Beyond the Interface: Towards a Human-Centered Future of Software-Intensive Systems

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***Abstract. Introduction**: One of the Grand Challenges in Human-Computer Interaction (HCI) in Brazil (GranDIHC-BR 2025–2035) calls for rethinking HCI in light of advances in Interaction with Emerging Technologies, emphasizing the need to consistently integrate Humans, Technologies, and Contexts. **Objective**: Our research aims to address this challenge in the domain of Software-Intensive Systems (SiS), with a specific focus on human-centered requirements analysis throughout the development lifecycle. **Methodology**: The study follows a qualitative and exploratory approach, combining theoretical development with practical investigation. **Results**: Initially, a systematic literature review was conducted to identify existing approaches to human-centered requirements analysis and best practices in Software-Intensive Systems (SiS). Based on these findings, the TRACE methodology was developed. By the conclusion of the project, the research is expected to contribute to the creation of SiS that are more transparent, responsible, and aligned with users' needs and capabilities.*
***Keywords** IHC em Software-Intensive Systems, emergent Systems, CG7, Emergent Behavior.*

1. Description of the challenge

Grand Challenge 7 (GC7) – "Interaction with Emerging Technologies: An Ecosystem Integrating Humans, Technologies, and Contexts" [Zaina et al. 2024] focuses on understanding and designing human-technology interactions within dynamic and interconnected ecosystems that integrate people, devices, algorithms, and contextual factors. It calls for the development of theories, design methods, evaluation approaches, and algorithms suited to emerging technologies; the expansion of equitable access to interaction devices; and the assessment of their social, cultural, and environmental impacts, with a commitment to inclusion, ethics, privacy, and well-being. This challenge encompasses complementary dimensions (*i.e.*, devices, algorithms, evaluation, design, theories, and impact of use), organized into three core elements:

- **Technologies**: refers to the integrated set of devices, algorithms, platforms, and digital infrastructures that enable and shape human–technology interaction. It includes emerging technologies such as artificial intelligence and augmented reality, as well as connected everyday devices, requiring investigation into interoperability, transparency, and their impacts on interactive ecosystems.
- **Human beings**: recognizes people as central agents in the design, use, and evolution of technologies, taking into account their cultural, social, and cognitive diversity. It encompasses aspects such as inclusion, accessibility, agency, and well-being, emphasizing the importance of participatory, value-driven processes to guide the design and evaluation of interactions.
- **Contexts**: addresses the dynamic and multifaceted environments in which interactions occur, including sociocultural, organizational, economic, political, and environmental variables. These contexts influence both the appropriation and adaptation of technologies, as well as perceptions of their impacts and the definition of success criteria.

2. Contributions and reflections for the advancement of the field

The GC7 challenge is directly aligned with the nature of Software-Intensive Systems (SiS), which are complex computational systems where software is the primary enabler of functionality and integration, coordinating hardware, algorithms, and data flows across physical, digital, and social layers [Sadeghi et al. 2024]. SiS are pervasive, autonomous, highly connected, and deeply embedded in sociotechnical ecosystems, underpinning critical infrastructures such as AgriTech 5.0, Industry 5.0, healthcare, smart cities, automotive, and aerospace domains. Their emergent, adaptive, and non-deterministic behavior challenges traditional Human-Computer Interaction (HCI) assumptions and demands ecosystemic, context-aware, and ethically grounded approaches as envisioned by GC7 [Guimarães et al. 2022, Chitchyan 2024]. In this context, we present the research that has been conducted since 2024, outlining its contributions, reflections, and proposals to support the human-centered requirements analysis for SIS.

2.1. Reports and analyses of what was carried out in 2024–2025

We introduce the development of a human-centered requirements analysis framework[1] for SiS, adapting traditional Requirements Engineering methods or evolving approaches specific to certain types of SiS, such as systems-of-systems and Internet of Things, to incorporate human factors throughout the entire system lifecycle systematically.

Our initial results emerge from the proposition of an agile and flexible process for the development of human-centered SiS, emphasizing a deep understanding of users' capabilities, limitations, needs, and contexts. The process spans from domain understanding to run-time operation, focusing on creating effective, efficient, and satisfying user experiences. To this end, the Technical Roadmap for Agile Cross-domain Engineering (TRACE) (Cf. Figure 1 methodology was developed, consisting of seven iterative activities that promote a systemic and user-oriented view.

The TRACE begins with **domain understanding**, which focuses on acquiring and organizing knowledge about the context in which the solution will be developed.

[1] The project is currently in progress as part of the first author's postdoctoral research at the Federal University of Viçosa, conducted in collaboration with PUC-Rio.

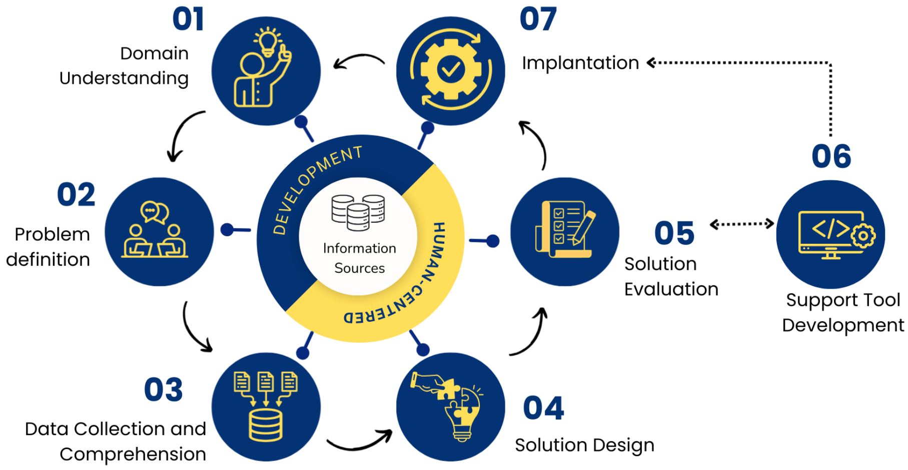

Figure 1. Trace Metodology

This includes processes, practices, terminology, constraints, and technical, social, cultural, and economic factors. Operational flows, existing technologies, standards, and opportunities for improvement are identified, producing validated documentation that guides the subsequent stages. In the **problem definition** stage, needs, challenges, constraints, and stakeholders are analyzed to establish a clear, shared understanding of the problem, including its causes, objectives, and success criteria. **Data collection and comprehension** integrates empirical and theoretical evidence from literature reviews, interviews, questionnaires, observations, or workshops, generating a comprehensive diagnosis that consolidates knowledge, highlights gaps, and emphasizes the problem's relevance. Building on this, **solution design** models a proposal that addresses requirements, user needs, and contextual constraints, following user-centered design principles and iterative development to produce a viable and well-grounded solution.

Solution evaluation then assesses utility, applicability, usability, and effectiveness through case studies, pilot projects, or experiments, collecting quantitative and qualitative metrics to guide improvements. When necessary, the **development of a technological support tool** encompasses requirements engineering, user-centered design, architectural definition, and iterative testing, resulting in a functional and validated tool that effectively supports the solution. Finally, **solution implantation** manages the controlled introduction of the proposal into the operational environment, addressing technical, organizational, and social aspects. Transition strategies, user training, and change management measures ensure sustainable adoption, smooth integration with existing processes, and acceptance by stakeholders, consolidating the solution as part of routine practice.

The evaluation of TRACE is currently underway, with plans to use multiple case studies and adopt methodological triangulation to demonstrate its effectiveness in meeting user needs and contextual dynamics, contributing to the design of more reliable, adaptive, and human-centered systems. Among the future research, we aim to advance TRACE to include continuous quality-of-use evaluation, conducted from system design through run-time.

2.2. Paths, strategies, and articulations for the coming years

Addressing the multifaceted challenges of interacting with SiS requires a sustained, interdisciplinary, and adaptive research agenda capable of responding to the evolving sociotechnical landscape. The deliberate consideration of these factors seeks to enable more human-centered interoperability among systems that were not originally designed to operate together, thereby reducing integration barriers and enhancing the end-user experience. The framework has been designed to address these challenges and to establish mechanisms for the continuous alignment of user needs, requirements, and business objectives, fostering a sustainable integration of technical, organizational, and human dimensions in the evolution of SiS. Accordingly, our project targets three strategic and complementary dimensions, organized around the thematic challenges of GC7:

1. **Theoretical Expansion - Theories, Algorithms, and Design:** This activity will advance a fundamental area in SiS by focusing on human-centered requirements analysis. It will operationalize cognitive perspectives through the use of validated and adapted usability and acceptance assessment tools, ensuring system specifications are consistently aligned with human cognitive abilities and limitations. Distributed perspectives will be addressed by modeling and orchestrating interactions among heterogeneous, interdependent subsystems and organizational layers, enabling seamless coordination during both design and runtime phases. Semiotic perspectives will be integrated via structured mechanisms that maintain meaning, coherence, and interpretability in exchanges between context, humans, and systems, even in conditions of autonomy, uncertainty, and partial opacity. Additionally, the incorporation of Artificial Intelligence techniques will support predictive and adaptive requirements analysis, allowing continuous alignment among evolving user needs, dynamic system behaviors, and organizational strategic goals. Together, these components will form a theoretically sound and empirically validated framework that will effectively guide the design, deployment, and evolution of SiS within complex, multi-agent, and multi-layered environments.
2. **Methodological Innovation - Design, Evaluation, Devices, and Use impact:** The evaluation methodologies for SiS will need to address the complexity of adaptive, multi-layered, and heterogeneous environments by integrating usability, accessibility, and interaction quality into the early design phase through participatory, scenario-based, and interdisciplinary approaches. Evaluation will extend beyond traditional usability testing to include acceptance modeling, user experience metrics, and immersive techniques such as digital twins, enabling anticipatory assessment of interaction quality under evolving requirements and multi-actor dynamics. Devices will be assessed for interoperability, performance, security, ergonomics, and multimodal feedback fidelity, ensuring consistent and effective interaction across diverse endpoints. Finally, the use impact will be examined through longitudinal and socio-technical studies that capture how interaction design influences performance, collaboration, decision-making, and ethical dimensions such as privacy, inclusion, and sustainability. Together, these dimensions will form a holistic, context-aware evaluation approach capable of guiding the conception, deployment, and evolution of SiS.
3. **Societal and Ethical Embedding - Use impact, Evaluation, Design:** The

societal and ethical embedding in SiS will require, during design, the integration of inclusion, transparency, privacy, and sustainability as core constraints, employing participatory approaches that incorporate diverse human values and apply semiotic principles to ensure clarity, coherence, and meaningful interaction. In evaluation, these principles will be operationalized through methods that assess not only usability but also trust, accessibility, environmental responsibility, and the interpretability of system communications, utilizing tools such as AI-driven analytics and immersive simulations to anticipate impacts before deployment. Use impact will focus on longitudinal and socio-technical analyses to monitor how interaction design influences equity, participation, and societal well-being over time, ensuring that SiS achieve both technical effectiveness and positive public value.

By synthesizing these actions, GC7 can operate as a strategic enabler for extending HCI beyond the conventional user–system dyad, advancing toward a systemic perspective that captures the interdependencies among human actors, computational agents, organizational systems, and contextual environments [Farooq e Grudin 2016]. This broadened conceptualization is expected to not only enhance interaction quality and reinforce user experience but also to inform the evolution of SiS as equitable, trustworthy, and socially responsible infrastructures.

2.3. Critical reflections on the directions outlined in the challenges

This project may contribute to GC7 by proposing a human-centered requirements analysis framework for SiS that extends the traditional user–system interaction and incorporates an ecosystemic perspective encompassing distributed, multi-actor interactions and sociotechnical contexts. The approach will integrate the real needs of multiple users, promote continuous alignment with usage contexts, and incorporate ethical, cultural, and organizational aspects, grounding human-centered decision-making throughout the system's lifecycle. Furthermore, the framework will include mechanisms to address usability in dynamic and opaque environments where systems evolve rapidly and operate with limited transparency to users. Adapted metrics and contextual analyses will be applied to ensure the adequacy and transparency of requirements, while elicitation and validation practices will enhance the explainability of functionalities and strengthen user trust. The framework will also integrate continuous real-time feedback collection, potentially supported by automated monitoring, enabling dynamic updating of requirements. Finally, participatory approaches such as co-design will be employed to actively engage diverse stakeholders in the definition and refinement of requirements, ensuring that the process reflects human perspectives, reinforces user centrality, and enhances both the effectiveness and social responsibility of SiS development.

2.4. Evaluation of the Framework for SiS: Challenges and Perspectives

Evaluating the proposed framework presents several challenges, particularly because it seeks to integrate technical, organizational, and human dimensions into a coherent approach. One of the main difficulties lies in defining suitable evaluation criteria, since traditional usability and requirements assessment instruments, such as the System Usability Scale or task efficiency measures, are insufficient to capture the broader scope of the framework. Another challenge is the methodological alignment: given that the framework encompasses processes of understanding, solution elaboration, evaluation, and continuous improvement, isolating its individual contributions while also assessing its holistic impact becomes complex. The diversity of stakeholders involved also complicates the process, as different perspectives, such as those of users, developers, and decision-makers, may generate conflicting expectations about what constitutes effectiveness and value.

Additionally, evaluating the framework requires balancing short-term validation with long-term observation. While pilot applications may provide immediate insights into usability or adaptability, only longitudinal studies can reveal how well the framework sustains alignment between user needs, requirements, and organizational goals over time. Another difficulty concerns the need to assess intangible dimensions, such as interpretability, collaboration quality, and ethical adherence, which are not easily quantifiable but are central to the framework's claims. Finally, evaluation itself must remain iterative, acknowledging that the framework evolves through its application, which means that traditional one-time assessments are insufficient. These challenges point to the necessity of hybrid evaluation strategies, combining quantitative and qualitative approaches, and of adopting a perspective that treats evaluation not as a final step but as a continuous mechanism for refining and validating the framework.

2.5. Gaps and opportunities in user-centered SiS development

The development of user-centered SiS still faces several gaps, particularly regarding the incorporation of heterogeneity and distribution among multiple actors, which hinders the effective capture and management of requirements that reflect the diverse and evolving needs of users. Furthermore, the integration of interoperability across heterogeneous subsystems, often distributed across different technological and organizational domains, requires approaches that align both technical and user-centered criteria, impacting the overall cohesion of SiS. Additionally, usability management in dynamic and opaque environments, where rapid changes and limited transparency challenge user control and understanding, remains insufficiently addressed, with continuous and adaptive evaluation of user experience still underexplored. Finally, participatory practices are underutilized, limiting the meaningful engagement of diverse stakeholders and the incorporation of their perspectives throughout the system lifecycle. These gaps highlight significant opportunities for advancing theories, methodologies, technologies, and evaluation strategies that account for the complexity of distributed interactions, promote both technical and social interoperability, ensure adaptive usability, and foster collaborative participation.

3. Ethical considerations and acknowledgments

This study does not involve activities with human participants, and the research adhered to ethical principles in accordance with the SBC Code of Conduct. ChatGPT was used to assist in the writing and review of this article.

References

Chitchyan, R. (2024). What can requirements engineering do for emerging system of systems? case of smart local energy. In *Proceedings of the 46th International*

Conference on Software Engineering: Software Engineering in Society, pages 189–200.

Farooq, U. e Grudin, J. (2016). Human-computer integration. *interactions*, 23(6):26–32.

Guimarães, L., Martins, N., Pereira, L., Penedos-Santiago, E., e Brandão, D. (2022). Interface design guidelines for low literature users: a literature review. In *Proceedings of the 2022 6th International Conference on Education and E-Learning*, pages 29–35.

Sadeghi, M., Carenini, A., Corcho, O., Rossi, M., Santoro, R., e Vogelsang, A. (2024). Interoperability of heterogeneous systems of systems: from requirements to a reference architecture. *The Journal of Supercomputing*, 80(7):8954–8987.

Zaina, L., Prates, R. O., Delabrida Silva, S. E., Choma, J., Valentim, N. M. C., Frigo, L. B., e Bicho, A. D. L. (2024). Grandihc-br 2025-2035-gc7: Interaction with emerging technologies: An ecosystem integrating humans technologies and contexts. In *Proceedings of the XXIII Brazilian Symposium on Human Factors in Computing Systems*, pages 1–21.