risk of false negatives, false positives can also trigger unnecessary quarantine, testing, and possible isolation, which are high-cost, high-stress events for individuals. Recurrent false positives are also likely to reduce public compliance with COVID-19 warnings and suggested interventions. False positives also carry a cost for public health agencies, as these agencies will likely use manual contact tracing resources to verify and contact potentially infected individuals. Beyond geolocation technology, there are tools that can help reduce false positives, such as social media, and it would be beneficial to focus research on false positive reduction in order to develop best practices and protocols.

Absolute versus Relative Location: Geospatial research typically focuses on absolute accuracy. However, in this case, it may be relative accuracy that matters most. Relative accuracy may be easier to map accurately, but errors may also compound. Research into relative accuracy of geolocation could expedite progress towards digital contact tracing.

Geomasking Methods: Personal trajectory data are key to digital contract tracing. There is a trade-off between locational privacy and geographic data accuracy and resolution. Obfuscation of point data, or geomasking, is a possible solution that aims to protect privacy and maximize preservation of spatial patterns. Trajectory data, with multiple locations recorded for an entity over time, is a strong personal identifier. We need to develop advanced geomasking methods to balance between privacy and spatial patterns. Grid masking and random perturbation are two promising methods applied to GPS trajectory data (30),

Computational complexity: While the idea of using GNSS and location technology to identify when and where people are in close proximity is conceptually simple, the computationally complexity should not be dismissed. Research is needed to identify the data streams, integration procedures, and conceptual frameworks that optimize the use of computational and human resources.

Contact Bubbles: As social distancing is relaxed, researchers should consider how to map bubbles or groups of people who trust each other to be virus-free. A bubble may include family members, room-mates, or other trusted close contacts. The bubble concept is already a part of how New Zealand is addressing COVID-19. Effectively, contact with one member of a bubble would be equivalent to contact with all members of the bubble. Within geospatial data frameworks, bubbles could be considered an object, and techniques for registration and monitoring interaction of bubble objects would help manage digital contract tracing using the same spatial unit as the social distancing process.

High Resolution Mapping of Risk: Another approach to tracing contact is to use high resolution maps. If we can develop a public COVID-19 risk map that is high resolution in space and time, individuals will be able to trace their own possible contact with COVID-19 positive people. Building surveillance programs that test and trace movement of high risk sentinels, first responders and front line workers, may allow high resolution COVID-19 risk mapping.

Integrating the Digital and the Analog: Digital contact tracing will likely be used to augment existing forms of contact tracing that have proven effective in many forms of disease control. Because they are only now being developed, we do not yet know how best to link digital contact tracing with these existing systems. We also do not know how best to link different systems developed and deployed in different states. At the same time, we do not know how to encourage enrollment or adoption of digital contact tracing systems by individuals. Without a better understanding of each of these issues, digital contact tracing is unlikely to be as effective as anticipated.

Societal Implications and Privacy: While the majority of research effort will likely focus on improving the efficiency and accuracy of digital contact tracing, research is needed into the social implications of these systems. Digital contact tracing raises a number of privacy and ethical concerns. While the technologies themselves are value neutral, how they operate and are deployed has important implications for the rights of individuals.

At the same time, we need to recognize that not all individuals own cellular phones or other mobile devices capable of operating digital contact tracing systems. In fact, many individuals who would likely not be digitally traced include those in the groups most vulnerable to COVID-19 such as the homeless or elderly. If these groups are excluded from contact tracing efforts, public policy interventions may not direct resources where they are needed most. Research into how to account for these deficiencies is an area of critical need.

Conclusion

The vast scope of COVID-19 pandemic challenges our lives and livelihoods in all dimensions. To be successful and sustainable, any solutions to pandemic problems must serve humanity. Geospatial researcher have the knowledge and expertise to meet this challenge and need to leverage these assets in the fight against COVID-19. As one example, geospatial experts have developed many methods for studying phenomena that move and spread through space and time and can support a broad range of efforts, including digital contact tracing. Because many challenges remain, the geospatial community should be pro-active in overcoming methodological barriers to digital contact tracing and should lead conversations that advocate for an understanding of privacy issues and challenges that will accompany technology as it is deployed. While no single solution is ideal in all respects, a digital contact tracing system operated at the national level in a transparent manner that is consistent with our privacy and ethical values by a trusted public health agency is perhaps most likely to provide the scale needed to meet the current challenge.

Many solutions for contact tracing are being developed by the information technology sector, with companies like Apple and Google leading efforts to provide digital solutions. While those in the academy can provide expertise and support to these efforts, they are also positioned to reflect on the broader societal implication of digital contact tracing systems and indeed the wider response to COVID-19. This role includes the responsibility to ensure that the best current understanding of the potential issues, limitations, and implications of these systems are accurately presented key decision makers, whether or not they wish to hear them. Lastly, those in the academy have a major role to play in cataloging and contextualizing how we as a society respond to COVID-19. Ensuring that we collectively fulfill the educational mission of our respective institutions and positions is key to ensuring the lessons for this pandemic are shared with the next generation, so they might be in a better position to make well-informed decisions that improve global health and preserve human lives.

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