Adaptive and intelligent user interfaces and how they adapt to users: A systematic mapping study

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Abstract. *This paper presents a systematic mapping study on Intelligent (IUI) and Adaptive (AUI) user interfaces to (i) get an overview of existing research topics and authors, (ii) identify publication trends, (iii) uncover potential gaps in research and (iv) observe the use of terms in academia. Terms AUI and IUI are used concurrently in papers; 30% of observed AUIs include some form of artificial intelligence. The focus for both is in solution proposals and validation research. Interfaces mostly adapt to history of users' behaviour, context changes, and users' actions.*

Keywords. Intelligent user interfaces, Adaptive user interfaces, IUI, AUI

1 Introduction

The idea of Intelligent user interfaces (IUI) has been around for decades, while the goal of developing computer systems which have the ability to accommodate themselves to different users, their skill level, experience and needs, is still very relevant today. Intelligent user interfaces (Maybury, 1998) are human-machine interfaces that aim to improve the efficiency, effectiveness, and naturalness of human-machine interaction. They achieve this by representing, reasoning, and acting on different models (eg. user, domain, task, discourse, and media models).

The IUI field (Alvarez-Cortes, Zayas-Perez, et al., 2007) is multi-disciplinary, interchanging the ideas from different areas, with emphasis on three core disciplines - Artificial Intelligence (AI), User Modelling (UM) and Human-Computer Interaction (HCI). A holistic meta-study (Völkel et al., 2020) was conducted on the use of intelligence in IUI research in the last 25 years. This sprouted our interest in conducting similar overview of the research area while focusing on how the interfaces are adapted to users and what terms are used to describe these interfaces in practice. Systematic mapping study was conducted in order to present comprehensive results. We hope to add some more insight to the debate on what makes user interfaces intelligent.

The main contributions of this paper are (i) Presenting an overview of primary and secondary studies on IUI, (ii) Conducting a review on methods used for IUI review form HCI point of view and (iii) Presentation of discovered research gaps in the field. The paper is structured as follows. Section 2 briefly discusses taxonomy in the field. Section 3 presents related work of secondary studies, concluded in this area. Section 4 presents the research method used to address the research objectives. Results of the systematic mapping study are presented in Section 5, while section 6 presents the conclusion and future work implications.

2 Adaptive and Intelligent User Interfaces

Adapted and adaptable user interfaces are not a point of interest in this study, but are mentioned for taxonomy clarification. Adapted user interfaces are UIs, that are adapted to the end user at design time, while adaptable user interfaces offer the end user to change (ie. to adapt) the characteristics or functionality of the UI (Schlungbaum, 1997).

Intelligent user interfaces "are human-machine interfaces that aim to improve the efficiency, effectiveness, and naturalness of human-machine interaction by representing, reasoning, and acting" (Maybury, 1998). They adapt at run-time and can make decisions about what, when, why and how to communicate with the user (Maybury, 1998). They decrease task complexity, bringing expertise to the user (in the form of expert critiquing, task completion, coordination), or simply providing a more natural environment for users to interact. IUI field is an overlap of multiple different fields, with Human-computer interaction and Artificial intelligence being the major ones. HCI provides efficient designing techniques for user interfaces and AI is used to automate or build intelligence in said interfaces (Shaikh et al., 2017).

In practice, the terms intelligent user interface and adaptive user interface are used concurrently in papers. The use of AI techniques to design adaptive in-

terfaces has been an accepted approach applied in various domains and applications (Alvarez-Cortes, Zayas-Perez, et al., 2007). Such adaptive interfaces, using AI methods and techniques are considered intelligent user interfaces. The term *adaptive intelligent user interfaces* (Ahmad et al., 2004, Raheel, 2016) has sometimes been used in papers proposing user interfaces with intelligent adaptive mechanisms, which are capable of monitoring the user behavior and then adapting the interface accordingly, beyond of the scope of predefined rules. Tahir et al. (Tahir, 2015) recognized *user-adaptive intelligent user interfaces* as a branch or a subset of IUIs. Volkel et al. (Völkel et al., 2020) observed the concurrence in their meta study of 504 papers on Intelligent user interfaces and confirmed that the researchers might call an entity both "intelligent" and "adaptive". However it is clear that intelligent systems with interfaces cannot be labeled as IUI, if they are only intelligent in machine point of view, but not in user or HCI point of view (Shaikh et al., 2017).

The terms are often confused and intertwined in papers (e.g. Patrick, 2003, Alvarez-Cortes, Zarate, et al., 2009, Alvarez-Cortes, Zayas-Perez, et al., 2007), as some researchers declare the terms as synonyms, even though not all adaptive user interfaces can be labeled as intelligent. By definition, IUIs are aimed to improve the efficiency, effectiveness and naturalness of human machine interaction by representing, reasoning and acting on models of users, domain, task, discourse and media. Therefore, "intelligent systems must be data driven, self-aware and have the capability to learn over time from experience" Mezhoudi and Medina, 2015. In this study we were interested in both, intelligent and adaptive user interfaces.

3 Related work

Similar secondary studies have already been conducted and are presented in this section. Gonçalves et al. (Gonçalves et al., 2019) conducted a systematic literature review on intelligent user interfaces in 2019, though only presented preliminary results with little data extraction and interpretation were presented. They investigated the design of IUIs in the context of contemporary software systems. Authors identified context model, dialog model and user model as most used models in IUI design. They also report IUIs mostly adapt to context of use, user's actions, user's preferences, context changes, device characteristics, platform characteristics, user behaviors and users´ characteristics. The research questions focused on domains where IUIs are used, trends regarding use if IUI in contemporary software systems and IUI evaluation were left as future work within this SLR.

In 2017 Sanchez et al. (Sanchez et al., 2017) conducted a similar systematic mapping study on IUIs, with focus on Ambient Assisted Living (AAL) technologies. The study included 43 papers and observed type of used media models (graphics, natural language, gesture), type of solution (application, mobile system, website), relationship between IUIs and Ambient assisted living and overview f applications that have adopted IUIs. Authors highlighted the importance of designing user-friendly interfaces.

Volkel (Völkel et al., 2020) conducted a Meta-Analysis of articles, published in ACM's database in the span of last 25 years. Study was conducted as text analysis and focused on intelligent aspects of IUIs from the view of the IUI community. Paper focused on what researchers deem intelligent, what characteristics are used to describe IUIs and how else are they characterized. Authors noted that considerable amount of articles never use the term 'intelligen*'. Authors conducted it has remained elusive what exactly renders an interactive system or user interface deserving of the term intelligent.

Miraz et al. (Miraz et al., 2021) conducted a survey on universal usability of IUI and AUI on 165 papers. They focused on whether the UI should be adaptive under system control or be made adaptable under user control, and conducted a performance evaluation of plasticity. They concluded adaptations can improve usability, but the trade-offs should be further analyzed. A taxonomy proposition for comparison of the various AUIs is also presented in their work.

To the best of our knowledge, none of the recently conducted secondary studies focus on the similarities and differences in the use of terms AUI and IUI in academia.

4 Method

The goal of this study is to determine current state-of-the-art of the research area, observe how are adaptive and intelligent user interfaces designed and developed, and to discover some of the possible research gaps. The study was conducted by following the guidelines for conducting a systematic mapping study, written by Petersen et al. (Petersen et al., 2008). The process was extended with iterative improvement of classification scheme during the pilot study, conducted on 20 papers. The data extraction and mapping process was based on the review of the whole paper, not just abstract and keyword screening.

4.1 Defining research questions

The objective of this study was to obtain a comprehensive overview of current research in the field of Intelligent User Interfaces, with emphasis on the assessment of human-computer interaction aspect. This lead to the following research questions:

- RQ1: What are key bibliometric facts of included publications?
  - RQ1.1: What are the publication counts in recent years?

  - RQ1.2: Which journals and conferences include papers on IUI and AUI?
  - RQ1.3: Who are the contributors in the field, who scientifically promote AUI and IUI topics?
- RQ2: How is research in the IUI area conducted?
  - RQ2.1: What types of papers are published in the area?
  - RQ2.2: Which domains do the identified publications address?
- RQ3: How is artificial intelligence included in user interfaces?
  - RQ3.1: What actions do intelligent and adaptive user interfaces perform?
  - RQ3.2: Which algorithms and methods are used to include the intelligence?
- RQ4: How are AUI and IUI designed and developed?
  - RQ4.1: What adaptive criteria are taken into account?
  - RQ4.2: What models are used in interface design?
  - RQ4.4: What programming languages, technologies, frameworks and tools are used?

4.2 Conducting search and screening

After identifying the research questions we defined the appropriate keywords for finding all published papers with topics from IUI. As we wanted to provide a general overview of the research area, broad keywords were used. As Volkel (Völkel et al., 2020) already pointed out, it is evident the articles in the Intelligent user interface research area do not always refer to their solutions with the terms "intelligen*". Therefore we broadened our search to also include term "adaptive", which was one of the most commonly used other terms used to describe them. The final query used was following: *"intelligent user interface" OR "intelligent user interfaces" OR "IUI" OR "adaptive user interface" OR "adaptive user interfaces" OR "AUI"*

There are many possible digital libraries available for conducting a literature search. We chose a wide range of the established ones: IEEE, ACM, ArXiv, Web of Science, Science Direct and Scopus. With pilot preliminary search, 5022 pieces of literature, fitting this criteria were found. Search was then limited with the exclusion criteria, presented in Table 1. The search was conducted on 19th and 20th April 2021.

Number of papers we found with automatic search in the first stage, by following the selected query, is presented in Table 2. All together 5022 possibly relevant papers were acquired. The highest number of possibly relevant studies was found in Scopus digital library.

The first stage of screening process consisted of acquiring the possibly relevant literature automatically from selected databases. In the second stage of screening, exclusion criteria E2 (year), E3 (literature type) and E7 (field) were applied, which reduced the number of possibly relevant papers to 1384. In the third phase, we screened the papers by abstract and applied

Table 1: Inclusion and exclusion criteria

	Criteria	**Description**
IC1	Field	Include studies, addressing IUI or AUI.
IC2	Language	Studies must be written in English.
IC3	Availability	Studies must be accessible electronically.
IC3	Area	Computer science and informatics or HCI literature.
EC1	Area	Exclude any non-computer science or non-HCI literature.
EC2	Year	Exclude any literature, published before 2010.
EC3	Literature type	Exclude any literature which is not journal or conference article (eg. books and theses).
EC4	Language	Exclude any studies, not published in English.
EC5	Duplicates	Exclude any duplicated studies found in multiple databases.
EC6	Availability	Exclude any studies that are unavailable online.
EC7	Field	Exclude studies outside of the IUI or AUI research area.
EC8	Short articles	Exclude articles with number of pages < 4.

Table 2: Papers retrieved from selected digital libraries

Database	Nr. of papers
ACM	298
ArXiv	18
IEEE	501
Science Direct	297
Scopus	2802
Web of Science	1095
Together	5022

E1 (Area) and E7 (Field). In the fourth stage, duplicates were removed (E5) in the chronological order of screening databases (IEEE, ACM, ArXiv, Web of Science, Science Direct and Scopus, respectively). In the fifth stage, we screened the content of 448 potentially relevant papers and further reduced the number of potentially relevant papers to 226.

4.3 Sampling

After obtaining the final number of relevant papers, we conducted sampling. Total number of relevant studies remaining after screening was 226, which represents a fairly small population size. A sampling strategy suggested by Israel (Israel, 1992) was followed - using a sample size of a similar study. Sanchez et al. (Sanchez et al., 2017) conducted the systematic mapping study IUIs in Ambient Assisted Living (AAL) technologies on the population of 43 papers, while Guerino et al. (Guerino and Valentim, 2020), who was observing evaluation and user experience of natural user interfaces, included 56 papers. After observ-

ing similar studies in the field, the final sample of 80 studies was included in our systematic mapping study. Papers were randomized before selection, with every paper having the same probability of being included.

4.4 Classification and data extraction

This section includes detailed overview of our classification scheme, which is later summed up in Table 3. First version of classification scheme was tested on 20 studies. We implemented some iterations during the piloting phase, mostly focused on changing the grouping the selected variables, while also some new variables and some additional possible values for existing variables were brought to our attention. After the iteration, the classification scheme was finalized, and was used as a data extraction tool for all the collected papers.

5 Results

This section presents and discusses the results of classification and data extraction of 80 studies. The objective of this study was to provide an overview on intelligent user interface research field and provide an overview in differences between what is labeled as AUI or IUI in practice. Gathered data is also available in a shared file. [1]

5.1 Key bibliometric facts

This section aims to answer RQ1. As noted in the previous chapters, we included intelligent and adaptive user interfaces in our study, as they are often used concurrently. We therefore firstly noted the terms primarily used for observed user interface in each paper. Use of term in title and in keywords was also weighted. Even if authors did not follow the definitions of IUI and AUI distinction, we noted the term used in the paper. Most papers (63%) used the term adaptive user interface, while 35% used the term intelligent user interface. One paper primarily used the term multi-modal user interface (reffered as MUI in this text). The results with citations to papers are displayed in Figure 4.

The selected papers were published between 2010 and 2021. As illustrated in Figure 1, the number of studies seems to be relatively constant, with some noticeable negative deviations every second year between 2010 and 2018, which could present a trend or could be a result of our sampling. Number of publications has slightly decreased in 2019 and 2020, compared to the trends in previous years. The representation of papers, published in 2021 is incomplete, since the initial query was conducted in March 2021. Number of papers primarily using the term AUI is higher compared to the number of studies, primarily using the term IUI.

[1] https://univerzamb-my.sharepoint.com/:x:/g/personal/sasa_brdnik_um_si/EQCj5P6nJW5PijMi61_VUqABkLDp5L8v12vcRmAH3TEWnQ?e=bjiXu3

Table 3: Research evaluation scheme

ID	Variable	Descriptors
E1	Term used	IUI, AUI, MUI
E2	Lit. type	Conference, Journal
E3	Research type	Validation, Evaluation, Solution proposal, Philosophical Paper, Opinion paper, Experience paper, Lit. review
E4	Source type	Primary, Secondary study
E5	Time scope	Cross-section, Longitudinal
E6	Standpoint	Software engineering/AI, Human-computer interaction
E7	Methodology	Case Study, Experiment, Grounded theory, Literature review, Mapping study, Meta-analysis, Observing, Other, Prototype, Questionnaire, Interview, Systematic literature review, Systematic mapping study, Field study
E8	Domain	Health, Education, Software development, Entertainment/Games, Industry, Communication, Cartography, Transportation, Accessibility, Security, Military, Tourism
E9	Engineering phase	Testing, implementation, design, analysis
E10	Action performed by intelligent entity	Assistance, Adaptation, Analysis, Communication, Creation (of content, etc.), Decision, Detecting or capturing information, Illustration, Improvement, Interacting with user, Learning Modeling, Monitoring, Perform, Prediction, Processing, Recommendation, Selection, Understanding, Utilisation
E11	Adaptivity criteria	Context changes, Device characteristics, Platform characteristics, History of users' behavior, Users' actions, Users' characteristics, Users' needs, Users' preferences, Task, User's emotions
E12	Models used	Context, Dialog, User, Device, Layout, Ontology, Platform, presentation, Task, Domain
E13	Proposed solution	Agent, Algorithm, Application, Approach, Architecture, Concept, Framework, Guidelines, Interface, Model, Not applicable, Other, Software, System, Technique / Method
E14	Environment	Open description of software environment

To get a broader view on who are the contributors in the field, who scientifically promote IUI topics, we observed where are first author's primary institutions located. Most of the first authors are active in Germany (13 authors), India (6 authors), and in Spain, China and Canada (4 first authors each). The largest part of the researchers (46,3%) were active in Europe, while further 35% were active in Asia. Further 11,3% of authors were from North or South America, while

Table 4: Term used

Term	%	Papers
IUI	36%	S3, S6, S8, S9, S10, S15, S16, S17, S18, S20, S22, S27, S29, S36, S37, S38, S49, S53, S59, S61, S62, S64, S66, S68, S70, S72, S76, S77
AUI	63%	S1, S2, S4, S5, S7, S11, S12, S13, S14, S16, S19, S21, S23, S24, S25, S26, S29, S30, S31, S32, S33, S34, S35, S39, S40, S41, S42, S43, S44, S45, S46, S47, S50, S51, S52, S54, S55, S56, S57, S58, S60, S63, S65, S67, S69, S71, S73, S74, S75, S78, S79, S80
MUI	1%	S48

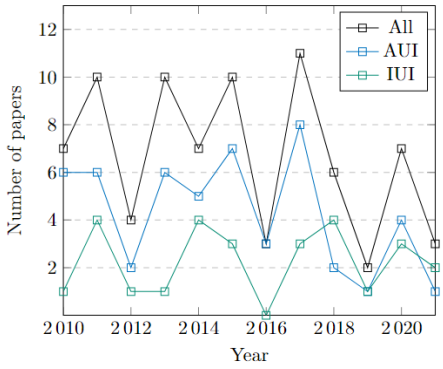

Figure 1: Number of publications by years

a smaller percentage (3,8%) were based in Australia and in Africa. We observed which authors are the most active in the observed fields and promote them scientifically. The most prominent author included in three papers is Dr. Sucheta V. Kolekar from India.

The main observed journals, where observed papers on Intelligent user interfaces were published are Interacting with Computers, Procedia Computer Science, ACM Transactions on Interactive Intelligent Systems and Personal and ubiquitous computing, all but one represented with two papers in our study. All of the mentioned journals are peer-reviewed. The main conferences observed are International Conference on Intelligent User Interfaces with four papers included in our sample, International Conference on Human-Centered Software Engineering (HCSE), with 3 papers included in our sample and ACM SIGCHI Symposium on Engineering Interactive Computing Systems, which is also represented with three papers in our sample. Most of the included papers were conference papers and proceedings (77,5%), while journal papers represented 22,5% of our sample. Division based on the term used is similar, conference papers represent most of the included AUI (78%) and IUI (75%) papers, similar ratio of IUI (25%) and AUI (22%) papers are published in journals.

5.2 Research data

This subsection aims to answer the RQ2 (How is research in the IUI area conducted?). Research type classification per publication year is presented in Figure 2. It is visible that most of the observed studies were solution proposals and validation researches. These representative trend of these two research types is visible in all observed years. No experience or opinion papers were included in our sample, while a small number of literature reviews, evaluation research and philosophical papers were observed (3 papers of each type).

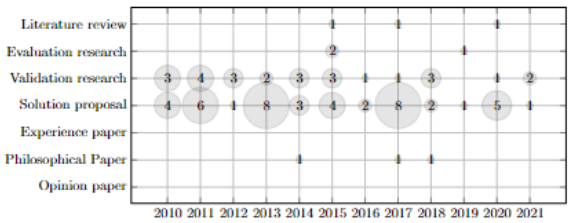

Figure 2: Publications per year by research type

Most of the papers included were solution proposals or validation researches, as visible from Figure 3. Closer look in division of papers by dominantly used term shows solution proposals present similar percentage of AUI and IUI papers (59% and 54% respectively). Same goes for validation research (29% of AUI and 36% of IUI). No philosophical papers or evaluation research were in included for IUI, while we noted one literature review for AUI and two for IUI. Most of the studies (50 papers) have been focused on software development area, with 29 studies offering solution proposals, while 15 of them were classified as validation research. Further, health presented the second most represented application domain with 7 papers. Most common contribution in observed papers was a framework (18 papers: 11 AUI and 7 IUI), followed by an interface (14 papers: 6 AUI and 8 IUI) and an approach proposition (5 papers; 2 AUI and 3 IUI). We have further observed the engineering phase of presented contributions in 68 studies (two literature reviews presented no additional solutions in the paper and were excluded). Most of the proposed solutions were in the testing phase (33 papers) or in the implementation stage (31 papers). Only a few papers presented the contribution in the analysis phase. Ratio between engineering phases is very similar for AUI and IUI papers. Majority of both are in testing phase (45% of AUI and 46% of IUI), while a third are in implementation phase (33% of AUI and 32% of IUI). Further 18% of AUI and 7% of IUI papers presented solutions in design phase, while some papers presented work in the analysis phase (2% of AUI and 11% of IUI).

5.3 Intelligence in user interfaces

In this section we aim to answer the RQ3 (How is artificial intelligence included in user interfaces?). Many

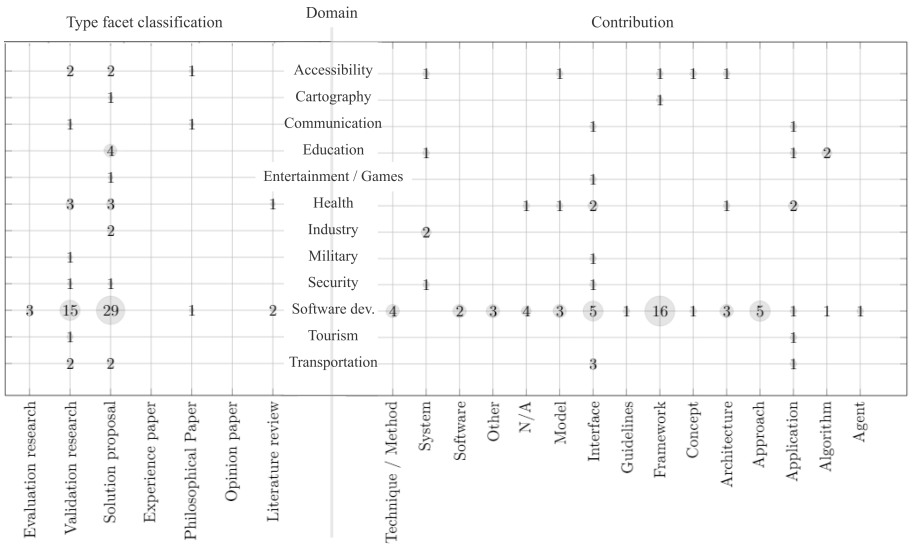

Figure 3: Research facet and type of contribution by domain

publications observed user interfaces perform more than one action. Most commonly performed action by intelligent entities was adaptation, which was described in 48 papers, followed by detecting or capturing information (18 papers), providing assistance (13 papers), recommendation (6 papers), interacting with user (4 papers) and analysis or understanding (3 papers each). Performed actions of user interfaces are visualized in Figure 4 (only primary studies included). The division between AUI and IUI shows they both perform adaptations of user interface or its elements, however, the action is more common with AUI papers. Detecting or capturing information, recommendation, analysis and understanding were observed in the same amount in IUI and AUI papers. More AUI papers focused on providing assistance, while more IUI papers covered creation of content (S49 - algorithm creates tables with unique color and digit combination) and illustration (S8 -virtual illustration of agents movement), conducted modeling and monitoring. It is interesting actions of prediction (S31 - predicting what to offer user next, S34 - predicting the contacts that a user will most likely call next on his mobile phone) and decision making (S31- deciding on UI adaptations) can be observed in AUI papers.

5.4 Design and development process

In this section we aim to answer RQ4 (How are AUI and IUI designed?) with overview of the adaptive criteria taken into account in the design process. In the process off designing the IUIs, there are generally various adaptive criteria into the account. We observed 68 papers (two secondary studies excluded), where researchers described the adaptive criteria. Mean number of adaptive criteria used in UI was 1,6. As visible in Figure 5, the most common criteria for adaptation

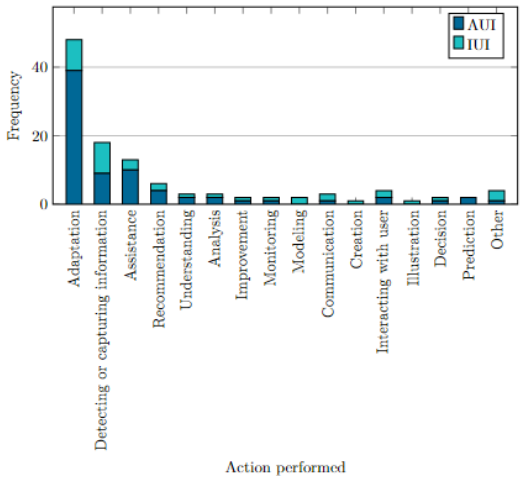

Figure 4: Actions performed by intelligent and adaptive user interfaces

is user's behaviour (25 observed papers), followed by the context change (21 papers), users actions (19 papers), users characteristics (15 papers), users needs (10 papers) and preferences (9 papers), and device characteristics (9 papers). Platform characteristics and users emotion were not as commonly used criteria. In terms of user interface type, papers describing AUI, have mostly used history of users behaviour (19 papers) and context changes (14 papers) as adaptive criteria, while papers describing IUI mostly focused on user actions (7 papers), context changes (7 papers) and history of their behaviour (6 papers). Model-driven approach has been used for the generation and development of adaptive user interfaces. User interface designer or developer specifies one or multiple models from which a UI is later developed or even generated. Researchers in both, AUI and IUI papers most commonly used the user model when they designed user interfaces. Further the task, context and dialog models were also commonly used in the observed papers.

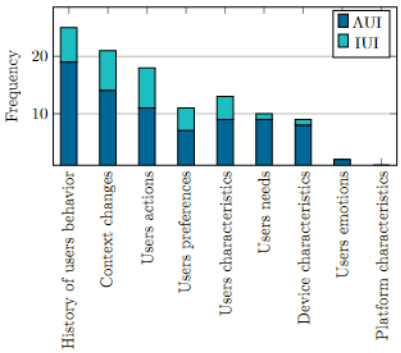

Figure 5: Adaptive criteria

To further analyze the development process of state-of-the-art IUI and AUI propositions, we noted the programming language, frameworks and tools, researchers used in their work. Not all researchers reported the metrics, and in some cases the variables were not applicable for the proposed solution. Researchers reported at least some of the variables in 49 papers. Most commonly the mobile applications were developed for Android OS (6 papers), while most commonly reported programming language was Java (6 papers). In terms of sensors, the most represented sensor was Kinect, which was used in three studies. In terms of software and development tools, three studies reported the use of MyUI Prosperity4All, 2017, an infrastructure, generating the individualized user interfaces and performing adaptations to cater the diverse user needs, devices and environmental conditions during run time. Further three papers reported use of Cedar Studio software.

6 Discussion and conclusion

In this work a systematic mapping study on Intelligent user interfaces was presented with the aim of providing the IUI research community with unbiased, objective and systematic overview of research between 2010-2021. We believe it would be beneficial to periodically conduct such studies to make researchers aware of progress, related work and possible gaps in the research. We observed that most of the research is conducted in the software development domain, with interests also showing in health, accessibility, transportation and education area. With most of the papers being solution proposals or validation research, we observe a lot of suggestions for IUI and AUI, which are already in the implementation or testing phase. Based on the number of publications by years (Figure 1), we can conclude both fields (AUI and IUI) are active and evolving further. Large number of papers (18) proposed new frameworks, which we interpret as development of the area and development process in a more structured and formal manner. Some of them focus on automatic adaptation of user interface (S13), on optimizing the design (S3, S65) and development process (S24, S45), while others focus on accessibility (S67, S79) or data mining (S16). We observed little difference in research approached in AUI and IUI papers. The research trends in research type, research phase, proposed solutions and UX and usability assessment is very similar in both fields. We also note a lot of observed AUI papers (16 papers - 33% of all AUI papers) included artificial intelligence techniques or algorithms. We therefore conclude that the AUI and IUI fields overlap and researchers should aim to separate the terms in future in order to achieve higher level of unification and standardization in the field.

Some of the papers mentioned Maes's (Maes, 1995) list of three major challenges of IUI field, which are presentation (computer-human interaction phase of IUIs), competence (AI methods or techniques) and trust (includes intelligibility and privacy challenges). In our overview we have gathered some additional challenges in IUI area. Savidis (S2) mentions lack of support and standards for including adaptive behavior to the existing non-adaptive systems, while Todi et al. (S12) adds cost of adaptation as a concern for adapting user interfaces. Contradictory to challenges presented by Maes, Ruijten et al. (S70) suggest the use of IUI as means of increasing the trust in autonomous vehicles. Researchers (S15) also expressed concern over potential high costs, that could be imposed by a carelessly picked adaptation and further advocate for strong policies on adaptation. Peissner et al. (S73) expressed concern over possible usability problems, including disorientation and the feeling of losing control in adaptive user interfaces. They advocated for transparency and controllability of automatic adaptations.

We observed no longitudinal studies in our sample, which is surprising, as the most commonly used model in observed IUIs was user model and the most commonly used adaptive criteria was history of user's behaviour, which must obtain at least some user-related data before it can commence the task of personalising the interface. It would be interesting to observe usability assessments over longer periods of time, from users' first interaction with the UI until the point in use when they are comfortable with the UI and when IUI or AUI have enough data to create an integrated user model and can further adapt itself to the user.

6.1 Threats to validity

Threats to the validity are possible in identification of relevant primary research, sampling, data extraction and classification. Some of the studies were excluded in our data query (eg. multi-modal interfaces). A large number of older, ground-setting studies were excluded, as we were interested only more in the recent trends. With randomized sampling some of the important recent studies could have been excluded. Data extraction and classification process was challenging due to wide range of the research area, interdisciplinarity and varying quality and complexity of the observed studies.

To improve validity of initially proposed classification scheme, we conducted a pilot study and improved the scheme over various iterations.

6.2 Future work

One of the main identified challenges is lack of consensus on when is user interface intelligent. Future research will focus efforts towards establishing that. As we observe a lack of evaluation research in the field, an overview of usability and user experience assessments of IUIs would be beneficial to further investigate the state of the research field and current IUIs.

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