Supporting User Control of User Interface Adaptation with an Extra-UI

Alaa Eddine Anis Sharaoui(✉)

Université catholique de Louvain, LouRIM, Louvain-La-Neuve B-1348, Belgium
Alaa.Sahraoui@UCLouvain.be
https://www.linkedin.com/in/alaa-eddine-sahraoui-018062159/

Abstract. In context-aware systems, user interface adaptation often occurs automatically, offering limited transparency and minimal user control. To overcome this limitation, this research elaborates on the concept of the Extra-User Interface, an additional user interface layer designed to empower users by enabling real-time observation, customization, and steering of adaptation behaviours. Positioned above the primary user interface, an Extra-User Interface extends the meta-user interface concept by providing structured services, such as inspecting and modifying underlying user interface artefacts. To assess the impact of Extra-User Interfaces on user experience, we adopt a Goal-Questions-Metrics approach, focusing on user satisfaction, comprehension, and performance. The research follows a multi-layered method, combining conceptual development, model-based design, and empirical validation. As a proof of concept, a prototype was developed and tested in a mid-air gesture-controlled environment, showing how an Extra-User Interface can enhance user autonomy and efficiency in controlling adaptation. Moreover, the research explores the applicability of extra-user Interfaces in high-stakes domains through the development of a second prototype for a data visualization interface designed to support critical decision tasks. Contributions of this work are threefold: (1) a theoretical framework defining Extra-User Interface concepts and primitives; (2) a model-based approach for designing graphical user interfaces whose adaptation is controlled by an extra-user interfaces; and (3) the implementation and evaluation of Extra-User Interface environments in realistic settings. Preliminary results validate the feasibility and usefulness of Extra-User Interfaces as a user-centric solution for controllable user interface adaptation in ambient intelligence and ubiquitous computing. AQ1

Keywords: Adaptive user interface · context-aware user interface · extra-user interface · gestural interaction · meta-user interface · user control

1 Introduction

Adapting User Interfaces (UIs) to their contexts of use aims at meeting both evolving requirements, such as the needs, desires, and preferences of individual

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users or user groups, and evolving resources, such as the available interaction devices in the surroundings that may all depend on the current situation. There are two categories of adaptation, depending on which entity is responsible for the adaptation: the end-user or the application [10].

Adaptability refers to the end user's ability to adjust the UI, while *adaptivity* or *self-adaptation* denotes the ability of application to perform UI adjustments [2]. *Adaptive User Interfaces* (AUIs) refer to user interfaces benefiting from adaptivity, which can be supported by animated transitions [8]. *Personalisation* or *customisation*, a subset of adaptivity, focuses on adapting the UI contents, presentation, and behaviour based solely on end-user data, such as personal traits [10]. When data comes from external sources, like other user groups, it results in *recommendations* instead. *Mixed-initiative adaptation* occurs when both the end user and the application collaborate to make adaptations [15].

Problem. In all cases, the adaptation process deserves to be under the user's control [9], even in the extreme case where any adaptation can be delegated to the application. To this end, it is necessary to define, design, develop, and test an interface capable of supporting the user's control over this adaptation process, known as an Extra-UI. The aim of this research is to investigate the concept of Extra-UI, to develop a design method for this Extra-UI, and apply and test it. To date, there has been little or no study of this control, and the way to implement this Extra-UI is still in its infancy.

Extra-UIs [7] are explicitly designed as an additional interface layer for **"real-time observation, customization, and steering of adaptive behaviours"**. In other words, an Extra-UI is not just a settings panel for cosmetic changes; it is a dedicated control interface sitting "above" the primary UI that allows users to inspect and modify the *underlying adaptation processes* (e.g. the rules or models that drive interface changes [19]). This concept extends the traditional *meta-user interface* [5] by giving users leverage over the adaptation engine itself, not only the look and feel of the interface, preferably through a dedicated user interface language [14] supporting the preferences [17].

For example, we will clarify that Extra-UIs enable user intervention in the **adaptive logic** such as changing how an algorithm decides to adapt the UI rather than just exposing standard user preferences. This clarification will stress that Extra-UIs support **both** types of adaptation: user-initiated adjustments (adaptability) and system-initiated adaptations (adaptivity), by providing a channel for the user to influence or override automatic behaviours. Recent research on adaptive systems emphasizes that a key design dimension is the **"extent of user control over the adaptation process"** [4], and this work targets increasing that user control and positions Extra-UIs as a unifying layer that facilitates **mixed-initiative adaptation** i.e. a collaboration between user and system in controlling adaptations.

In practice, this means the adaptive system can still make automatic adjustments (adaptivity), but the user has continuous oversight and the ability to intervene or adjust those automatic decisions (introducing adaptability). There is no contradiction because Extra-UIs do not replace automatic adaptation; rather, they augment it with user input, for example the system might normally adapt a layout when the screen orientation changes, but with an Extra-UI the user could set conditions or approve those changes, thereby blending automatic reaction with user preference.

Goal, Research Questions, Metrics. Following the Goal-Questions-Metrics (GQM) [1] framework, a hierarchical model that follows a top-down approach where a goal is first specified and associated with research questions collected and measured through metrics, contributions of this approach are presented in Sect. 2 Goal-Questions-Metrics.

2 Goal-Questions-Metrics (GQM)

To systematically evaluate the impact of the Extra-UI approach on user interface adaptation, we adopt the Goal-Questions-Metrics method. The primary **Goal (G)** is to assess whether providing an Extra-UI improves user control, understanding, and overall user experience in adaptive UIs, without significantly hindering the normal interaction. This goal is refined into specific research questions (Q), each question being associated with measurable metrics (M) (Table 1). AQ2

Table 1. GQM Description for Extra-User Interfaces.

Goal (G)	Improve user control, understanding, and experience in adaptive UIs through Extra-UI, without hindering normal interaction	
Question (Q)	**Metric (M)**	**Description**
Q1. What is an Extra-UI?	M1.1	Clarity of the definition (expert review)
	M1.2	Completeness of ontological coverage (adaptation operations, strategies, actions)
Q2. How to develop an Extra-UI?	M2.1	Functional coverage of Extra-UI primitives (discover, distribute [13], remodel, parameterize, extend)
	M2.2	Architectural compliance with continuous adaptation loop
	M2.3	Methodological completeness using SPEM (Software Process Engineering Metamodel)
Q3. How to evaluate an Extra-UI?	M3.1	Usability and user experience scores (e.g., SUS, UEQ)
	M3.2	Task success rate and effectiveness of adaptation
	M3.3	User perception of observability and controllability of adaptation

This GQM plan aims to guide the conceptualization, development, and evaluation of Extra-User Interfaces (Extra-UIs). It is structured around three key questions. The first question (Q1) seeks to define what an Extra-UI is, supported by metrics evaluating the clarity of its definition and the completeness of its ontological scope. The second question (Q2) focuses on how to develop an Extra-UI, assessed through metrics that cover service functionality, architectural alignment with continuous adaptation, and methodological completeness using SPEM. The third question (Q3) addresses how to evaluate an Extra-UI, using usability scores, task success rates, and users' perception of adaptation observability and controllability.

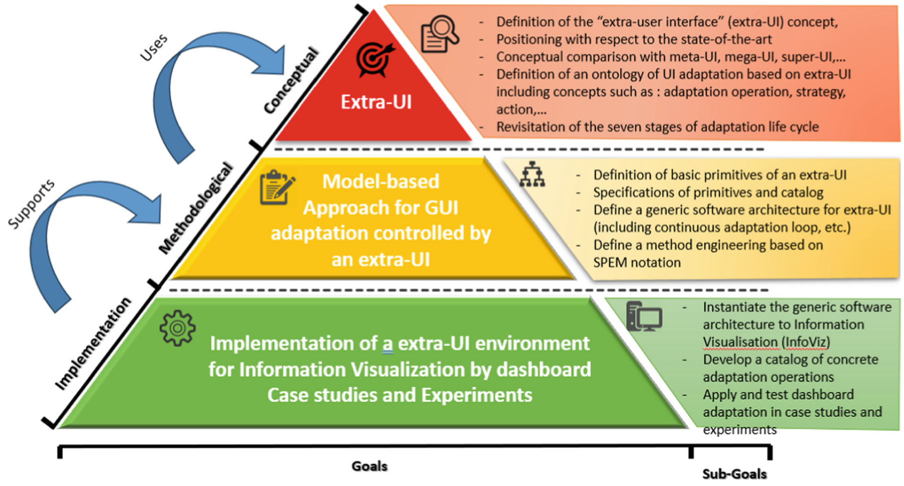


Fig. 1. The three-tiered architecture: progressing from conceptual foundations to method engineering and real-world instantiation.

3 Research Method

This research employs a three-tier approach as represented in Fig. 1:

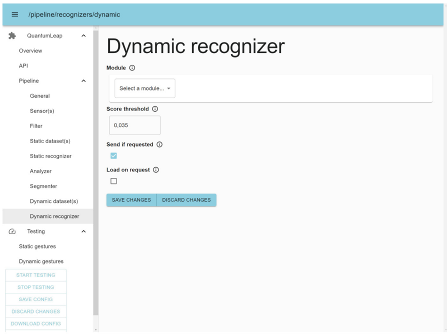
Conceptual: We define the Extra-UI concept and its theoretical foundation, identifying key services (e.g., discover, distribute, remodel, parameterize, extend) essential for supporting user-controlled adaptation. Extra-UI design guidelines ensure intuitive interaction, with controls presented contextually as overlays or side panels.

Methodological: We develop a model-based engineering method and software architecture, following a structured process for designing adaptive UIs enhanced by Extra-UIs, including clear service integration and adherence to a continuous adaptation loop.

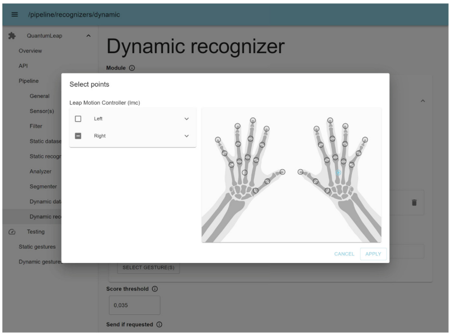
Implementation and Evaluation: Two prototypes are being developed:

1. A **mid-air gesture-controlled environment** using the QuantumLeap framework [18] and Leap Motion Controller. This allows users real-time customization of gesture-command mappings (Fig. 2).
2. A **data visualization dashboard for murder investigations**, enhanced by Extra-UIs enabling investigators to interactively control and fine-tune adaptive visualizations based on machine learning models (Fig. 3). Users can adjust model parameters, visualization thresholds, and interpretability settings directly through the Extra-UI, improving transparency and efficiency.

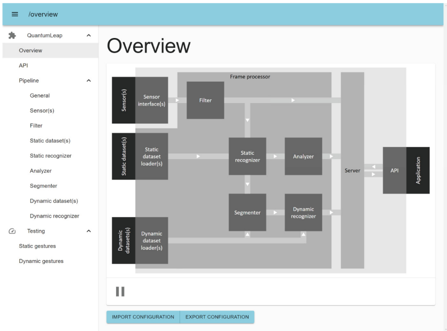
Empirical evaluation involves comparing interactions with adaptive systems both with and without Extra-UIs, employing usability questionnaires (SUS,



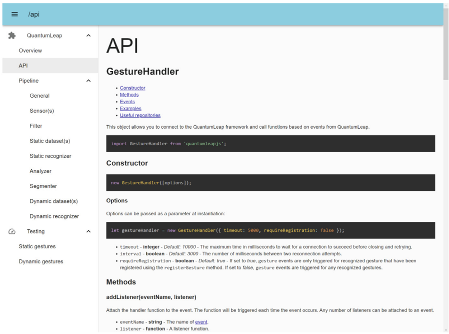
(a) Dynamic recognizer settings.



(b) Point selection dialog.



(c) Pipeline overview.



(d) QuantumLeap API (GestureHandler).

Fig. 2. Extra-UI control touchpoints in the QuantumLeap environment: (a) set score thresholds and loading policies; (b) select tracked joints; (c) inspect the adaptation pipeline; (d) programmatic control via API.

UEQ), performance metrics, and user interviews. Preliminary results demonstrate significant improvements in user control, comprehension, and satisfaction without substantial interaction overhead. Iterative feedback continuously informs refinements of the Extra-UI implementations.

4 Current Status and Contributions

The research has several activities in progress:

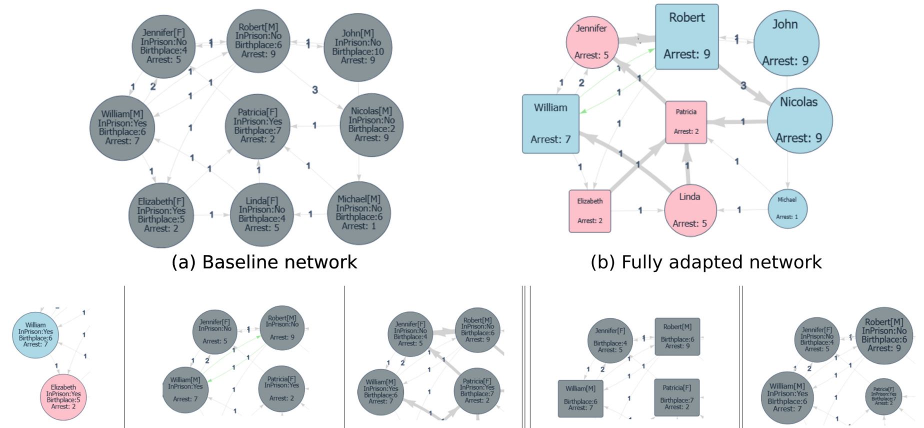
Conceptual Clarification: We define the Extra-UI concept, situating it relative to meta-UI and mega-UI frameworks, with an explicit focus on enabling runtime user control over UI-level adaptations. This definition helps distinguish Extra-UIs by emphasizing user empowerment and interactive transparency. For example, in a smart home, an Extra-UI might let users adjust lighting automation rules directly [20].

Taxonomy Development: A comprehensive literature review was conducted, resulting in a taxonomy classifying Extra-UIs by the type of objects manipulated (digital vs. physical), integration strategies (embedded vs. external), and provided adaptation services (discover, remodel, parameterize, extend). This taxonomy helps to understand existing solutions and identify research gaps [20]. While prior frameworks such as Meta-UIs and Mega-UIs enable inspection or coordination across interfaces, they rarely provide mechanisms for direct user steering of adaptive logic at runtime. The Extra-UI approach complements these by introducing a controllability dimension across the adaptation loop and by operationalizing user intervention in the decision-making pipeline of the system. This distinction positions Extra-UIs as a human-in-the-loop counterpart to autonomous adaptation, aligning with explainability and transparency.

Prototype Implementation: Two prototypes are developed and evaluated. First, the **Mid-Air Gestural Extra-UI** implementation, based on the QuantumLeap framework, enables users to interactively modify gesture-command mappings in real-time. Initial user studies validated the effectiveness of the prototype, highlighting enhanced usability and adaptability (Fig. 2). Another example is SketchiXML [6], which enables users to define how UI elements are recognized, structured and rendered through sketching, gesture training, and grammar editing, thus effectively shaping the UI's adaptation rules. By providing control over input interpretation, rendering fidelity, and widget logic, SketchiXML [6] empowers users to influence the interface design process at a higher level, making it a clear example of an Extra-UI focused on low-fidelity prototyping.

This research is also applied on an **Adaptive Data Visualization Dashboard** designed for murder investigations. It integrates Extra-UIs allowing interactive user control over visualization parameters and interpretability settings of machine learning [16] models, specifically Reinforcement Learning (RL) [11,12]. This prototype allows investigators to adjust the settings of a machine learning model or a visualization threshold, which is not analogous to changing a colour theme or font size. Instead, it directly influences the adaptive logic of the system: adjusting a model parameter (e.g. the threshold of a Random Forest for highlighting data points) changes when and how the interface adapts to new data or user actions. In essence, the user is tuning the adaptive behaviour of the system through the Extra-UI. We will make this explicit by rephrasing the example as follows: "For example, investigators use the Extra-UI to fine tune the criteria used in the visualization. The user sends the responses to the adaptive system, instead of configuring the UI appearance." (Fig. 3).

Preliminary Evaluation: Early pilot studies compared interactions with and without Extra-UIs, using usability questionnaires (SUS, UEQ), performance metrics, and user interviews. Results indicate potential improvements in user control, understanding, and overall satisfaction, validating the practicality and potential of the Extra-UI concept. Users reported increasing confidence and perceived transparency when interacting with adaptive systems. Ongoing feedback and iterative refinement processes continue to enhance usability and functionality. Two exploratory studies have been conducted so far. The first involved 12 participants using gestural Extra-UI to remap commands in real time, and the second involved 64 investigators exploring adaptive data visualizations. Both



(a) Baseline network (b) Fully adapted network

(c) Gender color (d) Same birthplace with green edges (e) Increased edge thickness shows relation (f) Square and circle for in prison status (g) Number of arrests with node size

Fig. 3. Data visualization adaptations with an Extra-UI.

used System Usability Scale (SUS) and User Experience Questionnaire (UEQ) metrics, complemented by interviews on perceived observability and controllability. Future work will expand these studies with larger and more diverse samples to strengthen statistical validity.

5 Conclusion

In conclusion, this doctoral research advocates for and investigates the use of Extra-User Interfaces as a solution to involve end-users in the adaptation loop of interactive systems. By providing an additional interface layer dedicated to observing and controlling UI changes, users are no longer passive recipients of adaptation but active participants who can tailor their experiences. The work so far has laid a strong conceptual and empirical foundation, demonstrating that Extra-UIs can significantly enhance user understanding, agency, and satisfaction in an adaptive mid-air gesture interaction setting. Ongoing and future efforts will broaden and deepen these findings, aiming to establish general guidelines and tools for implementing Extra-UIs across various domains. Ultimately, supporting user control of UI adaptation stands to make intelligent environments more transparent, trustworthy, and aligned with individual user needs – an important step toward truly user-centric adaptive systems.

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