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► **To cite this version:**

Ankica Barisic, Marco Winckler. Towards User Profile Meta-Ontology. Human-Centered Software Engineering. HCSE 2023. Lecture Notes in Computer Science. LNCS, 2023. hal-04210148v1

HAL Id: hal-04210148

<https://hal.science/hal-04210148v1>

Submitted on 18 Sep 2023 (v1), last revised 6 Dec 2023 (v2)

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Towards User Profile Meta-Ontology

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Abstract. As the user base becomes increasingly diverse, it is crucial to provide better development support for creating interactive systems that adapt to the varied characteristics and needs of their users. A deep understanding of user mindset and awareness is essential for achieving this goal. User-centred design approaches and a strong link between human characteristics and the application domain are instrumental in understanding user profiles and preferences. With the rapid advancement of digital transformation, a large amount of data related to human activities and states can be gathered. A meta ontology for user profiling is needed to effectively utilize this data and support developers in modelling, reusing, and sharing user profiles. This ontology provides a standardized framework for creating and representing user profiles, ensuring interoperability and facilitating data federation. This paper proposes a solution in the form of a meta-ontology for user profiling and explores its creation, utilization, and effective federation.

Keywords: User profiling · Persona · Ontology · Modeling

1 Introduction

The ongoing global technological transformation has revolutionised our interactions with software and systems. As the user base becomes increasingly diverse, it is crucial to enhance development support for creating interactive systems that adapt to users’ varied characteristics and needs. To achieve this, a deep understanding of user mindset and awareness is crucial.

Developers require approaches that enable them to empathise with and address the challenges faced by diverse end users, incorporating software solutions that cater to a wide range of human characteristics. Design support is also necessary, equipping developers with advanced techniques and tools to effectively address the complexities posed by diverse end users [7].

User-centred design approaches, considering factors like knowledge expertise and performance monitoring, have proven essential in understanding end users’ profiles. A *user profile* is the main component needed for the evaluation, personalisation and adaptation of interactive systems. It has played an active role in various domains such as healthcare sectors, banking sectors, social media, e-commerce, security, access control, and social networking [4]. Moreover, establishing a strong link between human characteristics and the application domain provides valuable insights into user behaviour and preferences [3].

With the rise of digital transformation, an abundance of data on human activities, and emotional, mental and physical states can be collected. This data, captured through mobile and wearable devices or biosensor cameras, holds immense potential. However, to harness its power, data sharing, reuse, and understanding patterns of unwanted human states are crucial. This data can be used to train AI models, adapt systems to individuals’ needs, and create personalised experiences.

To effectively leverage this data and assist developers in modelling, reusing, and sharing user profiles, there is a pressing need for a general ontology for creating user profiles [10], [4]. Such an ontology offers a standardised framework for creating and representing user profiles, ensuring interoperability and facilitating data federation. Model-driven engineering is a promising approach to enable developers to generate user profiles, reuse existing data, and receive guidance in modelling profiles from scratch.

A standardised user profile is expected to enable the implementation of interoperable adaptive systems sharing modelling information. Ontology-based user profiling is particularly vital for systems reasoning across multiple profiles, so-called social adaptive systems, or benefiting from complex inference on multiple ontologies representing different knowledge [16].

This paper presents the User Profile Meta Ontology (UPMO) as a proposed solution. In Section 2, we examine various techniques for acquiring user profiles. In Section 3, we present an overview of the existing ontologies in the field of user profile creation. Section 4 explores the effective design, utilization, and federation of UPMO. Additionally, in Section 5, we analyze the User Dimension, which serves as a guiding factor for the implementation of UPMO. Finally, in Section 6, we conclude the paper and outline our ideas for future research directions.

2 Techniques for Obtaining User Profiles

The concept of a *User profile* refers to the representation of an individual user, real or fictional, or a group of users. This profile is essential for understanding and catering to individual user needs in various applications [4]. User profiles are instantiated as a *User model*, which serves as a data structure to capture specific characteristics about an individual user. These models can be static or dynamic, with static models representing unchanging user data and dynamic models evolving based on user interactions and interests.

To meet the demands of human-centered socio-technical systems, highly adaptive user models are required. These models focus on personalized solutions and user-centric design, rather than relying solely on demographic data [16]. Gathering extensive information is crucial for highly adaptive models to reach their full potential. Qualitative methods involve understanding and interpreting subjective experiences, behaviors, and perceptions of individuals or groups. These methods focus on gathering non-numerical data through techniques such as interviews, observations, focus groups, case studies, and user storytelling. They provide detailed insights into the meanings, contexts, and in-

terpretations of the target user. Quantitative research methods, such as surveys, experiments, statistical analysis, machine learning, and data mining, offer ways to analyze large datasets, identify patterns, and make predictions. Combining qualitative and quantitative methods provides a comprehensive understanding of users. Thematic analysis and content analysis are common techniques used to extract valuable insights for creating user profiles and models.

We highlight three common approaches to obtaining user profiles and models: user profiling, persona development, and role-based approach. The *role-based approach* creates user profiles based on the specific roles and tasks of users when interacting with a system. This approach focuses on understanding task sequences, interactions, and user roles in accomplishing those tasks. *User profiling* aims to create detailed representations of real users or user groups, capturing individual characteristics based on actual user data. *Persona development*, on the other hand, involves creating fictional characters that represent target user archetypes, guiding design decisions and representing user groups.

Role-based approach: In the role-based approach, user profiles are created based on the roles and tasks that users perform within the system. This approach focuses on capturing the user’s responsibilities, goals, and behaviors related to particular tasks or activities. The process typically begins by identifying the key tasks or activities that users engage in during their interactions with the system. To gain insights into the underlying cognitive mechanisms involved, cognitive task analysis methods are often employed [17]. These methods analyze and capture the cognitive aspects of tasks, such as problem-solving, decision-making, and information processing. Understanding how individuals think, reason, and make decisions during task execution can be leveraged to inform the design of various interventions aimed at enhancing task performance and supporting cognitive workload. Once the tasks are identified, the associated roles are defined. A uniform task meta-model is developed to facilitate the transformation of individual task models into their standardized counterparts while minimizing the loss of information [11].

Persona development: Personas are fictitious representations of target users that resemble real people. They provide shared mental models, facilitate communication among team members, and help empathize with end-users [13]. Personas are useful for segmenting diverse online audiences and integrating human aspects into the development process. They are commonly used in requirements engineering, often represented as text-based descriptions obtained through qualitative approaches like focus groups and workshops [9]. Personas enhance stakeholder satisfaction, prioritize human-centric design, support developers, and are often combined with scenarios to depict user behaviour. Salminen et al. [14] investigated the application of personas in different domains, highlighting their predominant usage in software development (40% of cases) and other fields such as healthcare, higher education, marketing, and robotics. Personas were found to be valuable in organizing user information, and adapting to both short-term tasks and long-term goals. They also proved useful in expert verification during testing, usability testing, and guiding semi-structured interviews.

In a separate study [13], the authors focused on quantitative persona creation, emphasizing the potential of algorithmic methods to generate accurate and up-to-date personas from numerical and textual data. They noted the absence of a unified metric for evaluating persona quality but highlighted clustering as the most commonly employed technique.

User profiling: User profiling helps organizations better understand their users, anticipate their needs, and make informed decisions during product design and personalization [5]. The process involves data collection, analysis, and interpretation. Recent studies have focused on authorship attribution, social annotation profile modeling, data acquisition, feature extraction, modeling techniques, and performance metrics. These studies highlight the need for user profiling approaches that support general-purpose user profiles, are language-independent, have ontological representation, and address dynamic, distributed, and secure user profiles with predictive and temporal features [4].

3 Existing Ontologies for creating User Profile

To enable the sharing and reusability of user profiles, standardized domain representations and common vocabularies are necessary. Existing taxonomies in software engineering often fall short in reflecting human values, needs, and characteristics, emphasizing the need for ontologies that describe general user profiles independent of specific domains [7]. The integration of user profiling and web ontologies explores the combination of semantic trends in web development with modern user profiling technologies [16]. While many user-adaptive systems utilize ontologies for semantic representation and knowledge acquisition, they tend to be tightly coupled to specific domains and lack reusability.

Several ontologies have been proposed in this context. The General User Modelling Ontology (GUMO) [8] defines user dimensions and analyse in detail properties such as heartbeat, age, position, birthplace, or swimming ability. This ontology identifies 1000 groups of auxiliaries, predicates and ranges. The User Profile Ontology (UPO) [6] aims to model user profiles at a high level, incorporating relevant concepts and properties. The Ontology-based User Modeling framework (OntobUMf) [12] focuses on analyzing user behaviour in knowledge management systems. The Grapple ontology [1] supports the rule-based creation of domain-related statements for users. The Holistic Persona Ontology [2] proposes a persona ontology framework with five dimensions, encompassing factual, personality, intelligent, knowledge, and cognitive process aspects. The Persona Ontology [15] provides a comprehensive set of concepts related to personal characteristics and environment, by having separate ontologies for requirements and behavioural aspects which are connected in a model-driven way. The User Modelling Meta-Ontology (UMMO) [18] offers a top-level classification of the user modelling field, analyzing diverse data collection and interpretation approaches.

It is important to note that these ontologies are predominantly static and lack support for dynamic and temporal features. Implementation details and availability may be limited, and the existing approaches primarily adopt a top-

down approach, requiring developers to start from scratch. There is a need for bottom-up approaches that enable the generation of user profiles from existing datasets, particularly ones that are domain-independent and applicable to various applications. Analyzing general user profile characteristics and establishing mappings to domain-specific profiles is the crucial starting point in addressing these requirements.

4 User Profile Meta-Ontology (UPMO)

The ontology representation of user-profiles serves as a means to define and represent the knowledge contained within them, enabling the sharing and reuse of domain knowledge [4]. It facilitates the analysis and extraction of domain-specific information from operational knowledge and supports the explicit sharing and exchange of profiles based on an agreed model.

4.1 Role of UPMO during system development

UPMO is expected to play a significant role in designing, implementing, and testing emerging socio-technical systems. We highlight here how it can contribute to each of these development phases:

Design: UPMO help in the design phase by providing a standardized vocabulary and a conceptual model that captures the key concepts, relationships, and constraints regarding user linked to a specific domain. It helps designers understand and model the characteristics and needs of the target users, by capturing user preferences, interests, demographics, and other relevant factors, designers can create user personas, profiles and role/task models. Obtained artefacts serve as a foundation for designing tailored interactions, content recommendations, and personalized features while ensuring consistency and interoperability between the user profiling model and other system components.

Implementation:: UPMO guide the implementation of personalized features and adaptive functionalities. Developers can integrate the ontology into the system architecture, allowing user data to be collected, stored, and processed in a structured manner. It serves as a common representation that facilitates communication between different software modules and enables the effective utilization of user profile information. Developers can use UPMO to define rules, algorithms, and mechanisms for personalization and adaptivity.

Testing: Testers can use UPMO to simulate different user profiles and interactions, evaluate the data collection, interpretation mechanisms and system's ability to deliver personalized content, adapt to user preferences, and provide relevant recommendations. It helps in defining test cases, expected outcomes, and criteria for assessing the system's performance in terms of user modelling and personalization accuracy.

4.2 UPMO requirements

According to presented research trends, there are several requirements that contribute to the wide dissemination of user profiles [10],[4], [16], and which are defined in Table 1. These requirements aim to ensure the versatility, effectiveness, and adaptability of UPMO, promoting their widespread implementation and usability across different contexts and applications.

Table 1. Requirements for User Profile modelling

<i>Requirement</i>	<i>Description</i>
Generality	UPMO should exhibit generality by explicitly representing domain-independent properties of user profiles. They should be designed to be compatible with various applications and domains, enabling their utilization in different contexts.
Expressiveness	UPMO should demonstrate a high degree of expressiveness, enabling it to effectively represent a wide array of facts and rules pertaining to the user. This includes accommodating diverse types of information, allowing for the comprehensive and flexible representation of user attributes, characteristics, and behaviours.
Import of external data	UPMO should possess the capability to integrate data from multiple heterogeneous sources into a unified data source, regardless of their formats, structures, or locations. This data federation is expected to provide a unified and consistent view of data, enabling querying of integrated data as if it were stored in a single centralized database.
Integrating multiple ontologies	UPMO should support combining ontologies from different sources to enhance reuse, knowledge sharing and interoperability. Ontology federation allows for the integration of ontologies that capture different perspectives of user profiles or specialize in specific domains. It involves establishing mappings between the concepts and relationships which enable the knowledge exchange.
Extensibility	UPMO should provide the interface for the modelling of new features at the meta-level and APIs that allow for the exchange of user information between user modelling tools, such as data collection methods, analysis algorithms, and modelling approaches. It should be capable of accommodating evolving user modelling techniques and supporting a wide range of user modelling tasks and applications.
Privacy	It is essential for the user model to adhere to privacy policies, conventions, and both national and international privacy legislation. To ensure user privacy, the UPMO should incorporate robust tools and services that safeguard sensitive user information.
Reasoning abilities	The UPMO should possess capabilities to perform diverse forms of reasoning and effectively handle conflicts that may arise from contradictory facts or rules. Model verification enables the user modeller to effectively handle ambiguity and reconcile conflicting information.

4.3 User modelling process with UPMO

Using a UPMO is expected to provide developers and domain experts with a solid foundation, standardized representation, and guidance throughout the development process. It can help them align their understanding of user profiles with established best practices, facilitating knowledge sharing and collaboration. The interpreted modelling environment is expected to save time, promote consistency and interoperability, facilitate integration with external data sources and domain ontologies, and allow for iterative improvements based on feedback and evolving user modelling needs. In Figure 1 we illustrate the high-level modelling process of user profiles with UPMO, which consist of the following steps:

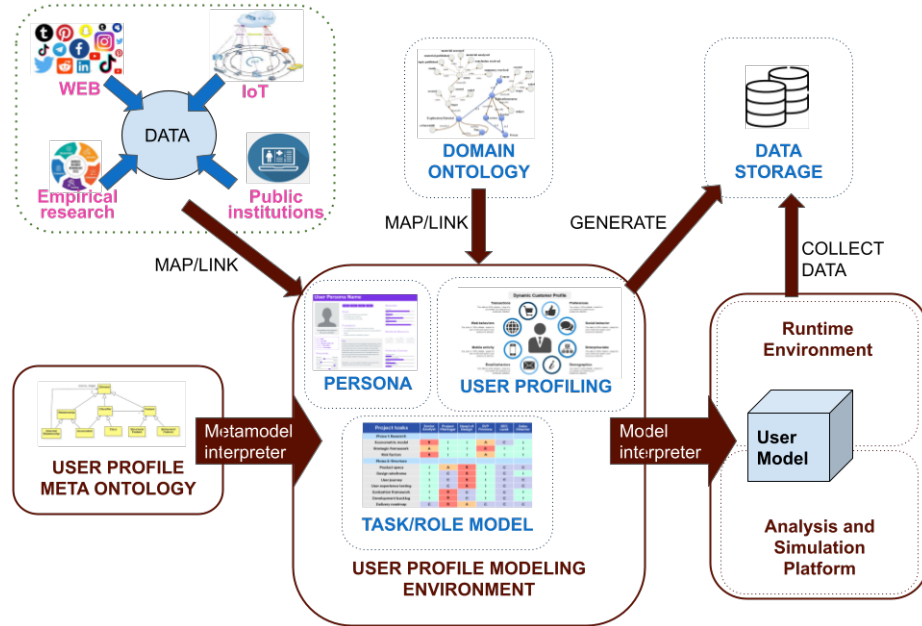


Fig. 1. Modelling process with UPMO

Identify User Profiling Needs: UPMO provides a comprehensive set of concepts and relationships, guiding developers in identifying user profiling requirements specific to their system and determining the types of user information needed for personalization and automation, such as for instance temperature preferences, lighting preferences, activity patterns, and security preferences.

Create/Extend the User Profile Ontology: UPMO serves as a starting point for developers to extend and customize the ontology, and to link existing domain ontologies necessary for capturing user profiles in the given context. This saves significant effort and time compared to starting from scratch, as developers can build upon the existing ontology structure and relationships.

Capture and map User Profile Data: Identify the data sources available from IoT devices (e.g. cameras, motion sensors, security devices), web (e.g. social networks, e-commerce platforms), public institutions (e.g. education institution, healthcare institutions) or existing empirical studies (e.g. surveys, user logs, usability studies). Having a UPMO helps developers to map the ontology’s predefined concepts and relationships with collected data to ensure data consistency and interoperability.

Implement Data Storage and Retrieval: UPMO provides guidance on how to organize and store user profile data, enabling developers to create efficient and scalable storage systems that are compatible with the ontology.

Test User Profiling Functionality: UPMO is generating a user model component which can be integrated with a simulation environment. It supports the development of test cases and scenarios to validate the user profiling functionality of the system. It helps to verify that the system correctly collects, stores, and retrieves user profile data and that it effectively uses ontology to personalize interactions.

Integrate User Profiling capabilities: UPMO allows developers to integrate user profiling capabilities into system components. They can design modules that utilize user model component to access and leverage user profile data enabling personalized automation, adaptive interfaces, and decision-making processes based on standardized representations.

Iterate and Refine: By leveraging the UPMO as a starting point developers benefit from the iterative refinement process when extending the user profiling ontology. It helps them to continuously iterate and refine the ontology and its implementation based on feedback, user evaluations, and system performance.

5 User dimensions

The core idea of adaptation is based on the assumption that differences in some user characteristics affect the usefulness of the services or information provided to the individuals. Thus if a system’s behaviour is tailored according to such individual characteristics, its value to individuals will be increased. Based on the mapping of existing categorisations introduced in Section 3, we derive the user dimensions in Table 2 to guide UPMO implementation. We differentiate between domain-specific and general dimensions. Domain-specific is highly dependent on the application domain, e.g. they are not valid in the other domain. General, or domain-independent, characteristics are ones which we can reuse in between domains. They can represent the general user characteristics and abilities, which later we can relate to the context of the study to understand their impact. They can also represent the existing data from which the human state is interfered with for the user. In most cases when the user profile dimensions are measured person has a rough idea about the expected expiry [8]. For instance, human states are highly dynamic, and some of them can change within a few seconds, while person characteristics, in general, don’t change.

Table 2. User Profile Dimensions and Encapsulated Concepts

<i>Dimension</i>	<i>Description</i>	<i>Scope</i>
Demographic [4], [16], [8]	encompass the fundamental information commonly used for segmentation and categorization purposes. This includes basic user details such as name, date of birth, email, and contact information [8], as well as information related to the user's place of residence and type of housing [6]	General
Characteristic [4], [16], [8], [6]	represent a range of attributes that can be categorized into general physical traits and personality traits. General characteristics include physical features such as eye colour, height, and weight, while Personality traits encompass qualities such as talkativeness, dominance, reservedness, shyness, kindness, warmth, and openness to experience. Commonly used models like the Five-Factor Model define a set of properties that describe personality, including extroversion/introversion, thinking, feeling, and sensing [2].	General
Role [8]	encompass various aspects such as user Profession [6] and Occupation [15]. Additionally, roles refer to specific positions or responsibilities that users hold within a particular system or context. These roles can include administrator, manager, employee, customer, guest, moderator, contributor, and other relevant roles based on the specific application or domain.	General
Ability [8], [6], [15]	represent the user's Proficiency [8] or Expertise [6] in performing various tasks or activities. These abilities can vary widely including user's level of Education [6], [15], Qualifications, Certifications, and Licenses [12], user's Knowledge which comprises factual, procedural, conceptual, and metacognitive aspects providing insights into their cognitive abilities, such as learning process (remembering, understanding, applying, analyzing) [2] or their Intelligence [2], technical skills, physical capabilities, language proficiency.	General
Relation	represents the connections or associations between users and other entities or users within a system or context. It signifies the relationships to Thing (Ownership), Contact (Other persons) [6] or to certain Organisations.	General
Human state	encompasses various aspects of the user's well-being, including their nutritional status, emotional state (such as worry, boredom, hope, joy), mental state (including sleep, drowsiness, stress), physiological indicators (such as heartbeat, blood pressure, temperature), and even their motion or facial expressions [8]. These states are observed and captured to gain insights into the user's Experience and overall Condition.	General
Behaviour [12], [15]	include user activity patterns, interaction sequences, frequency of actions, duration of engagement, and other behavioural indicators exhibited by the user while interacting with a system or engaging in specific activities.	Domain-specific
Interest [12], [15], [6]	refer to the topics or subjects that attract the user's attention or curiosity or areas of expertise that they find engaging or enjoyable	Domain-specific
Preference [6]	refer to the individual choices, inclinations, or options that a user favours or selects in various contexts. They encompass a wide range of aspects, like preferences for specific features, functionalities, or settings of a system or application. They can also include preferences for certain types of content, styles, layouts, or presentation formats.	Domain-specific
Goal/Task [12], [15]	represent the specific objectives, aims, or activities that a user intends to accomplish within a system or context. They reflect the user's intended outcomes or desired results while interacting and provide insights into the user's motivations, intentions, and priorities.	Domain-specific
Environment [15]	include physical location where the user interacts with a system (e.g., home, office, public space), the social context in which the user operates (e.g., social networks, online communities), and the technological infrastructure and devices available to the user (e.g., IoT devices, internet connectivity)	Domain-specific
Requirement [15]	include functional requirements, which describe the specific features, functionalities, or capabilities that the user expects from a system or application and non-functional requirements, which focus on aspects such as performance, reliability, usability, security, or accessibility.	Domain-specific

6 Conclusions and future work

This paper presents the design of the User Profile Meta Ontology (UPMO) and conducts an analysis of the user dimensions, which serve as high-level concepts guiding the development of UPMO. We explore the anticipated development process for adaptive systems and examine the potential benefits for developers and domain experts through UPMO-supported artifacts.

For future work, our plans involve validating the feasibility of the proposed dimensions by mapping existing user and data models to them. We aim to identify the more detailed structure of the envisioned metamodel and analyze the interrelationships among its components. Additionally, we intend to enhance our metamodel by incorporating mapping capabilities, which will provide an auto-generated modelling environment.

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A Appendix

A.1 Author experience

Ankica Barišić is a postdoctoral researcher at the Université Côte d’Azur, specializing in Software and System Engineering with a focus on Model-Driven Engineering (MDE) and Human-Computer Interaction. Her research contributes

to new modelling techniques and evaluates their effectiveness, particularly in ensuring that modelling languages are suitable for their intended context of use. She has a specific interest in Domain-Specific Languages (DSLs) that empower domain experts in developing computing solutions. Her doctoral thesis focused on the usability evaluation of DSLs, and she has contributed to the field through empirical studies and solutions that facilitate end-user development. Improving the usability of modelling languages is expected to enhance developer productivity and reduce development costs. Additionally, she emphasizes the importance of including the human-in-the-loop as an integral part of the system, rather than merely an operator. To address this, she highlights the need for systematic approaches, appropriate tooling setups, and comprehensive measurement suites to evaluate complex interactive systems.

Marco Winckler is a full professor at the Université Côte d’Azur, where he leads the Human-Computer Interaction (HCI) track in the Informatics department. His research focuses on the Engineering of Interactive Systems, addressing various aspects such as system description, assessment, usability problems detection, and automation. One of his objectives is to assist designers and developers in building usable interactive systems while considering the diversity and evolving needs of users. He relies on model-based approaches, including dialogue and task models, to describe systems, specify user needs, evaluate interactions, and facilitate communication among stakeholders. He has applied these approaches in different domains, including ground segment systems, e-government, mobile applications, and web engineering. In the web engineering domain, his current interests lie in specifying online/offline navigation, a client-side adaptation of websites, and information visualization techniques, including complex visualization pipelines and chained visualizations, with a focus on linked data and semantic web data processing.

A.2 Motivation to participate in the International Workshop on Human-Centered Software Engineering

We perceive the User Profile Meta Ontology (UPMO) as an innovative approach that aligns seamlessly with the workshop’s objectives, making it a valuable contribution to the discourse and knowledge exchange. As proponents of human-centered software engineering, we are captivated by the transformative potential of digital technologies and their profound impact on various facets of emerging systems. The UPMO approach effectively addresses the challenges engendered by the digital transformation process through the provision of a comprehensive modeling framework that facilitates an in-depth comprehension of user profiles. By integrating diverse user dimensions, UPMO serves as a robust foundation for the development of adaptive and user-centric software solutions.

The workshop’s focal point on the interplay between Human-Computer Interaction and Software Engineering strongly resonates with our research interests. We firmly believe that bridging these disciplines is imperative to effectively tackle the ever-evolving technological landscape. Drawing upon our expertise

and insights, we are confident in enriching the workshop discussions by offering a unique perspective.

Our participation in this workshop would yield several benefits. Firstly, it would grant us profound insights into the latest advancements in the field, enabling us to stay at the forefront of research. Additionally, the workshop provides an exceptional platform for networking with fellow researchers and practitioners, fostering meaningful discussions, idea exchange, and the exploration of potential collaborations. Through these endeavors, we seek to further advance our collective understanding of the intricate interplay between humans, software engineering, and the challenges and opportunities presented by digital transformation.

We extend our gratitude for considering our work for participation in the Workshop on Human-Centered Software Engineering. We eagerly anticipate the opportunity to share our knowledge and learn from the diverse perspectives offered by fellow workshop participants.