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Leveraging map use context for advancing cartography in the 21st century

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Abstract: Mobile maps are an integral part of our daily routines, serving a variety of purposes in different environments. Designing maps for different use situations is essential for a user-centered and context-aware approach. Previous research has explored map use context and context-aware mobile maps from interdisciplinary perspectives. This paper aims to consolidate and unify existing research on context in cartography and related fields, identify current challenges, and propose ways to advance context-awareness for designing mobile maps. We present a map use context taxonomy that provides an overview of context elements, possible context-sensing methods, and corresponding application fields. We invite the cartographic community to expand on our proposed context taxonomy and explore the extensive field of context acquisition methods, applications, and related literature for advancing research on map use context.

Keywords: context, context-awareness, map use, mobile maps

1. Introduction

Mobile maps are becoming an indispensable aid in modern life. They serve a wide range of purposes, such as self-locating, searching for places, planning journeys, or wayfinding, and are used everywhere. The abundance of geographic base data and geographically referenced data on the Internet and social media substantially contribute to the pertinence of mobile maps. As a result, the environments in which mobile maps are used and the purposes they serve have multiplied. We can now effortlessly move between locations while using maps for different tasks, at different times and places. To better support and meet the general needs of mobile users in their everyday spatial tasks and map use situations, accounting for the context of map use is fundamental to a user-centered and context-aware design process.

Previous research efforts have focused on map use context and context-aware mobile maps from various perspectives. The interdisciplinary nature of the research landscape has resulted in a range of research approaches to this topic. In this paper, we aim to consolidate existing and interdisciplinary research on context in cartography and related fields and seek to align them in a unifying scheme to create a more cohesive understanding of context for mobile maps. We further aim to identify current challenges and propose ways to advance context-awareness for future map designs and mobile cartography. Although we recognize the importance of including context in the design of all types of maps, our paper primarily focuses on the pressing need for context-awareness in the mobile use case. Nonetheless, we acknowledge that studying and including context in the design of all map types is essential.

2. Context and maps

Recent developments in mobile technology have provided the ground for the cartographic community to increasingly conduct research on mobile cartography and mobile context. Mobile systems and context have their foundation in computer sciences, with Abowd et al. (1999, p. 305) providing a widely used definition of user context: “Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves”. The definition, sensing, and modeling of user context provide the ability to determine necessary and relevant information for establishing context-aware and adaptive systems and interfaces (Abowd & Mynatt, 2000).

During the early 2000s, the cartographic community established fundamental principles for transferring the concepts of context-awareness and adaptivity to mobile cartography (Meng et al., 2005). Reichenbacher (2003) provided the basic principles of mobile map use context and adaptive mobile maps. Since then, various research efforts have emerged, discussing context and context-awareness to varying degrees and from different perspectives.

Predominantly, the development and research on Location-Based Services (LBS) have evolved locational information as a relevant context attribute on which to

adjust the displayed information of mobile maps. Huang et al. (2018) present a research agenda for LBS and highlight various open research questions concerning context-awareness and its practical implications for LBS applications. As the authors discuss, these open research questions are interdisciplinary and apply to context-awareness in mobile cartography in general as well.

Subsequently, Reichenbacher & De Sabbata (2011) began to expand the concept of information relevance for mobile users and proposed the term geographic relevance (GR). The GR concept focuses on the mobile use case and utilizes context to evaluate the relevance of information. This assessment can then be applied to filter and adapt the visual representation of information in mobile maps.

Similar to the GR concept, Griffin et al. (2017) also explore the idea of relevant map use context and how to assess which context is central for adjustments to the map design. They present various open research questions to establish a research agenda on map use context for evaluating the transferability of map design. These research questions aim to evaluate map use context in association with map design in general, without explicitly focusing on mobile maps.

Several research developments address map use context in conjunction with the adaptation of mobile maps, utilizing various terms, such as context-based map adaptations (Bartling et al., 2021), adaptive geovisualization (Reichenbacher, 2003), map personalization (Ballatore & Bertolotto, 2015), adaptive map interfaces (Kiefer et al., 2017), or neuro-adaptive mobile geographic information displays (Fabrikant, 2022, 2023). These topics all share similarities in that they utilize (selected) map use context for designing and adapting mobile maps.

In addition to the research topics that specifically focus on map use context and mobile map adaptation, several research themes touch upon these aspects. For example, there is a growing focus on mobile-first and responsive design (Ricker & Roth, 2018; Roth, 2019b), which highlights the importance of designing for mobile devices and considers related design constraints associated with mobile contexts. Research on inclusive processes and inclusive design also relates to context in terms of user constraints and characteristics, addressing issues of accessibility that are relevant in a mobile context (D'Ignazio & Klein, 2020; Roth, 2019b). Furthermore, numerous empirical studies evaluate selected map use context in association with mobile map design or the mobile environment (e.g., Anderson & Robinson, 2021; Bestgen et al., 2017; Edler et al., 2019; Golab et al., 2021; Han et al., 2020; Mavros et al., 2022). Additionally, studies on interactivity behavior and ecologically valid/ambulatory assessments of map use have emerged, which evaluate how mobile maps are used in real-world settings with mobile context playing a critical role (Savino et al., 2020; Zingaro & Reichenbacher, 2022).

With these research themes and range of studies, developments from different research perspectives and disciplines related to the cartographic community have emerged and point to increased research on map use context and mobile cartography. Depending on the research perspective, the focus differs and centers on the assessment of map use context for mobile cartography, mobile mapping, or cartographic design considerations in general, for map design adaptation, or the evaluation of (selected) map use context through the lens of empirical research.

3. Consolidating research on context

The current research landscape regarding map use context and context-awareness encompasses numerous research themes offering interesting and broad-ranging research aspects and perspectives. Nevertheless, we see several challenges that have emerged from the advancement of these various research efforts.

Firstly, as outlined in the previous section, the terminology used to discuss map use context and context-awareness varies between research approaches and disciplines. While some terms are used interchangeably and appear to be rather similar (e.g., adaptive map, adaptive map interface, map adaptation, etc.), other terms are used to address different research foci (e.g., map design transferability, GR, neuro-adaptivity, mobile-first map design, etc.). This presents a challenge in terms of finding relevant research on map use context or overlapping research concepts when, for some instances, parallel research developments occur without building on each other.

Moreover, the research directions highlighted in section 2 emphasize various context attributes or facets of context-awareness relevant to mobile maps. As there is a lack of a common way to model map use context (Griffin et al., 2017), with Figure 1, we seek to provide a taxonomy that consolidates the terms and concepts that surround existing research on map use context.

The top-level categories of our map use context taxonomy are extrinsic, intrinsic, and behavioral context (Figure 1, top tier). The extrinsic context category includes the environment, technology, and virtual information of the device and systems. The intrinsic context category encompasses all individual and cognitive contextual factors of users. And the behavioral context category exhibits user activities in both physical and digital spaces. As such, it links intrinsic and extrinsic context, i.e., it manifests activities shaped by individual users in a specific environment.

The various contextual factors can be sensed and acquired in many ways (Figure 1, middle tier). In modern smartphones, a variety of sensors are available to capture extrinsic contextual elements (Grifoni et al., 2018). These can be complemented by sensors in the surrounding environment (e.g., Internet of Things).

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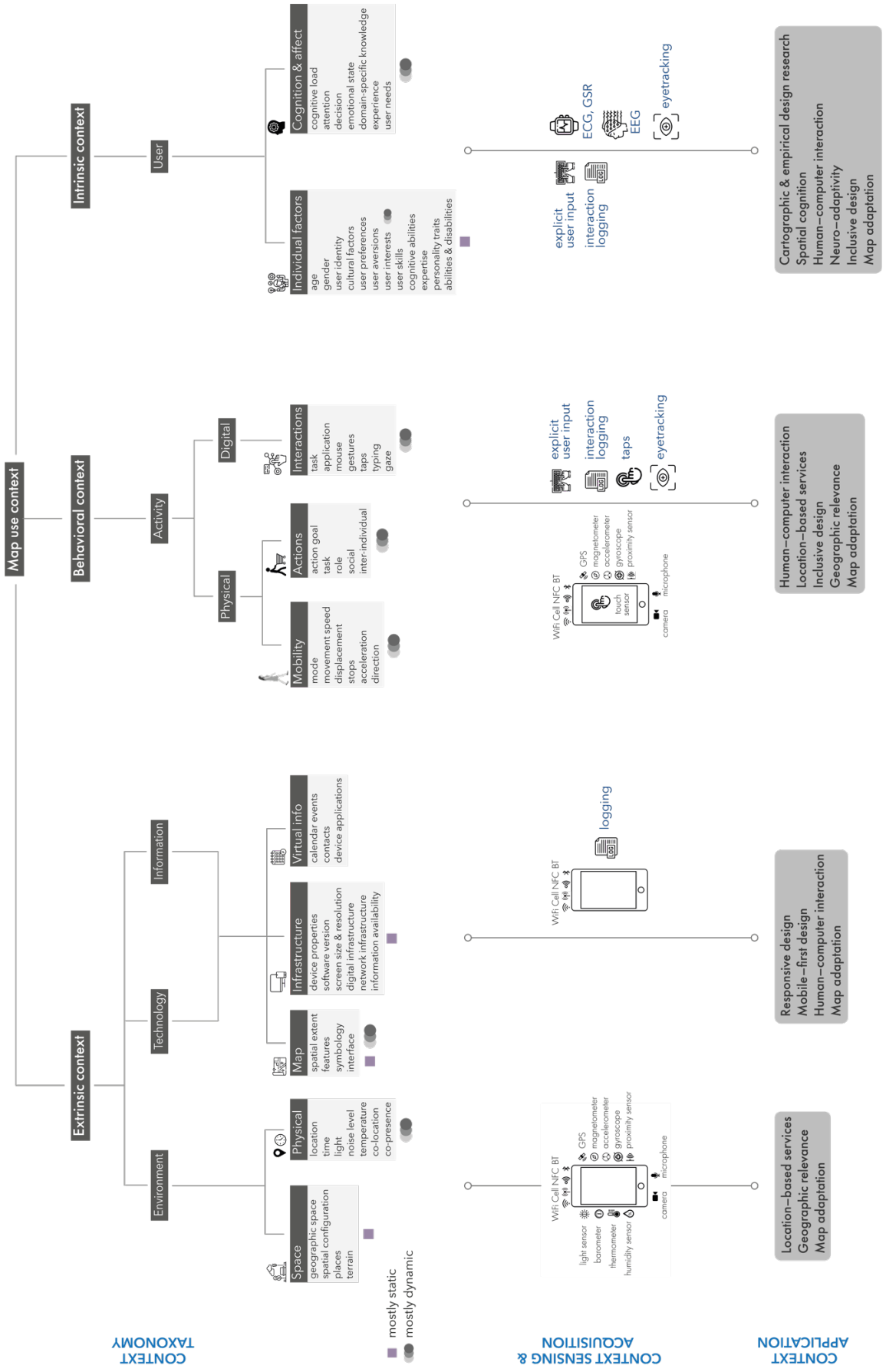

Figure 1: Map use context taxonomy

Technical aspects can also be acquired through log files (Hilbert & Redmiles, 2000). Behavioral context can be sensed through smartphone sensors (e.g., GPS, accelerometer, etc.) (Huang et al., 2018), interaction logging, explicit inputs, eyetracking (Kiefer et al., 2017), and tap recording (Reichenbacher et al., 2022). Intrinsic context can be obtained through explicit user input (Roth et al., 2015), interaction logging, or dedicated psychophysical sensors, such as eyetracking, electroencephalogram (EEG), or galvanic skin response (GSR) (Fabrikant, 2022).

To derive meaning from low-level context data collected from sensors, it is necessary to aggregate these data into higher-level context elements that are more meaningful and useful for later applications (Abowd et al., 1999). For example, the exact time in milliseconds can be transformed into the time of day, day of the week, or even the season and single GPS coordinates can be transformed into movement trajectories. Furthermore, virtual sensors are commonly employed to process and combine measurements from one or more physical sensors, resulting in more accurate data and meaningful information (Martin et al., 2021). For example, GPS data can be complemented by calendar information from the smartphone to provide semantically enriched location information of the users (for a comprehensive review on context-sensing and context-awareness see Yürür et al. (2016)).

We further seek to emphasize that many context attributes in our proposed taxonomy of Figure 1 are dynamic in nature. However, past research on map design has mainly focused on explicit context of user attributes, mostly gender and age, neglecting the importance of other dynamic context attributes in informing map design (Thrash et al., 2019). The collection, measurement, and interpretation of dynamic context are more challenging than that of static context. While explicit and static context can be rather easily collected through, e.g., questionnaires, dynamic context has to be implicitly acquired, resulting in increased technical demands to design and conduct user studies on map design. Here, studies such as Zingaro & Reichenbacher (2022) and Savino et al. (2020) are important in collecting data on ecologically valid map use situations that consider dynamic contexts.

Hence, as a second challenge, we need to shift our research focus on map use context from predominantly collecting static and explicitly derived context to encompassing dynamic and implicit context to gain a comprehensive understanding of map use context. In addition, to account for the intertwined nature of context, it is essential to integrate multiple context sources (Bartling et al., 2022). With the depiction of these various possible context acquisition options in the middle tier of Figure 1, we provide an overview of how to sense different context elements by applying the most common and accessible sensors. Nevertheless, there are more sensors available that could be complemented for context acquisition.

The bottom tier of Figure 1 provides an overview of possible applications of sensed and acquired context information based on the research outlined in section 2. Here, the application domain of LBS mainly concentrates on environmental and behavioral context elements and emphasizes technical implementations and implications of these context categories. GR focuses on the environment and mobility context elements to define relevant information for mobility-related activities of mobile map users. Responsive and mobile-first design focus on map devices and limitations of the used technology and infrastructure. Cartographic and empirical design research, spatial cognition, neuro-adaptivity, and inclusive design predominantly use individual or cognitive contextual factors of map users. HCI research primarily focuses on users' interactivity behavior, the technology context, and user factors. And map adaptation spans across all context elements. Table 1 serves as an initial (but not exclusive) source for literature on these context applications and seeks to point to relevant research that focuses on these different context elements.

Table 1: Context application and relevant literature references

Context application:	References:
Location-based services	Grifoni et al. (2018) Huang et al. (2018)
Geographic relevance	Reichenbacher & De Sabbata (2011) Crease (2014) De Sabbata et al. (2015)
Mobile-first and responsive design	Ricker & Roth (2018) Roth (2019b)
Cartographic and empirical design research	Roth et al. (2017) Griffin et al. (2017) Roth (2019a)
Spatial cognition and neuro-adaptivity	Thrash et al. (2019) Ottley (2020) Fabrikant (2022, 2023) Ishikawa (2022)
Human-computer interaction	Savino et al. (2020) Zingaro & Reichenbacher (2022) Schade et al. (2023)
Inclusive design	Roth (2019b) D'Ignazio & Klein (2020) Kraak et al. (2020) Kelly (2021)
Map adaptation	Reichenbacher (2003) Meng et al. (2005) Sarjakoski & Nivala (2005) Raubal & Panov (2009) Kiefer et al. (2017) Bartling et al. (2022)

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4. Conclusion and outlook

With the advent of mobile technology, mobile maps are becoming ubiquitous in our daily lives. Nowadays, we employ mobile maps for a wide range of activities and purposes and in very different environments; consequently, mobile maps have evolved to be used for a variety of map use scenarios and contexts. Designing for these differences in map use context is essential for a user-centered and context-aware mobile map design. Subsequently, throughout the past two decades, an array of interdisciplinary research efforts has emerged, resulting in various research perspectives on the topic.

This paper sought to consolidate and align these research perspectives to advance context-awareness for designing mobile maps. We presented a map use context taxonomy, which is aimed to guide and unify the various context elements that exist, their sensing and collection methods, and the corresponding application domains where they are explored. For these application domains, we point to relevant literature that can be helpful to review research on corresponding context elements. The presented map use context taxonomy as well as the corresponding list of literature references aim to provide an overview to help finding relevant research on the topic; both can be further extended in a thorough literature review.

We have further pointed to the challenge that even though many of the context elements are dynamic and need to be collected through implicit methods, most research on map design focuses on explicit user context attributes. We assume that the difficulties in evaluating dynamic context are the main reason why implementations of context-awareness and adaptivity in cartography are still scarce. However, context-sensing technology and computing power are readily available. For cartographic research on context-awareness in mobile maps, technical frameworks for user-centered design evaluations could be developed, which provide the ability to sense and evaluate a range of implicit context (e.g., frameworks such as MapOnTap (Zingaro & Reichenbacher, 2022) or MapRecorder (Savino et al., 2020)) or virtual reality could be used to simulate context. Ecologically valid studies (such as Savino et al. (2020)) could be combined with lab studies to evaluate and verify insights (Roth et al., 2017). Several research articles and agendas over the past years (e.g., Griffin et al. (2017), Huang et al. (2018), Bartling et al. (2022)) have pointed out open research questions and have conceptually discussed context-awareness. However, it is important to start addressing these open research questions and move context-awareness in mobile cartography from theory to implementation.

Hence, we need to bundle our efforts as a community and build upon these resources to move towards understanding a fuller set of map use contexts and context-awareness that shape our understanding of mobile map use behavior and needs for adaptations. We would, therefore, like to invite the cartographic community to build on this draft of our proposed taxonomy and pay attention, amplify, and extend the rich field of context acquisition methods, potential applications, and their related literature for advancing research on map use context.

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