Integrating Adaptation and HCI Concepts to Support Usability in User Interfaces - A Rule-based Approach

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A Rule-based Approach

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Abstract: A common problem in information systems development is to provide support for *adaptation*, to automatically adjust their services to different users and contexts. User Interfaces (UI) are required to adapt to those contexts and to satisfy specific criteria and standards to guarantee usability. Several methods have been created to ensure a degree of usability in UI. However, these methods focus mainly in the design stage of the development process. The benefits of these methods may be lost during execution time, since they do not address the necessity to dynamically adapt the interfaces both to context and users. To address this issue it is necessary to integrate User Interface Design with Adaptation, to ensure that UI usability is preserved at the execution time, for different users and contexts. This paper proposes the framework *Tukuchiy*, a rule-based system that dynamically generates Adaptative User Interfaces, based in HCI precepts. This guarantees their usability during execution time, while taking into account user preferences and context. This paper focused in the rule-based system of *Tukuchiy*. That rule system includes usability criteria commonly used for web pages, which were mapped to a desktop application.

1 INTRODUCTION

When users interact through a computational system, they do it through a User Interface (UI). An adequate user interface design has become a very important aspect in software development (Stone et al., 2005). This problem is studied by two areas: HCI and Adaptation. Human-Computer Interaction (HCI) is a discipline that utilizes ideas from Psychology, Ergonomics, and other disciplines, to improve usability of user interfaces and provide better interaction between users and systems. Adaptation considers the heterogeneity of users and the context in which they utilize computers and requires that UI could be easily adapted to perform various tasks.

User interface design in HCI is commonly performed at the design stage in software development, but some usability characteristics defined at the design stage are lost during execution time. Adaptation, however, does not prescribe ways to improve usability of information systems. To address this issue, previous work of the authors proposed *Runa-Kamachiy* (Barrera et al., 2013a), a model to integrate HCI and Adaptation concepts, to improve the interaction between user and Adaptative systems, and improve usability. To validate the Runa-Kamachiy model, a framework, called *Tukuchiy* (Barrera et al., 2013c) was created. Tukuchiy realizes Runa-Kamachiy as an infrastructure to generate dynamic user interfaces. Two prototypes were created to validate the model in two application areas: *Idukay* (Barrera et al., 2013c) for education and *Midiku* for clinic radiology.

This paper describes a rule-based system utilized by Tukuchiy to dynamically adapt user interfaces, and the way Adaptation concepts can be utilized to improve usability of user interfaces.

The remainder of this paper is organized as follows. Section 2 explains basic concepts required to understand Tukuchiy. Section 3 reviews related work. Section 4 describes Tukuchiy and the way it addresses the Nielsen criteria. Section 5 details Tukuchiy's rule-based system for UI generation and its application in the Midiku prototype. Section 6 describes the validation of the prototype. Section 7 concludes and describes future work.

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2 BACKGROUND

This section describes background concepts required to understand Tukuchiy.

First HCI concept that we use is the “Five User Interface Laws”. Hale *et al*. (Hale, 2011) indicate that there are five laws that every user interface designer should know and apply: *i*) *Fitts Law* (Guiard and Beaudouin-Lafon, 2004); *ii*) *Miller Law* (Miller, 1956); *iii*) *Steering Law* (Accot and Zhai, 2001); *iv*) *Hicks Law* (Seow, 2005); *v*) *Practice Law*, (Roessingh and Hilburn, 2000).

The second HCI concept is “Nielsen's Usability Heuristics. Nielsen proposes ten heuristics to design user interfaces (Nielsen, 1994). They are as follows: *i*) System state visibility; *ii*) Coincide real world and system; *iii*) User control and freedom; *iv*) Consistency and Standards; *v*) Error prevention; *vi*) Recognizing instead of remembering; *vii*) Flexibility and efficiency; *viii*) Static and minimalistic design; *ix*) Help the user to recognize, diagnose and recover from errors; *x*) Help and Documentation, documentation should be easy to search, focus in user task.

In adition, Tukuchiy utilizes two main Adaptation concepts: User, and Context Profiles. User profiles represent tastes, necessities, and preferences of each user in a system, and can be used to adjust the services provided by the system, according to individual user aspects. Context profiles represent the user environment, characteristics that may affect the system's usability. Particularly, Tukuchiy takes into account the time of the day to adjust UI illumination. This adjustment is based in the Berry criteria (Berry, 2013), which indicates the way to manage brightness to ensure that user interface colors are comfortable for the user and would not reduce his/her perception capabilities.

3 RELATED WORK

Related Work Table 1 shows a comparison between related work about UI usability and UI generation, based in our work in (Barrera et al., 2013c) and (L. F. Barrera et al., 2013a). Columns are the related works. Rows are the criteria to evaluate each work. The columns 1-6 are as follows: 1(Moussa et al., 2000); 2 (Criado et al., 2010); 3 (Zimmermann et al., 2013); 4 (Namgoong et al., 2006); 5 (Akoumianakis and Stephanidis, 1997); 6 (England et al., 2009).

The criteria used in Table 1 were chosen to highlight the deficiencies with respect to interfaces usability.The evaluation comprises both HCI and Adaptation. Most works do not focus on improving usability. Although most take into account user profile and his/her context, they do not take into account HCI standards. These works do not take into account that interfaces change during execution time and that it is necessary to avoid losing standards given during design time.

Table 1: Related Work Comparison.

Criterion	1	2	3	4	5	6
Takes into account usability criteria during Execution (E) time or Design (D) time.	D	E-D	D	D	D	E
UI let the user recognize, diagnose, and recover from errors	-	-	+	-	-	+
UI include help and documentation	+	-	-	-	+	-
Keeps consistency between the real world and the system	+	+	-	+	+	-
Adapts to different types of users	-	+	-	-	-	+
Takes into account user context aspects	-	+	+	+	-	-
Uses HCI techniques	+	-	-	-	+	+
Utilizes a rule-based system to generate UI	-	-	-	-	+	-

4 TUKUCHIY

Tukuchiy ("*Tukuchiy*" is a Quechua word that means "*To Transform*") is a framework based on the Runa-Kamachiy model (L. F. Barrera et al., 2013a), to generate dynamic user interfaces, adjusted to specific user characteristics, context, and presentation preferences.

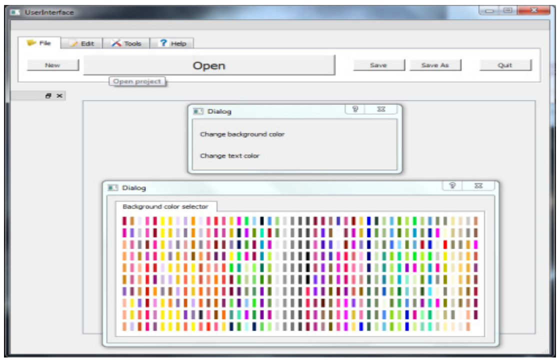


Figure 1: Tukuchiy Base Interface.

Tukuchiy keeps some usability standards at execution time, so that UI usability can be kept across the entire life cycle of the system (Figure 1). The Figure 1 shows some of the usability rules in Tukuchiy.

The description of Tukuchiy's component and

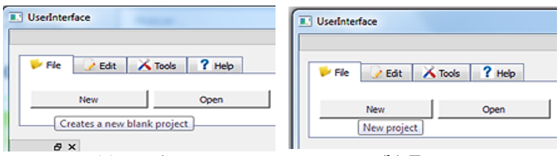
Table 2: Usability Criteria and Heuristics.

Usability Criterion	Heuristic
Learning	User control and freedom. Recognize instead of Remembering.
Error prevention	Help the user to recognize, diagnose, and recover from errors. Help and Documentation.
Memorization	Consistency and Standards. Help and Documentation.
Efficiency	Flexibility and Efficiency.
Satisfaction	System state visibility.
Efficacy	Static and minimalistic design.

conceptual integration can be found in (Barrera et al., 2013b). This section focuses in explaining the way Tukuchiy adapts usability concepts in web pages to desktop applications. Table 2 shows the usability criteria addressed by this research and the heuristics utilized to address them.

4.1 Learning

Learning is related to the capacity of the software to let users learn to use its components (Carvajal and Saab, 2010). Tukuchiy uses Practice Law (Section 2.1) to provide different types of help, with various levels of detail, depending on the user expertise. If the user is new, help is more detailed (see Figure 2a). As the user gains more experience utilizing the system, help is reduced (Figure 2b).



(a) Novice (b) Expert

Figure 2: Learning in Tukuchiy.

4.2 Error Prevention

An error-tolerant interface is designed to assist the user in recovering from errors (Carvajal and Saab, 2010). Tukuchiy utilizes tooltips with more or less information, according to the user experience level. Users with less experience received more detailed tooltips, while users with more experience received tooltips with less detail.

Additionally interface buttons are associated to intentionality and a color that represents that intentionality. Figure 12 shows the color palette utilized when one wants to change the color to the "close" button. Since this button is associated to a "danger" intentionality, blue and green colors, which represent "harmony", are not present in the palette.

4.3 Memorization

The memorization aspect enables users to easily remember how to interact with that system, after a period without using it (Nielsen, 1995). To address the memorization aspect, this research utilized the Miller Law (section 2.1). Tukuchiy groups buttons according to functionality based in this Miller rule (see Figure 3). Changes performed by the user in design (personalization) of the UI persist across sessions.

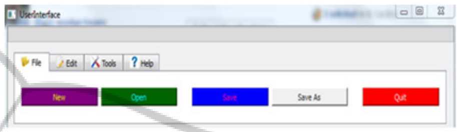


Figure 3: Memorization in Tukuchiy.

4.4. Efficiency

Efficiency is associated to the amount of effort required by the user to achieve a specific goal in his/her interactions with the system (Carvajal and Saab, 2010). Tukuchiy enlarges buttons (see Figure 8), based in the Fitts Law. In addition, it reduces in the amount of colors in palettes. These two strategies reduce the user efforts to accomplish a task or to personalize the interface.

4.5 Efficacy

According to ISO 9131-11, efficacy is the degree in which planned activities are performed and the planned results are achieved. In other words, can users do what they need in a precise manner?

The use of tooltips and Fitts Law to enlarge UI elements, seeks to improve the precision of the performed tasks. In addition, color transformation assists people with color blindness to properly identify colors and avoid mistakes. As seen in Figure 6, for people with Protanopy (red color blindness), Tukuchiy changes the color palette, discarding red colors, so that the user may distinguish a broader range of colors.

4.6 Satisfaction

Satisfaction is the perception of pleasantness and positive attitude towards the utilization of a product. That perception is reflected in the physical and emotional actions of the user when utilizing the system (Carvajal and Saab, 2010). The system does not directly address this criterion. However, we sought to indirectly satisfy the user by integrating all of the other criteria. For instance, the palette change for color blind users (Flück, 2006) may be pleasant for them.

5 RULE SYSTEM

To maintain usability characteristics during execution time, Tukuchiy utilizes a rule-based system, which is detailed in this section. To test the rules, *Midiku* was built, a clinic radiology application, to support the diagnostic process and medical image simulation. To build the system, two groups of rules were created: HCI rules and Adaptation rules. Both are detailed in the following sections.

5.1 HCI Rules

This group of rules realizes a subset of HCI standards. To build that subset, this research verified all of the standards that could be kept during execution time. The rules are the following:

5.1.1 Physical Conditions

The system focuses in assisting two physical difficulties: color blindness and myopia. Two processes are performed to assist in these difficulties: color simulation and polarization and button enlargement.

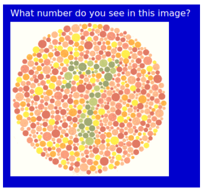


Figure 4: Ishihara Test (Flück, 2009).

For color blindness, Tukuchiy changes the palette using the following rule: *i)* Color blindness identification: when entering the system, the user is shown an image corresponding to the Ishihara Test (Flück, 2009). This test determines which type of color blindness the user (see Figure 4); *ii)* based in the code of (Duck, 2012), a simulation is performed in which palette colors are changed, so that they could be perceived by the person, according to his/her color blindness type.; *ii)* base colors are compared with simulated colors and the difference is calculated. This is used to change colors that are visible to the user.

Figure 5 is a fragment of the rule for color changes. This rule is utilized when the user needs to use the palette to personalize the interface colors.

```
{   // Initial LMS
    float l, m, s;
    float L = (17.8824f * r) + (43.5161f * g) + (4.11935f * b);
    float M = (3.45565f * r) + (27.1554f * g) + (3.86714f * b);
    float S = (0.0299566f * r) + (0.184309f * g) + (1.46709f * b);
    ...
    else if (enfermedad=="Tritanope"){
        l = 1.0f * L + 0.0f * M + 0.0f * S;
        m = 0.0f * L + 1.0f * M + 0.0f * S;
        s = -0.395913f * L + 0.801109f * M + 0.0f * S;
...}
```

Figure 5: Color transformation rule fragment (color blindness).

The Ishihara test is performed several times, to mitigate any external factors that could affect the validity of the user answers (*e.g.* screen resolution).

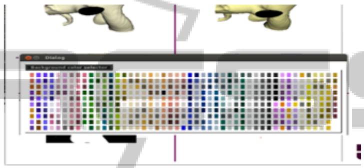


Figure 6: Midiku Color Transformation, user with protanopy (Barrera et al., 2013).

As shown in Figure 6, this rule changes colors both to the buttons and the medical image being examined.

The following algorithm is used for button enlargement: *i)* Identify the visual problem is explicitly, asking the user if he/he has myopia, this is stored in the user profile; *iii*) button properties are changed, so that, whenever the user points to the button, it changes its size. The layout of buttons within the same functional group is re-arranged.

```
void UserInterface::ButtonMouseOver_ui(){
    focus=focusWidget();
    if(focus->inherits("Button"))
    {bool fittsTrue=rules->evaluateFitts(user->
        userPhysical.getScaleFuntionalDiversity());
    if(fittsTrue){((Button*)focus)->changeSizeFitts();}}}
```

Figure 7: Button enlargement rule.

Figure 8: Button Enlargement.

Figure 7 describes the way button scale is changed according to the user profile. This rule is based in the Fitts Rule (Guiard and Beaudouin-Lafon, 2004). Figure 8 shows an example of button enlargement in Midiku.

5.1.2 Effective Color Combinations

Wright et al (Wright et al., 1997) indicates that colors are not visible when they overlap. To ensure that this rule is enforced during execution, Tukuchiy performs the following algorithm: *i*) identify the color of the element that contains the component whose color is going to change; *ii*) identify the color of the elements contained by the component whose color is going to change; *iii*) using the above information, the color palette is filtered to eliminate the colors that, according to Wright, do not match adequately (Wright et al., 1997). Color combinations are organized in a pessimistic manner, i.e., there is a list of colors that do not match in the previous steps; *iv*) Presentation of the color palette, the filtered palette is presented to the user.

```
void Rule::changeCustomPalette(Button *w){
   removeOriginalStyleColorGroup(w);
   removeParentColorGroup(w);
   removeChildrenColorGroups(w);
   removeIntentionGroupColor(w);}
```

Figure 9: Color combination rule.

Figure 9 shows the palette change rule according to color combination.

Figure 10: Color combination example.

Figure 10 is an example of a palette change, in which the text of the red button contains only the colors that combine or contrast with the button color.

5.1.3 Widget Intentionality

In a study performed by Bedolla (Bedolla, 2002), colors are associated to specific psychological states and have specific intentionality (*e.g.* red is associated to danger situations). This is taken into account to assign to each UI element, an intentionality associated to a color, to keep each element's essence. The algorithm for this task is the following: *i*) a table is created that maps intentionality to allowed and forbidden colors, an XML file is used to store that table. *ii*) when the user is going to change a color, it is evaluated whether the color keeps the same intentionality, according to the table. Similarly to the color combination rule, this filter is performed pessimistically and is presented as a palette to the user

```
void Rule::removeIntentionGroupColor(QWidget *w){
   Dialog * auxDialog=((Button*)w)->getMenu()->getDialog();
   evaluateColorButtonIntention(w->objectName().toStdString());
   vector<Intention> vecAux = intentions->getIntentions();
   vector<string> colorIntention;
   for(int d=0;d<vecAux.size();d++)
   {for(int y=0; y<this->buttonIntention.size();y++)
      {if(vecAux[d].getIntentionName()== this->buttonIntention[y]){
         colorIntention = vecAux[d].getForbiddenColors();
         for(int j=0;j<colorIntention.size();j++){
         ((Button *)w)->getMenu()->removeColorFromPalettes(colorIntention[j]);}
   }}}
((Button*)w)->getMenu()->setDialog(auxDialog);}
```

Figure 11: Button intentionality.

Figure 11 is a fragment of the rule that performs the filter (eliminate colors of the palette) of the colors that are not allowed, according to the button intentionality. Figure 12 shows the allowed colors for the "close" button.

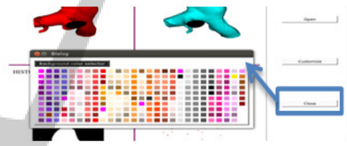


Figure 12: Widget Intentionality in *Midiku.*

5.1.4 Luminosity

Given the importance of luminosity (see Section 2.3), a rule was created to transform the colors of the entire interface. The transformation takes context into account. For instance, illumination is changed according to the time of the day.

```
RGB colorblind::brightness(RGB color, int delta){
   this->R=color.red+delta; this->G=color.green+delta;
   this->B=color.blue+delta;
   this->R = qBound(0, (int) R, 255);
   this->G = qBound(0, (int) G, 255);
   this->B = qBound(0, (int) B, 255);
   RGB rgbFinal;
   rgbFinal.red=this->R; rgbFinal.green=this->G;
   rgbFinal.blue=this->B;
   return rgbFinal;}
```

Figure 13: Color brightness.

Figure 14: Brightness palettes in Tukuchiy.

Figure 13 and Figure 14 is an example of the way illumination is updated according to context. This rule does not perform changes while the system is being utilized, to avoid being too intrusive for the user.

5.2 Adaptation Rules

This section shows the Adaptation rules that complement the dynamic generation of interfaces, based in user characteristics and context.

5.2.1 Help

Tukuchiy filters information during the system startup to evaluate the user experience level and language preferences. This rule process is as follows: *i*) the user profile has an attribute that indicates the amount of time the user utilizes the system, which determines the experience level of the user; *ii*) when starting the system, the user chooses his/her language of preference; *iii*) from the information in *i*) and *ii*), the system changes the names in its UI elements according to the chosen language. Tooltips are automatically changed according to the experience level. Currently, the system has two tooltips that are more detailed for novice users than for expert users.

```
Void UserInterface::reloadUserInterface(){
    if(user->useLevel=="Novato"){
        if(this->language=="English"){
            loadUserLevelLaguageFile(":files/messages-en-rookie.xml");
        }else{
            loadUserLevelLaguageFile(":files/messages-es-rookie.xml");}
    }else if(user->useLevel=="Experto"){
        if(this->language=="English"){
            loadUserLevelLaguageFile(":files/messages-en-expert.xml");
        }else{
            loadUserLevelLaguageFile(":files/messages-es-expert.xml");}}}
```

Figure 15: Use level about use level.

Figure 15 illustrates the help rule. Each help has an XML file that associates UI elements with different tooltips and names.

5.2.2 Color Preferences

Each user may have different preferences about colors to display each UI element. To realize this in the preferences, a rule was created that organizes the color palette, to show the UI according to the tastes of the user.

This rule is utilized as follows: *i*) each time a user selects a color, a counter is updated, which is used by the system to find out which the degree of color preference; *ii*) based in the degree of color preference, the color palette is reorganized from most preferred colors to least preferred colors.

```
void Dialog::initializeBg(map <string,vector<RGB> >
        palette,vector<pair<string,int> > colorPreferences){
    ...
    for(int i=0;i<colorPreferences.size();i++){
        string nombreLlave=colorPreferences[i].first;
        vector<RGB> colores=palette[nombreLlave];
        for(int j=0;j<colores.size();j++,cont++){
            RGB color=colores[j];
            colorblind aux;
            //brightness change
            color = aux.brightness(color, this->delta);
            //disease change
            string cadenaTransformada = aux.corregirColor(color.red,
                    color.green, color.blue, this->getPaletteType());
...}
```

Figure 16: Color preferences rule.

Figure 16 is a code fragment that denotes the way the palette is organized according to the user preferences. Figure 17 shows the palette that result from applying the above rule. In this example, the preferred color is green.

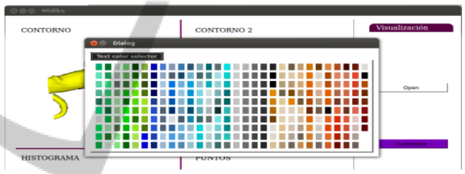


Figure 17: Color preferences in Midiku.

6 PILOT TEST

The authors are currently developing a functional prototype called Midiku. Since this is a work in progress, its initial assessment has only been performed over the design of Midiku's User Interface. This design includes functionality given by Tukuchiy (see Section 4).

6.1 Evaluation Process

To evaluate the usability of Midiku's interfaces, Mock-ups (Soegaard, 2004) were utilized. Mockups are a digital demonstration of the way the UI will look like in the final system. Mockups were shown to three physicians of the San Ignacio Hospital in Bogotá, Colombia. One of them is an expert radiologist with several years of experience, who is not proficient with current computing technologies. The other two are physicians who are specializing in radiology and have high proficiency utilizing current computing technologies. The three physicians answered a survey based in QUIS (Questionnaire for User Interface Satisfaction) (Chin et al., 1988). The questions answered focused exclusively in evaluating the UI design.

Table 3: Example questions of the survey.

Criterion	Question	Scale
1.Interaction and Adaptability	Flexibility of the user interface	Very rigid, Rigid, Flexible or Very Flexible
	Complexity of the user interface	Very hard, Hard, Easy or Very easy
2.Screen and Display	Organization of information on screen	Very confused, Confused, Clear or Very clear
	Is the screen density:	Very inadequate, Inadequate, Adequate or Very adequate
3.Presentation and Visualization	Are groups of info demarcated?	Very confused, Confused Clear or Very clear
	Does it provide visually distinctive data fields?	Very high grade, High grade, Low grade or Very low grade

Table 3 shows some of the questions, grouped by evaluation criteria. The first criterion is the user appreciation with respect to the interface. The second criterion is the organization and meaning of graphical elements in the screen. The third criterion is about the color utilization and screen zones delimitation.

6.2 Pilot Test Results

Surveyed subjects were divided in two groups: expert and novice. Three questions from Criterion 1 (Interaction and Adaptability), six from Criterion 2 (Screen and Display), and four from Criterion 3 (Presentation and Visualization). Figure 18 indicates the results of the survey.

For each criterion, results are shown for the expert group, the novices group and the expected value, which is the maximum score that can be obtained in each criterion.

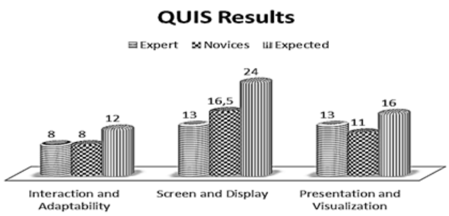


Figure 18: Survey Results.

The Figure 25 indicates that the expert radiologist valued the first criterion as 66.7%, emphasizing the interface flexibility, but he expressed that the attractiveness of interface has a low level. He valued the second criterion as 54.2%, emphasizing the adequate density of elements in the screen, but indicating the difficulty to understand the meaning of buttons. He valued the third aspect as 81.3%, emphasizing the adequate use of colors.

For novice users, the answers were averaged. The first aspect was valued as 66.7%, emphasizing the ease of initial interpretation of the interface. The second aspect was valued as 68.8%, emphasizing the organization and adequate terminology, but they expressed the density of elements in the screen are inadequate. The third aspect was valued as 68.8%, emphasizing the adequate visual distinction among screen zones, but indicating the inadequate utilization of colors.

The users commented that they would want to have more intuitive and less complex radiology interfaces. They also commented that there are “dead spaces” in the screen that could be better utilized to present information. They indicated that the survey could be enriched by using videos of the mockups, to better understand the functionality.

7 CONCLUSIONS AND FUTURE WORK

This paper presented Tukuchiy, a framework that integrates several methods and techniques in HCI with Adaptation concepts to improve user interaction with systems in changing contexts. Tukuchiy's rule-based system ensures usability criteria are preserved at execution time in changing interfaces.

This paper also presented a functional prototype (Midiku) that supports radiologists to diagnose medical images. An initial assessment at this stage has only been performed over the UI design of Midiku. This assessment was performed through a Mockup and a survey that was answered by an expert and two novice radiologists. The results emphasize positive aspects, such low UI complixity, adequate organization of information on the screen and the ease to visually distinguish data fields. Negative aspects found are the difficulty to understand the meaning of buttons, inadequate characters visualization and inadequate terminology.

Future work includes fully developing the functionality of Midiku and performing a more detailed analysis of the capabilities of Tukuchiy in terms of efficiency, efficacy, and user satisfaction. In addition, Tukuchiy will be assessment with fully test (20 observer’s approx.). The assessment includes an initial perception test and then interaction atoms test (key functionalities).

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