RUNA-KAMACHIY: CONCEPTUAL INTEGRATION MODEL BETWEEN HCI AND ADAPTATION ORIENTED TO USER INTERFACE USABILITY

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ABSTRACT: There are two key areas related to user interfaces: Human-Computer Interaction (HCI) and Adaptation. Adaptation builds user interfaces adapted to user characteristics and preferences, but it does not take into account the basic principles associated with human interaction. HCI, takes into account said principles, but does not address the varying preferences and user characteristics. The basic premise of this research is that the integration of HCI with Adaptation can yield better user interfaces, since both areas can complement each other. This paper analyzes and compares several research works on HCI and Adaptation. Based on this analysis, this paper proposes a conceptual integration model of HCI and Adaptation.

KEYWORDS: HCI, Adaptation, Usability, User Interfaces, Dynamic User Interface Generation

1. INTRODUCTION

Usability is a quality attribute that is reflected both in the interaction and presentation of user interfaces [20]. One important usability issue is user heterogeneity. Users have different mental models to learn and comprehend. This means that, while some people may easily interact with user interfaces, others may have important difficulties to accomplish similar tasks [26].

User interfaces and usability involve several knowledge areas: Human-Computer Interaction (HCI), Adaptation, Human Factors Engineering, and Ergonomics, among others. Some common problems addressed by the above disciplines are: use of color in user interface design [4], type of information to display [31], and task automation [9]. Although these disciplines focus on improving the interaction between users and systems, there is an important difference: all of these disciplines tend to work isolatedly and each one solves the above problems using their own models, techniques, and technologies. This situation makes it difficult to provide users with an integrated solution to their interactions with systems, solutions that both address users’ individual characteristics (e.g., preferences, specific tasks, context) and are built according to well-proven methodologies [30][13][22].

Two areas that may benefit from integration are Adaptation and HCI. Adaptation focuses on modifying content, presentation, and navigability, based on user characteristics and necessities. HCI does not directly address some user interface issues, such as color and graphics choices, or ensuring that users
are not overwhelmed with excess information.

HCI focuses on design techniques and models that address color and shape choices, structures, and I/O devices, with a focus in making user interaction more natural, closer to real-life concepts. HCI does not address the issue that different users may have different characteristics, knowledge, and preferences.

This dichotomy yields the following question: How to integrate the methodological rigor of HCI for user interface design with the characterization of users and their context provided by Adaptation? [16]. To address the above question, this paper proposes a conceptual integration model called Runa-Kamachiy. This model introduces HCI formalisms into Adaptation models to improve usability of user interfaces. The expected long-term result is that users’ interaction with the system would be dynamic, according to their own individual characteristics and preferences.

The remainder of this paper is organized as follows. Section 2 describes background concepts of HCI and Adaptation. Section 3 describes related work. Section 4 describes the Runa-Kamachiy model and Section 5 concludes.

2. BACKGROUND

This section describes basic concepts associated to Human-Computer Interaction (HCI) and Adaptation.

2.1 Human-Computer Interaction (HCI)

According to ISO DIS 20282-1, “The control and information giving elements of a product and the sequence of interactions that enable the user to use it for its intended purpose” [5]. The goal of user interfaces is to make the interaction with information systems as simple and natural as possible. Also, HCI focus on assisting users to accomplish tasks efficiently [8].

User interfaces are also “a logical layer that supports a dialog with the user and that has two main functionalities” [19]: i) Input, receive orders, information, and commands provided by the user through various interaction devices; and, ii) Output, present results, feedback, and cooperate with the user to accomplish tasks through the system.

Another important concept is plasticity, “the capacity of a user interface to withstand variations of both the system physical characteristics and the environment while preserving usability”. [28].

There are some HCI standards that are used to achieve a good user interface design and to comply with usability criteria. These standards provide criteria, techniques, and concepts that are general for any type of information system. According to Bevan [5], HCI standards are grouped into four categories: i) Context and Test Methods, which identify effectiveness, efficiency, and satisfaction criteria for a particular use context (e.g., ISO 9241-11, ISO/IEC 9126-1); ii) Interfaces and interactions, which support user interface attributes such as look and feel, behavior, evaluation criteria, among others (e.g., ISO 14915, IEC TR 61997); iii) Development process, the activities required to develop user-centric systems (e.g., ISO 13407, ISO TR 16982); and iv) Usability capability, which addresses process improvement and making systems usable, healthy, and safe (e.g. ISO-PAS18152, ISO-TR 18529).

2.2 Adaptation

Adaptation in HCI is modeled as two complementary system properties [28]: adaptability, the ability of the system to allow users to modify pre-defined system parameters; and, adaptivity, the ability of the system to adapt automatically.

Adaptation in HCI is modeled as three orthogonal axes in the user interface design space: Goal, Meaning, and Temporality. Goal is the purpose of Adaptation: adaptation to users, adaptation to the environment (context), or adaptation to the physical
characteristics of the system (e.g., interaction devices). Meaning is associated to the system components that are involved in Adaptation: a) System Tasks Model, “how the work tasks could be achieved with the introduction of the designed system” [28], and User Tasks Model “formal or semi-formal transcription of the real world activities” [28]; b) Rendering Techniques that denote the system’s presentation and behavior; and, c) Help Subsystems, that provide assistance in the system and the task domain. These components, defined in [28], can be modified to satisfy the Adaptation goal (first axis in the design space). Temporality of the Adaptation can be static or dynamic [28]. Static adaptation is the coupling of services before the execution of the system. Dynamic adaptation involves all of the modifications performed during the execution of the system.

Yen et al. [34] define seven variables to adapt user interfaces in the space design: i) User Performance, the amount of errors in the execution of a task and the time required to accomplish it; ii) User Goals, high-level or low-level goals required to accomplish a task; iii) Cognitive Load, which can be measured through psychophysical means (electroencephalogram), subjective means (evaluated by the user him/herself), Secondary Task Method (the user performance is measured while executing a secondary and a main task simultaneously); iv) User Awareness of the context; v) User Knowledge, vi) Situation Variables, such as system state, environmental conditions, social characteristics, etc.; and, vii) Task Variables, errors or failure of a process or the system.

The user profile model [29], must provide the means to do implicit adaptation (without direct user intervention). A related concept in HCI is model-based user interface engineering that creates and redefine models to describe user interfaces at different levels. Such descriptions include tasks, presentation, interaction, and platform model [1]. The user model is the central point to generate services that take into account user characteristics.

2.3 Usability

According to ISO 9241-11, usability is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”. Usability has two important dimensions: usability combined with adaptation and usability combined with HCI.

2.3.1 Usability and Adaptation

Adaptation of user interfaces is a mechanism to adapt interfaces to specific device characteristics and services required by the user. Adaptation modifies the interface according to requirements, objectives, and utilization context [21]. However, user interface adaptation has not been successful in practice, since Adaptation is, in some cases, unpredictable and fails to provide users the feeling of control over the system [21].

Gavrilova and Vasilyeva [12] propose a user model for distance-learning systems based on the individual learning process. They propose a user interface model based on four parameters: i) Functional parameters that contribute to system interaction behavior; ii) Interaction parameters that determine usability during system interaction and characteristics of interaction scenarios; iii) Service parameters that include all of the objects that participate in a service and user interface dialogs; iv) Interface design parameters that characterize screen design and degree of participation of users.

The work in [3] indicates that Adaptation improves usability when it takes into account user characteristics given by a profile. Therefore, application navigation and presentation is facilitated, according to device characteristics. Alvarez-Cortes et al. [3] indicates that context-sensitive, unpredictable user interfaces reduce usability. To solve this issue, they propose
artificial intelligence techniques that make the adaptation process less intrusive.

Overall, usability in adaptation has four main aspects: creating personalized systems, addressing user tasks, reducing information overload, and provide help in new and complex applications.

2.3.2 Usability in HCI
Usability is defined as “Usability is when a user utilizes the system's functions easily, properly and clearly”[21]. Nielsen [24] proposes ten user interface design principles with a focus on usability: visibility of the system state; unification between the system and the real world (utilize user concepts); give users freedom and control over the system; consistency and standardization of concepts and actions; error prevention to avoid interaction problems; recognition over recalling, to reduce user memory overload; flexibility and efficiency, to improve interaction of both beginner and expert users; an aesthetic and minimalistic design, to provide only the required information to the user; assistance to recognize, diagnose, and recover from errors; and, help and documentation.

3. RELATED WORK
This section describes related research in dynamic user interface generation. These works are classified according to the usage of adaptation and HCI elements.

3.1 Approaches with HCI but no Adaptation
There are information systems that are created specially for users with visual impairment. However Savidis and Stephanidis [27] indicate that those systems are rigid and they should be dual, addressing both people with and without visual impairment. They propose HOMER, a system that uses HCI principles to generate interactions for people with visual impairment and making it easier to transform a system designed for normal people into a system for people with visual impairment. However, HOMER only addresses aspects related with visual communication. It does not adapt to user characteristics, preferences, or context.

3.2 Approaches with Adaptation and without HCI
According to Schwartze et al. [28], user interface generation should be context-sensitive and take into account user preferences. They indicate the necessity of automatic run-time adaptation to provide users with mechanisms to intervene the adaptation process. To achieve this goal, they propose a Dynamic Layout Model that comprises visual elements, such as buttons, images, text, etc. and defines the spatial relation between those elements and resizes and distributes them, according to the environment characteristics, platform, and user. One advantage of this model is that adaptation not only can be automated, but the user can intervene in that adaptation. Moreover, this approach generates interfaces based in generic, platform-independent models. However, adaptation only focuses on visual design; it does not take into account other user characteristics. In addition, this approach does not use HCI principles when positioning and resizing user interface components.

Ye et al. [33] adapt user interfaces according to devices and their characteristics. This is one of the most common adaptations, given the increasing usage of mobile devices [23][18][10]. Although this kind of adaptation adjusts interfaces based on devices and, in some cases, in user characteristics [10], it does not address interface elements, such as color and plasticity, which can affect usability.

According to Gajos et al. [12], user interface generation assumes that the user: i) has no physical limitations; ii) utilizes typical I/O devices; iii) has typical perceptive, cognitive and motor skills; and iv) is in a stable and warm environment. Gajos et al propose SULE, a runtime user interface generation system that takes into account tasks, preferences and user skills. SULE generates interfaces according to a
user preference model and a user motor skills model. SULE does not take into account other user characteristics that affect usability, such as experience, learning styles, and environment.

Blumendorf et al. [6] describe a meta-model to dynamic user interface generation that comprises: i) Definition Elements, for static structures; ii) Situational Elements, which change across time and change the state of the model, i.e., task states; iii) Execution Elements, which formalize execution logic and model semantics. Their meta-model does not take into account HCI elements that would allow users to naturally interact with the system.

Lehmann et al [18] support the vision of [6] through an intelligent system that detects changes in the environment and modifies the meta-model. However, they indicate the need to generate a dynamic system based in the user preferences.

3.3 Approaches with both adaptation and HCI

Breiner et al. [7] point out usability problems associated to new devices, due to different user interface paradigms, complexity, look and feel, and interaction styles. The acceptance degree of a user interface is determined by ease of use and comfort. Device utilization can be more efficient if the interface adapts to the user necessities and characteristics [7], and if it provides context-sensitive information, particularly user location. They propose SmartFactory, a system that controls user interaction with different devices and adapts user interfaces to the functions of each device and the user role at runtime. A drawback of this system is that user interfaces address a static user, a user that does not change over time. Another drawback is that this system does not utilize some important HCI design principles: visibility, match between system and the real world, consistency, error prevention, plasticity, and others [24].

Akoumianakis y Stephanidis [2] propose a tool called USE-IT, to create adapted user interfaces that utilize some HCI principles for design and interaction. USE-IT simplifies the creation of user interfaces in a system during its life cycle, relying on a rule-based system that performs user interface adaptation at design-time.

England et al. [10] describe a method for dynamic user interface generation, based on history and user profile. The aim is to show the user processes, predict the results, and use that information to dynamically generate an interface that supports the decision-making process of the user. This approach does not take into consideration that each user manages information differently and that user decisions are affected by the way the information is presented.

Maat et al. [18] propose Gaze-X, a system that makes user-machine interaction adaptive, affective, and multi-modal, within standard office environments. Gaze-X uses a system called Face Reader to detect the emotions of the user (surprise, fear, anger, happiness, sadness, and displeasure). Interaction is adapted accordingly and can be of three different types: i) Help, if the user selects a column and examines the menu for too long; ii) Addition/removal of automatic tasks; and iii) Change in the presentation of information. The system also automatically selects characteristics and relevant options according to the user state. However, Gaze-X received bad evaluations from experts, who said that the system is invasive and overloads easy-to-perform functions with unnecessary information. Moreover, Gaze-X does not take into consideration some HCI design principles; it only considers interaction aspects.

AVANTI [30] provides high-quality access and interactions in web applications for disabled people. It provides dynamic user interfaces, according to abilities, skills, requirements, and preferences of the user, under different usage contexts. It supports the integration of special I/O devices for users with visual or motor disabilities.
Table 1. Summary of Related Work

<table>
<thead>
<tr>
<th>Criterion</th>
<th>[24]</th>
<th>[25]</th>
<th>[33]</th>
<th>[11]</th>
<th>[6]</th>
<th>[17]</th>
<th>[7]</th>
<th>[2]</th>
<th>[10]</th>
<th>[18]</th>
<th>[27]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takes into account user characteristics</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
<td>+/-</td>
<td>-/+</td>
<td>+</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>Takes into account environment characteristics</td>
<td>+</td>
<td>-</td>
<td>+/+</td>
<td>+</td>
<td>-/+</td>
<td>+/+</td>
<td>-</td>
<td>-/+</td>
<td>+/+</td>
<td>-/+</td>
<td>-/+</td>
</tr>
<tr>
<td>Uses HCI techniques</td>
<td>+</td>
<td>+/-</td>
<td>-/+</td>
<td>+/-</td>
<td>+</td>
<td>+/-</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
<td>+</td>
<td>+/+</td>
</tr>
<tr>
<td>Relates HCI techniques with adaptation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-/+</td>
<td>+/-</td>
<td>-/+</td>
</tr>
<tr>
<td>Uses models as a base to generate interfaces</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+/-</td>
<td>+/-</td>
<td>-/+</td>
</tr>
<tr>
<td>Takes into account design aspects based in the user profile</td>
<td>-</td>
<td>+/-</td>
<td>+/-</td>
<td>-/+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-/+</td>
<td>+</td>
<td>+/-</td>
</tr>
</tbody>
</table>

Interfaces are created, based on certain techniques (voice synthesis, voice and gesture recognition Braille hypertext) and special devices (Braille screen, binary switches, voice I/O, among others). These techniques are used for both navigation and presentation, in addition to interface design. However, AVANTI has two limitations: i) It focuses only on web applications, so it is restricted to specific navigation and design techniques and ii) User interface adaptation is not dynamic, which limits its flexibility.

3.4 Summary

Table 1 summarizes strengths and weaknesses of related work. The ‘+’ symbol means that the corresponding criterion is satisfied. The ‘-’ symbol means that the criterion is not satisfied. The ‘+/-’ symbol means that the criterion is partially satisfied. Although most works recognize the importance of user and environment characteristics for user interface creation (e.g., define color, size, shapes, and object positions) most of them do not emphasize design based in such principles. The approaches that take into account the above principles only focus on one type of user with specific characteristics. The lack of adaptation in these approaches requires to create different systems for different types of users. Although there are works that take into account both adaptation and HCI elements, they are not dynamic. Profiles and models for user interface generation are predefined. Therefore they do not seamlessly adjust to changes in the environment or in the preferences of the user.

4. RUNA-KAMACHIY: CONCEPTUAL INTEGRATION MODEL

This section proposes a taxonomy, which is the first step towards the conceptual integration model, called Runa-Kamachiy (RK). RK focuses on adaptation concepts that can be addressed by HCI techniques and formalisms, to improve usability of user interfaces. The concepts in the taxonomy were selected according to the following criteria: i) they are oriented to user interface design; ii) they are related to usability, i.e., they contribute towards usability; iii) they are part of the user-computer interaction; and iv) they are concepts oriented to the physical, mental, and emotional user characteristics.

Figure 1 describes the selected HCI concepts, while Figure 2 describes the concepts of adaptation. Figure 1 shows three main concepts: Design principles, cognitive principles and human factors. Design principles comprise methods, standards, and techniques to ensure that objects in a user interface (drawings, lines, text, etc.) have an adequate position, color, and size. Design principles also involve user interaction with those objects. Cognitive principles and human factors focus in the way the user learns, abstracts, and associates, together with their physical characteristics, communication, etc.

Figure 2 describes models that represent the users (state, needs, preferences, among others), their environment (usage context); their goals (task model); and, information display (content, navigation, and presentation). Those models are used to create two types of systems: i) Adaptable systems that use models to change information display (event-driven)

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1 From the Quechua language, “Runa” means “person” and “Kamachiy” means “to adapt”
and *ii*) adaptive systems, which are static systems that adapt before displaying information.

Table 2 (end of this paper) is the conceptual integration matrix that describes the way HCI and Adaptation can enrich each other, particularly in concepts associated to user interface creation. The rows have the HCI concepts described in Figure 1, while the columns denote the concepts of adaptation, described in Figure 2. The ‘+’ symbol indicates that the corresponding HCI and adaptation concepts fully complement each other. The ‘+/-’ symbol means that the corresponding HCI and adaptation concepts partially complement each other.
5. CONCLUSIONS

Although both HCI and adaptation have similar essential concepts, no formal integration between them was found in the bibliography, with the exception of the aim for a more natural and transparent interaction between user and system. To address this issue, this paper presented a conceptual integration model between HCI and adaptation. From this integration model, several conclusions can be formulated, which are detailed as follows.

HCI evidences a gap in the knowledge about dynamic user characteristics. Although HCI takes into account human factors, it may overlook some specific user characteristics (e.g., visual impairment). Adaptation also overlooks some human factors, such as the user cognitive processes (learning, knowledge level, etc.) or the adequate use of the language in the interfaces.

None of the HCI concepts involve service enrichment. Only specific modifications are performed, which are not focused on improving user experience or displaying only relevant information.

From the processes used by HCI to create user interfaces, such as LUCID [15], one can conclude that adaptation concepts can enrich the creation phases. For instance, the Envision and Discovery phase can be enriched by creating a user profile (static and dynamic) and an environment model (usage context) to gather formal knowledge of the user for user interface creation. On the other hand, adaptation can be improved by using HCI’s formalism of the task model.

There are some intersections between adaptation and HCI found in this analysis that are not in the literature. For instance, the way interaction (direct or assisted manipulation) can be modified according to user characteristics, particularly context, or if the user prefers to perform tasks supported by the system.

Overall, the integration of HCI and Adaptation may bring several benefits. User interaction could be personalized, enabling user intent recognition, and letting the user focus only on tasks that cannot be performed automatically. This reduces the cognitive load of the user and improves the presentation of only relevant information, thus improving usability.

REFERENCIAS


[31] Vasilyeva, E., Pechenizkiy, M., Puuronen, S., Towards the framework of adaptive user interfaces for eHealth. Presented

Table 2. Conceptual Integration Matrix

<table>
<thead>
<tr>
<th>ADAPTATION</th>
<th>User Model</th>
<th>Display Model</th>
<th>Tasks Model</th>
<th>User Context</th>
<th>Adaptation Process</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Static</td>
<td>Dynamic</td>
<td>Navigation</td>
<td>Content</td>
<td>Presentation</td>
</tr>
<tr>
<td>Paradigms</td>
<td>+ [9][10]</td>
<td></td>
<td>+ [3]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction Design</td>
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<td>+/− [2][27]</td>
<td>+ [34]</td>
<td>+ [34]</td>
<td>+</td>
</tr>
<tr>
<td>Interaction Types</td>
<td></td>
<td></td>
<td>+ [34]</td>
<td>+ [34]</td>
<td></td>
</tr>
<tr>
<td>Layout</td>
<td></td>
<td></td>
<td>+ [34]</td>
<td>+ [34]</td>
<td></td>
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<tr>
<td>HCI</td>
<td></td>
<td></td>
<td>+ [34]</td>
<td>+ [34]</td>
<td></td>
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<tr>
<td>User Interface Model</td>
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<td></td>
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<td>+ [34]</td>
<td></td>
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<tr>
<td>Ergonomic</td>
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<td></td>
<td>+ [12][23]</td>
<td>+ [34]</td>
<td>+</td>
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<tr>
<td>Language</td>
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<td></td>
<td>+ [34]</td>
<td>+ [34]</td>
<td>+</td>
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<tr>
<td>Cognitive Information</td>
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<td>+/− [34]</td>
<td>+/− [23]</td>
<td>+/− [18][32]</td>
<td></td>
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<tr>
<td>Physical and Mental</td>
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<td>+ [18][27]</td>
<td>+ [27]</td>
<td>+/− [12][18][27]</td>
<td>+/− [10]</td>
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<td>Characteristics</td>
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<td>+/− [23]</td>
<td>+/− [18][27]</td>
<td>+ [23]</td>
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<tr>
<td>Cognitive Task Analysis</td>
<td>+/− [18]</td>
<td></td>
<td>+ [23]</td>
<td>+ [7][2]</td>
<td>+/− [2]</td>
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<td>+ [7][2]</td>
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<tr>
<td>Envision and Discovery</td>
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<td></td>
<td>+ [23][14]</td>
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<tr>
<td>Phase</td>
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<tr>
<td>Base Design Phase</td>
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<td>Implementation Phase</td>
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<tr>
<td>Plasticity</td>
<td></td>
<td>+ [23][28]</td>
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