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Apps and Infrastructures – a Research Agenda

ARTICLE INFORMATION

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ABSTRACT

In this special issue editorial, we introduce a research agenda for empirical app studies. First, we introduce the three main strands of scholarship that have engaged with (mobile) apps and infrastructures so far. This enables us to position the contributions to this special issue at the cutting edge of the research on apps and infrastructures. We present our theoretical perspective on the infrastructural situatedness of apps to foreground how apps are always relational and, therefore, situated in a technological as well as social and cultural sense. From this perspective, we outline the contours of the *app/infrastructure stack*, which proposes to account for the hierarchical layered structure of apps and infrastructures, including their various interrelations and interdependencies. Finally, we derive six emerging research themes for future app studies based on the eight contributions included in this special issue that we hope will motivate further innovative and critical research into apps and infrastructures specifically as well as into computational culture in general.

Introduction

In 2018, the number of mobile apps downloaded worldwide exceeded 194 billion, with consumers spending more than \$101 billion USD in the two leading app stores operated by Google and Apple.¹ With China accounting for nearly 40 per cent of total consumer spend, the app economy has become a truly global economic phenomenon. In terms of their functionality, these apps cover a wide range of areas: from simple digital calculators and flashlights to apps for banking and dating, to even apps which are more complex. These more complex, multi-purpose offerings comprise a handful of 'super apps' such as WeChat and Facebook Messenger, which increasingly resemble, and have even begun to rival mobile operating systems.² For their part, users spend an average of more than three hours per day on mobile devices.³ Consequently, presently, mobile advertising accounts for 65 per cent of all digital advertising spend in the United States, surpassing linear TV advertising.⁴ The world's largest, multi-billion dollar businesses (e.g. Google, Facebook, and Uber), as well as entire market sectors (e.g. social networking and communication, urban transport, gaming, and news), have become significantly dependent on mobile apps and distribution channels.

In sum, apps have become a culturally, socially, and economically significant software form, residing in our pockets, offices, stores, homes, and cars.⁵ Most of today's apps are designed to run on smartphones or other mobile devices but provide functionality associated previously with other software forms.⁶ Apps are increasingly part of our everyday lives, embedded in mundane objects, devices, structures, and social settings. They may appear as discrete software objects, but as we suggest in this special issue editorial, they can only be understood by attending to their various entanglements. Therefore, they are more than just software programmes; they represent new and specific ways in which software is developed, tested, packaged, promoted, distributed, monitored, monetised, downloaded, integrated, updated, stored, accessed, archived, interpreted, rated, reviewed, and, ultimately, used.

The contributions to this special issue propose an understanding of apps that focuses on their socio-technical embeddedness and situatedness by foregrounding the technical and material dimensions of apps and, or in relation to, infrastructure. Each of the contributions to this issue address the multiple relations apps enable and which support apps on a technical and non-technical level (e.g. cultural, social, political, and economic). The authors engage with various mobile apps and app collections from technical, critical, political-economic, and praxeological perspectives to detail how the relations of apps

often stand in for and can reveal much about the interests and strategies of connected stakeholders as well as their implications. In this special issue editorial, we advance a research agenda for studying apps empirically regarding their infrastructural relations. Moreover, not only is such an approach relevant to the study of apps, but it is also relevant to the study of computational media in general as it spells out how research can take its social, technical, and material properties on an empirical level seriously. However, apps come with particular challenges as their infrastructural relations are often obscured if not obfuscated.

With this piece, our aim is to introduce a particular outlook for the study of apps as a significant software form in contemporary computational culture. In the following sections, first, we outline the three main strands of scholarship that have engaged with apps and infrastructures so far, before introducing the authors' contributions. This enables us to advance app studies as a cross-cutting area of emerging interdisciplinary research interests. We distinguish multiple analytical levels for app research and conclude with six themes for future research into apps and infrastructures.

Background: Strands of App Research

Despite apps being ingrained fully in the everyday practices of billions of users around the globe, app studies, whether conceived as an approach, a research area, or a (sub)field is only just emerging. That said, studies about the economics, usage, and software of mobile apps are proliferating. In this section, we introduce three strands of research that are concerned with apps primarily. An overview of previous scholarship suggests that app research – like computational research more generally – is highly interdisciplinary and draws on several adjacent research areas, including (mobile) media and communication studies, (information and media) infrastructure studies, software studies, social media and platform studies, business and management studies, and computer and information systems research.

The first strand of app research considers apps as 'mobile media' and is concerned primarily with themes of mobility, location, and mobile communication. Mobile media scholars consider mobile apps as a form of locative media transforming and generating new forms of communication and sociality, places, and publics, through the affordances and practices associated with mobile artefacts.⁷ This body of work is positioned primarily in the fields of media, communication, and information studies, and therefore, spans across

the humanities and social sciences. Particularly prolific has been a collective of Australia-based scholars who defined the initial contours of mobile media and communication studies.⁸ While their work presents a systematic effort to theorise mobility in communication and, sometimes, includes general questions about app economies and infrastructures of mobile media, attention is directed predominantly at apps as compartmentalised software applications and their relations with interfaces, cultures of use, affect, bodies, and locales.⁹ Launched in 2013, the journal *Mobile Media & Communication* serves as another good example of research that tackles the wider issue of mobility and publishes interdisciplinary research on, e.g. dating apps, local and national cultures of app use, and mobile methods. Here, we also see contributions that suggest a material approach to apps by tracing the physical infrastructures supporting the connectivity and locality of mobile media as well as the power dynamics behind them.¹⁰

The second strand of app research focuses on the business of mobile media use and specific user practices that are supported, structured, and monetised through mobile apps. This includes critical political economic research that considers, e.g. the commodification of app-based data and mobile media practices through advertising.¹¹ Because of their economic impact, increased attention is being paid to app monetisation, app advertising, and app stores in the fields of business studies and economics. Here, less attention is paid to critical questions of labour, capital, or power, and instead the second strand discusses app innovation,¹² app stores and rankings,¹³ or how apps are positioned within 'multi-sided' or platform markets.¹⁴ Recent work in management studies builds on work in organisational sciences and information systems research and addresses infrastructural questions concerning the roles of institutional actors within information 'ecosystems' such as app stores.¹⁵ Despite the clear relevance to infrastructural approaches to apps, the first and second research strands – barring exceptions – have seen very little dialogue and are evolving along different disciplinary lines.

The third strand of app research is part of a recent wave of attention given to media infrastructure, or the 'infrastructural turn' in media studies and adjacent disciplines.¹⁶ These approaches concern the technicity and materiality of internet infrastructure and signal traffic,¹⁷ examining how apps are infrastructurally situated by 'sniffing' network connections and data traffic flows, detecting app package contents, revealing design patterns and principles, and identifying platform logics that ultimately form the broader conditions of possibility for infrastructures and supported practices.¹⁸ Therefore, this strand

shifts the material focus from physical network infrastructures to software-based infrastructures, e.g. recent case studies of Facebook Messenger and WeChat demonstrate that apps are able to gain infrastructural properties.¹⁹ This research builds on software studies, e.g. by developing methodologies to account for the different scales at which software operates,²⁰ and on platform studies, by foregrounding the programmability and multiple stakeholder groups of hardware and software platforms.²¹

Crucially, this third strand maps onto our focus in this special issue on the infrastructural situatedness of apps. We conceive situatedness not only in the geographical or locational sense of the term, such as in the first strand of mobile media studies, but also, and especially, in a more directly relational sense, i.e. taking the infrastructural situatedness of apps seriously involves attending to apps' relations to one another and to other things, practices, systems, and structures. This approach allows for greater sensitivity to questions of relational power, such as economic, data, platform, and infrastructural forms of power. Thus, not only are apps situated in a technical or material sense, but also they are situated in an economic and institutional sense and can be related to other objects, devices, systems, infrastructures, clouds, and environments, both by humans and nonhuman actors. The next section details what it means to study the relationality of apps and infrastructure and to conceive of apps as a specific software form.

The Relationality of Apps and Infrastructure

Central to a technical and material perspective on the study of apps is the notion that apps are not stand-alone objects but are inherently entangled in multiple socio-technical assemblages, are part of diverse environments, and operate on different levels,²² e.g. the app stores that are part of mobile operating systems determine the conditions for users to access, download, purchase, review, and rate apps, while they afford app developers a means to deploy, promote, distribute, and monetise apps. App developers further employ a variety of sanctioned and third-party data and developer tools, such as application programming interfaces (APIs), software development kits (SDKs), and integrated development environments (IDEs), such as Google's Android Studio and Apple's Xcode. These developer tools are obligatory if one wants to access user data, the software-based functions of mobile operating systems, as well as sensors and other functionalities integrated into mobile devices.

The app development and distribution described here are a rather recent

phenomenon. A decade ago, mobile phones were far less accessible to third-party developers. Many scholars point to Apple's 2007 introduction of the iPhone as the key moment which ushered in the smartphone era, which coincided with the rollout of 3G connectivity.²³ The first iPhone only contained Apple's native apps, which developers criticised. A few months later Apple launched an SDK, enabling third-party developers to build on top of Apple's mobile platform, turning the phone into a networked and programmable device.²⁴ We should note that Apple was certainly not the first cell phone manufacturer to operate a mobile app store. Already in the 1990s, the Japanese i-mode project had pioneered the ideas of mobile applications, third-party application development, as well as setting up 'multi-sided markets' that allowed for revenue-sharing business models.²⁵ The opening of the iOS App Store in 2008 marked a boost for Apple as the company followed a distinctive strategy of offering a 'censored marketplace', choosing centralised app distribution, curation, and billing, over less selective approaches.²⁶ Therefore, the introduction of the smartphone marked a fundamental shift in the mobile ecosystem. Throughout the 1990s, telecommunication network operators (e.g. Orange and T-Mobile) and handset manufacturers (e.g. Nokia, Motorola, and Ericsson) dominated the mobile value chain.²⁷ The introduction of the iPhone and the subsequent popularity of Google's Android mobile operating system reoriented the mobile ecosystem towards software development and distribution, controlled via mobile operating systems, app stores, or a combination of both.

What Is an App?

To some, apps have a rather narrow meaning: a small programme for a mobile device, downloaded from a central distributor such as an app store.²⁸ Similarly, an app is seen as a stand-alone, self-contained software application and is argued to be becoming 'the organizing logic of the Internet' rapidly.²⁹ From a political economic perspective, apps are 'a specific manifestation of the software commodity', similar to the MP3 format for music.³⁰ We follow the understanding of apps as application software commodities but suggest a broader perspective. From an infrastructural perspective, apps cannot be accounted for without considering their broader operating environments. Over the past decades, software applications have evolved from shrink-wrapped products to box to cloud-based services (e.g. PaaS, SaaS, and IaaS), which have profound technological and economic implications. As we will argue in more depth in the next section, the app is best seen as a layer within a larger computing stack, which not only serves as an interface between a user and its environment but also especially serves as an interface to cloud-based services and larger

databases.³¹

Therefore, our approach considers apps to be inherently distributed, regardless of whether one studies apps regarding their production, distribution, consumption, or reception. As Miller and Matviyenko argue, 'An app, itself an assemblage, also enters other technological assemblages' and, therefore, could be considered in relation to other things.³² From a purely technical point of view, the mobile app exists as a relational software entity which is being assembled at 'runtime' – when an app's compiled code and resources are loaded when it interfaces with the (technological and non-technological) environments in which the app instance is running.³³ This computational process concerns internal as well as external resources which the app requires, such as access to operating system functions or to remote data storage and cloud servers. Therefore, the app is a specific historical configuration of the relationships among hardware, software, and services.³⁴

From a sociotechnical point of view, not only is an app programmed automatically to seek network connections and check for software updates in an app store, but it typically also customises and localises the experience for each individual user. As a result, the mobile app (and the app user) is 'tethered' to, and variously dependent on, a myriad of remote services, systems, and structures, without the user necessarily knowing exactly when, how, and where connections are made.³⁵ This is particularly true for apps which contain advertising technology, most of which do. Consequently, by opening an app, a diverse and complex series of data transfers are initiated.³⁶ In this way, Zittrain calls attention to the political economy of apps by stressing their relationality and contingency,³⁷ foregrounding the emerging power dynamics between apps and the various for-profit platforms to which they are connected. From an economic perspective, apps are not only contingent on platforms but have also become contingent as commodities, as their developers favour business models which demand apps to be updated and altered continuously.³⁸

Following this economic logic brings us to a techno-material point of view that mobile apps, similar to any other new media and software forms, are inherently modular and, again, relational.³⁹ In practice, most apps situate themselves through explicit and implicit forms of customisation while simultaneously obscuring their distributed nature and the infrastructural dependencies they invoke. This obfuscation or 'black-boxing' of their modular composition is often highly strategic on the part of developers as it hides the for-profit actors primed to derive value from app usage, and most importantly, the data flows running

through them – as is common for many contemporary software forms. Therefore, to comprehensively and critically study apps, one needs to account for the multiple social, technical, and material layers beyond the user's default experience.⁴⁰ This means moving beyond the graphical user interface towards a recognition of the software interface which allows us to engage with the techno-cultural and political economy of apps, its multiple stakeholders, and associated data infrastructures.⁴¹

What/When Is an App Infrastructure?

Apps exist fundamentally in relation to infrastructure as they are embedded in multiple environments and operating systems. As Star and Ruhleder have argued, infrastructure is commonly presented as a substrate: 'something upon which something else "runs" or "operates"', which presents it as 'something that is built and maintained, and which then sinks into an invisible background', positioning it as a 'fundamentally relational concept'.⁴² Therefore, they asked '*when* – not *what* – is an infrastructure'.⁴³ When people imagine infrastructure, they often focus on their physically tangible aspects. However, contemporary app infrastructures are decidedly not purely physical. They are increasingly made of layers of software, stacked on top of one another. As Bratton has observed, we are dealing with a 'multilayered structure of software protocol stacks in which network technologies operate within a modular and interdependent order'.⁴⁴ Similarly, Fagerjord notes how these hardware and software layers made the labour associated with app production and maintenance only more efficient. Therefore, instead of ignoring the infrastructural dimension, software studies approaches should examine the power distribution among these layers critically.⁴⁵

This special issue contributes to the 'infrastructural turn' in media and communication studies which focus on how digital platforms are taking on infrastructural properties, and conversely, how infrastructures become platformised.⁴⁶ All the contributions to this special issue depart from the materiality or 'stuff' of apps to develop adequate points of entry, or methods, for the description and analysis of apps and infrastructures.⁴⁷ As these contributions suggest, there is no privileged scale for this approach: relevant points of entry may be located anywhere from the physical components of a mobile device to large-scale commercial ad-serving infrastructure. Thus, the study of apps extends into the adjacent area of study of computational culture and similarly requires a technical and material understanding of infrastructure. Because of these multiple entry points, it is important to explicate the multiple layers of the object of study: how the app is embedded or 'sunk' into other

(already existing) structures and systems, which activities and practices it supports, and when certain aspects of the infrastructure which are normally invisible, become visible. Questions such as these foreground not only how mobile apps are governed and controlled by mobile platform owners, but also these questions foreground their broader social, political, economic, and cultural consequences. Next, we advance this infrastructural perspective and outline a set of specific layers associated with app infrastructures which enable methodological and empirical studies.

The App/Infrastructure Stack

When taking an infrastructural approach to the study of apps, what are the relevant units of analysis and how do they relate to one another? Moving towards a research agenda, we distinguish seven levels of analysis or points of entry across what we call the *app/infrastructure stack*. It describes the hierarchical layered structure of software and infrastructure – and the various interrelations and interdependencies between elements and layers – needed to support an app such that it ‘runs’ or ‘runs on top of’ a platform (e.g. Android, iOS, Amazon Web Services, and Facebook Platform). Consequently, the levels and their interrelations provide entry points for examining the distribution of power throughout the app/infrastructure stack, which is further relevant to the study of computational culture in general.

(i) On the *physical* level, we consider the various hardware sensors added onto smartphones or other mobile devices, which are increasingly important to an app’s routine functionality, such as for motion and position detection, navigation, and monitoring air temperatures.⁴⁸ Although most on-device sensors are hardware-based (i.e. with physical components) there are also software-based sensors (i.e. they derive data from multiple sensors), such as gravity and rotation vector sensors, which are not physical components but may mimic them.⁴⁹ Additionally, we include the physical dimensions of media infrastructures in general.⁵⁰

(ii) On the *system* level, we consider the Android and iOS operating systems, which enable different kinds of functionality due to their unique platform architecture design, governance framework, and data strategies.⁵¹ This level encompasses integrated system-level services which typically come pre-installed by the device manufacturer (e.g. BlackBerry, Samsung, and Windows Phone), which highlights the strategic position of software distribution platforms, most notably the app stores. Actually, many system-level services

are routine background tasks which do not have any graphical component and may continue to operate long after an app is closed – processing, downloading, and uploading data in the background.⁵²

(iii) On the level of object *code* and programme *execution*, it is relevant to inspect the runtime environments of the operating systems and apps installed on mobile devices (e.g. Android runtime, Objective-C runtime for iOS), or how an app's object code (e.g. in Java or Objective-C) is translated into machine-readable 'native' instructions, which is typically reflected in the formats and standards of app (store) package files (e.g. .apk for Android and .ipa for iOS).⁵³ Previous research on gaming platforms has demonstrated how a runtime environment defines the conditions and limits for 'running' an application like a game.⁵⁴ When an app needs to use resources or information beyond those limits, it needs to request the appropriate permissions from the user. Today, such permissions are normally listed in an app manifest file (e.g. AndroidManifest.xml for Android and Info.plist for iOS) by the requirement of the app stores, and in case of Android apps, they are requested from the user at runtime.⁵⁵

Additionally, these files declare an app's device compatibility and backward compatibility for previous app versions. Methodologically, this layer foregrounds a crucial distinction for app studies research, namely, between static and dynamic modes of analysis, i.e. whether one studies an app as a software package (e.g. as source code) or as its 'runs' or 'operates', which then situates the app in relation to users' media practices.⁵⁶

(iv) On the *network* level, it is important to detect, analyse, and follow an app's network connections, inbound and outbound data traffic flows, and the services (or organisations, countries) establishing those connections. Whether network traffic between apps and various infrastructures are encrypted securely or not matters greatly for a user's data protection and privacy (although encryption in itself does not prevent interference by a malicious interceptor). Privacy International has reported that at least 61 percent of apps tested for a report transferred data to Facebook at runtime automatically, in one way or another.⁵⁷ On this layer, we further consider the different forms of connectivity, the pace of automatic software updates, the politics of protocols and standards (e.g. GSM, CDMA, CSMA/CA, and GPS), internet speeds, and other aspects of network infrastructure.⁵⁸

(v) On the app (store) *package* level, we encounter specific data formats and

syntax, which encourages us to engage with the technical aspects of app- and data-structuring practices. For instance, we can study the official and third-party development tools to determine the relationship between a platform and its developer ecosystem, including governance frameworks and best practices for developers (e.g. Android Studio and Xcode for iOS apps). Due in part to these development tools and environments, there are significant technical differences between apps for different platforms, between their architecture design, and subsequently, their unique cultures of connectivity and development. On this layer, we also consider the role of APIs, SDKs, software object classes and libraries, app templates, and the programming languages used to develop apps. Additionally, app store review guidelines specify the various safety, performance, design, and legal requirements for apps listed in app stores.

(vi) On the level of *in-app services*, it is worthwhile considering how services continue to shift the concept of software,⁵⁹ foregrounding an already diverse and still growing number of connected services for things such as authentication and login, monetisation and mobile app advertising, cloud-based data storage and computing, content delivery networks, and tracking technologies. At this level, we further encounter app interface design, (dark) design patterns, behavioural manipulation, and standardised front-end development practices. Moreover, at this level, we encounter APIs, which are of particular importance because they determine the rules of connectivity and data exchange among different endogenous and exogenous system components, either on the same layer or across multiple layers, e.g. an Android app interacts across the entire Android stack,⁶⁰ which includes not only internal layers but also includes a myriad of external in-app services.

The layers of this app/infrastructure stack are not neatly separable from one another. When thinking critically about software stacks, and about the app/infrastructure stack, in particular, hierarchical order matters greatly. It is not trivial that most mobile apps run 'on top of' – rather than, say, 'underneath' – partly or wholly proprietary software stacks and inside secure, isolated 'sandbox' environments.⁶¹ Similarly, it is not coincidental that platform operators increasingly turn towards infrastructure. Therefore, turning things around, 'infrastructural inversion' is a critical research strategy for uncovering how app infrastructures are embedded in everyday practices and structures, and how these, in turn, evolved with those infrastructures. By bringing app infrastructure to the fore as the main object of study, through disassembling apps or by detecting traces and data traffic flows, we learn about the

layeredness, interconnectedness, and embeddedness of apps. Due to their increasing interoperability with other services and systems, mobile apps blur the distinctions between applications and infrastructures, with certain components being more infrastructural compared to others. Further complicating a clear-cut separation between layers is the contingency of platforms and apps, which both evolve in iterative, responsive cycles: new apps rely on existing, 'legacy' infrastructures and simultaneously inspire the development of new infrastructures which enable certain apps to proliferate by reducing the production costs for similar apps.⁶² In short, these analytical layers foreground the various intricate technical and material dimensions of how apps are situated. Insights gained from studying these different levels are also relevant to other software forms and the study of computational culture in general since computational objects are similarly layered and situated.

Six Themes for Future App Studies

In this final section, we introduce six key themes which are central to this special issue. They are not only intended to summarise the contributions included in this issue but are also intended to formulate focus points for future app studies research.

(i) First, several contributions engage with the *imaginaries* and visions of apps. Since mobile apps are still a relatively new commodity form, they are inevitably part of the visions, projections, plans of developers, users, and other stakeholders, who imagine for what apps can, should, and could be used. For instance, Théo Lepage-Richer argues how, in the case of Snapchat, vision can be understood beyond its meaning as computer vision only, namely, as an infrastructure of, but as making certain futures more 'visible' and, therefore, more likely than others. Michael Dieter and Nathaniel Tkacz discuss imaginaries pertaining to the experience of 'security' and the 'securitisation' of experience. In her work on Axon's policing platform and its related apps, Stacy Wood argues that these infrastructures co-produce imaginaries around the future of policing. Johannes Paßmann discusses the imagined affordances of the infrastructures and platforms underpinning mobile apps and the stabilization of features through a historical study of experimentation around early retweeting functionality. Relatedly, Carolin Gerlitz, Anne Helmond, Fernando van der Vlist, and Esther Weltevrede point to apps which seek to revive former platform functionality or imagine and build new ones, even if that is not allowed by the platform in question. Jeremy Wade Morris and Austin Morris detail how rhetorics of success and failure have both become central to app store infrastructures.

Finally, Rowan Wilken, Jean Burgess, and Kath Albury draw our attention to the business models and imaginaries of dating apps through a critical analysis of their business plans, patents, and ownership models. All these contributions encourage us to unpack further the imaginaries which entangle apps and infrastructures.

(ii) Second, the contributions advance our understanding of apps as *intermediaries*. An infrastructural perspective on the study of apps inevitably challenges the perceived centrality and discreteness of an app, since it is always connected to other components, objects, and systems. In their contribution on the infrastructures of intimate data, Esther Weltevrede and Fieke Jansen suggest that apps operate as the 'in-between brokers' between heterogeneous data sources, devices, social media platforms, advertising services, and other infrastructures. Similarly, Paßmann focuses on apps as mediating between users and use practices on the one hand, and platforms and development practices on the other hand. Additionally, Gerlitz et al. point to the central role of social media platforms as infrastructures which purposely facilitate such forms of intermediation between use practices, developer practices, and platform strategy. Finally, Wood shows how Axon's policing platform serves as an intermediary aggregator of data from disparate law enforcement agencies, thereby creating infrastructural dependencies on the platform.

Precisely due to their role as intermediaries, apps have become increasingly contingent and inherently unstable, and they are not usually designed to last for longer periods in the first place. Therefore, they require continuous maintenance and repair. Morris and Morris illustrate how the logic of failure and app discontinuation are crafted into app stores, which, Weltevrede and Jansen note, is also due to the politics of platforms, operating systems, and APIs. As Dieter and Tkacz contend, the commonly encountered, iterative cycles of usage, monitoring, testing, and rapid development increasingly entangle developers and users in the design of the 'user experience', which in turn comes to reflect the evolving programmability of a platform.⁶³ In these cases, apps are the distributed accomplishment of infrastructures, users, developers, institutions, and practices, while simultaneously having generative characteristics commonly associated with infrastructures, or becoming infrastructure themselves.⁶⁴

(iii) Third, the contributions explore how apps and infrastructures partake in the *redistribution of value and economic power*. As a key revenue generator and economic form, apps and app stores contribute to a redistribution of value by introducing new and specific forms of monetisation. App stores remain the

primary and most important infrastructural services for the monetisation of apps, sanctioning revenue creation via mobile payment, transaction, and subscription fees, in-app purchases, data sharing and licensing, and mobile advertising.⁶⁵ Due to their intermediary position, the commodification of users' attention, behaviour, and personal information extends far beyond app stores. Both Paßmann and Gerlitz et al. contend that apps can serve as testing grounds for platform innovation which negotiate users' needs while aiming to intensify engagement. Dating apps, Weltevrede and Jansen show, highlight the immense value of, or commercial interest in, intimate data forms, which describe users' daily routines, habits, inclinations, and environments, all of which are part of the business models of Tinder, Bumble, and Grindr, as outlined by Wilken, Burgess, and Albury. Similarly, (neo-)banking apps, Dieter and Tkacz argue, do not merely structure and process monetary transactions but afford new action paradigms and 'scripted economies of the everyday' by creating intersections between various data forms and everyday life. Finally, Morris and Morris examine the 'para-industries' which form around apps and app stores, which reap the benefits from app stores' failure in promising app visibility.

(iv) Fourth, the contributions explore the specific relationships between *user practices* and *data practices*. An infrastructural perspective on apps shifts our attention from user and media practices to data practices.⁶⁶ Importantly, practice-based approaches, which put user, media, and data practices at the centre of analysis, can cut across and involve multiple layers of the app/infrastructure stack. Several contributions argue that user practices cannot be accounted for without also attending to datafication and calculation. For instance, Wood analyses the emergence of 'platform policing' by pointing to the transformations of policing practices as they are increasingly recorded, structured, managed, and directed by apps and platforms. Lepage-Richer's contribution focuses on visual and sensor-based data capture and analysis regarding economic interests, habits, and practices. Weltevrede and Jansen introduce a methodological perspective on the study of data infrastructure supporting data and dating practices. Wilken, Burgess, and Albury develop a political economy of communication approach to dating apps and their integration with data markets. Morris and Morris unpack how formerly individualised software development practices are now part of more controlled environments by app stores, including through standardised development tools. Additionally, several contributions demonstrate how app studies research practices could benefit from a combination of quantitative and qualitative strategies to enable situative modes of enquiry.

(v) Fifth, the contributions engage with the *heterogeneity of datafication*. The large number and variety of apps and the data practices afforded by them encourage us to unpack the heterogeneity of data forms and formats further: from device-level sensor data to app code to network traffic data to API and GUI interface-level data to 'user journeys' to in-app behavioural and services data. By focusing on the heterogeneity of app-based data forms, app studies scholars could contribute to critical data studies.

Various contributions concern the multiplicity of device-based and sensor-based data forms which capture user behaviours, practices, and environmental information. Lepage-Richer details how computer vision technologies operate at a device level, arguing how Snapchat's vision technologies are not so much designed to capture how things appear in the phenomenal world but rather the prioritisation of what should be detected and recognised. Others touch upon the data work which is needed to render app data portable, interoperable, and ultimately commensurable, such as in the cases of policing (e.g. Wood), dating (e.g. Weltevrede and Jansen, Wilken, Burgess, and Albury), and banking (e.g. Dieter and Tkacz).

(vi) Sixth, the contributions advance *research practices* and *sources* for infrastructural inversion. The proliferation of data forms and formats also calls attention to the methodological affordances and challenges of app studies research. Among the most pressing challenges is the contingent nature of apps, app stores, and platforms, which frustrates historical approaches (e.g. Paßmann) as much as contemporary ones (e.g. Gerlitz et al.). Additional challenges concern accessing, running, and reconstructing the user, media, and data practices of current and historical app versions, as well as their current and historical infrastructural embeddings and environments (e.g. entanglements with social media platforms). The contributions respond to these challenges by experimenting with new research practices and heterogeneous sources. In their contribution, Gerlitz et al. develop a methodological approach to study the relations between apps and popular social media platforms beyond APIs, using Google Play and Apple's App Store as points of entry. Weltevrede and Jansen repurpose methods of computer network security, while Wilken, Burgess, and Albury perform a critical reading of trade sources to examine dating data markets. Across all the contributions, we find resourceful uses of app-related patent applications, business plans, interface elements, app details and descriptions in app stores, technical relations between apps and social media platforms, and industry sources such as authoritative technology blogs which write about apps and app stores. Such trade sources, Wilken, Burgess,

and Albury note, are vital because it is difficult to obtain reliable corporate data sources.

Since the objects of study as well as the related user and developer practices are unstable and change continuously, it is increasingly becoming difficult to 'follow the methods of the medium' as a research practice.⁶⁷ Yet, the distinctive ephemerality of apps can also be sought out and repurposed through more experimental methodological practices which can complement 'API-based research',⁶⁸ e.g. by drawing on multi-situated approaches to app studies.⁶⁹ On the one hand, these efforts can be aimed at describing apps and infrastructures, and their specific cultures, logics, and mechanisms. On the other hand, they can be aimed at learning to work with those apps and infrastructures – learning to notice things which are specific to apps to understand their forms, their embeddings, and their relationships to other things, i.e. closely observing and exploring the affordances of apps in their various 'native' environments enables research *about* as well as *with* apps and infrastructures.

Each of the contributions explore and present research practices which are sensitive to the relations between apps and their infrastructures. They attend to the technical and material dimensions of apps and infrastructures as well as the practices they support. They refuse to simply 'follow' the app, the company, or the user; rather, they are attentive to imaginaries, intermediaries, the redistribution of value and economic power, the evolving relationship between user and data practices, the heterogeneity of data forms and formats, and advance research practices and materials. We hope that future app studies research addresses these challenges and continues to advance innovative and critical enquiries into the app/infrastructure stack.

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