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A CLOUD-BASED ARCHITECTURE PROPOSAL FOR REHABILITATION OF APHASIA PATIENTS

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Aphasia concerns neurological disorders of speech, with moderate to severe dysfunction of the mechanisms involved in language expression and understanding, and influencing the major components of language behavior. Aphasia rehabilitation involves a speech language therapist and the principles of therapy regard the intensity of exercises execution, the use of multiple forms of sensory stimuli and the increase of exercises difficulty. The therapy is expensive and has to be customized to patients' specificity, including their native language. This paper proposes, as a work in progress, a cloud-based architecture for aphasia rehabilitation of patients having Romanian as their native language. The plaltform comprises an application database, an application logic and interfaces for patients and therapists. Accompanied by a virtual assistant, the patient has to solve exercises built by the therapist and, depending on the obtained scores, the treatment is adjusted and data can be stored in a statistic module. A scoring procedure is proposed, as part of the application logic and back-up solutions for minimizing the estimated riksks during the project's lifecycle are formulated.

1. INTRODUCTION

Aphasia represents a set of neurological language disorders resulting from damage of the language areas of the brain, with multiple causes, such as stroke or traumatic injury. Once the underlying cause has been treated, the primary treatment for aphasia is *speech therapy* that focuses on relearning and practicing language skills and using alternative or supplementary communication methods.

According to the National Aphasia Association [1], aphasia affects about one in 250 people in the USA. Considering the importance of communication in all aspects of life, getting help for a communication disorder is critical. A recent study from the USA [2] showed that patients with aphasia experienced longer length of stays, greater morbidity, and greater mortality than did those without aphasia.

The cost of medical assistance for patients with language disturbance are increased, both direct – personnel, space, disposable items–, and indirect– days of hospitalization, time until return to work, change in work status, change in personal income, quality of life. As intensive medical treatment is more efficient in reducing these associated costs, there is an increased interest for developing IT-supported solutions aimed to assist and partially substitute the activity of the therapist [3]. It has to be emphasized that the use of IT-based applications constitutes a general trend also in other service sectors traditionally dominated by human-human interactions, like teaching [4].

Aphasia treatment depends on the langauge and cultural particularities of the patient [5] and, despite the existence of a number of software packages that are specially designed for rehabilitation of aphasia patients, most of them are dedicated to native English patients. Presently, there are no cultural and linguistic-specific tools adapted for most populations with regional languages, such as the Romanian population, this representing a domain where some improvement is required.

This contribution presents a proposal for a cloud based architecture for apahsia rehabilitation of patients having Romanian as their native language. Aphasia types and rehabilitation principles are reviewed in Section 2, followed by a presentation of the principles of IT-supported aphasia rehabilitation tools, in Section 3. The proposed dedicated cloud-based platform for aphasia rehabilitation, with an original logical model, is finally presented in Section 4, followed by concluding remarks.

2. APHASIA REHABILITATION

2.1. TYPES OF APHASIA DISORDERS

Aphasia concerns neurological disorders of speech, with moderate to severe dysfunction of the mechanisms involved in *language expression and understanding*, and influencing the major components of language behavior (*speech comprehension*, *spoken language repetition*, *object naming* and *speech fluency*). After being diagnosed by a neurologist, the aphasia patient is subject to more extensive tests, conducted by a *speech-language pathologist*, who performs a comprehensive examination of the person's communication abilities.

There is no highly accurate classification for all aphasia types [6], but one can distinguish among four main types:

- *Expressive aphasia* – the patient knows what he wants to say, but he has trouble expressing himself.
- *Receptive aphasia* – the patient hears the voice or sees the images, but he is unable to make sense of the words.
- *Anomic aphasia* – the patient has trouble using the correct word for objects, places or events.
- *Global aphasia* – the patient is not able to understand speech, speak, read or write.

Among the various common symptoms of aphasia, the following have to be taken into consideration, among others:

- the inability to understand the language, the inability to pronounce (not due to muscle paralysis or weakness),

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- the inability to speak spontaneously, the inability to form words,
- the inability to name objects, poor enunciation, excessive creation and use of personal neologisms,
- the inability to repeat a phrase, persistent repetition of phrases,
- paraphasia (substituting letters, syllables or words),
- agrammatism (inability to speak in a grammatically correct fashion),
- dysprosody (alterations in inflexion, stress, and rhythm),
- using of incomplete sentences,
- the inability to read,
- the inability to write.

In the general terms of information theory, one can regard these symptoms as losses of efficiency of meaning of the transmitted information, with the patient either sender or receiver [7].

2.2. APHASIA REHABILITATION PRINCIPLES

The rehabilitation principles rely on modular models of the brain, which aid in the understanding of the brain as a complex system by decomposing it into structural modules or functional modules (*schemas*) and exploring the patterns of competition and cooperation that yield the overall function [8].

Given the various sources, symptoms and types of aphasia, there is no universal treatment for this language disorder. The traditionally used method of rehabilitation involves a speech language pathologist, because it focuses mostly on the impairment.

The goals of the rehabilitation plan are very specific to each patient, and they must be agreed upon, before the rehabilitation program is initiated. Several *principles of therapy* have been shown to improve the outcome of therapy [9, 10]:

1. Regardless of the type of therapy used, the outcome is better if *the intensity of therapy is increased*. A given number of hours of therapy will yield a much better outcome if they are given in a few sessions over a few days rather than in many sessions over many days.
2. The effectiveness of aphasia therapy increases when therapists use *multiple forms of sensory stimuli*. For instance, auditory stimuli in the form of music, and visual stimuli in the form of pictures, drawings, are routinely used during aphasia therapy sessions.
3. *Gradual increases in the difficulty of language exercises* practiced during a given therapy session improves the outcome.

3. IT-SUPPORTED REHABILITATION TOOLS. STATE OF THE ART

According to the sources in the literature [9–11], with all the advancements in computer technology today – such as computational speed, network bandwidth, streaming video, disk storage, recording technology, and compression software – it is natural to see the computerized treatment methods implemented in a variety of clinical settings. In this regard, IT-supported aphasia rehabilitation can be implemented either *as the only method of treatment*, where the patient performs the exercises alone and afterwards his or her performance is reviewed by a clinician, or *it can assist the clinician* in showing the stimuli to the patient.

There are two main treatment approaches using IT-based rehabilitation tools: *Substitute Skill Model*, based on using a visual aid to improve spoken language and *Direct Treatment Model,* based on using specific sets of exercises for treating different aphasia deficits.

Numerous studies, such as the ones reported in [12] and [13], were conducted to investigate the use of delivery therapy remotely via a computer and Internet connection, under the direct supervision of a speech and language therapist. The results were encouraging, showing improvements in language function outcomes and decreases in the time required to be spent together with the therapist [11].

There are a number of existent software packages that are specially designed and aimed for use in the rehabilitation of aphasia patients. Among them are a freeware program described in [14], the suite from Bungalow Software [15], the Clicker-5 and CHAT programs from Crick Software referred in [3] or Parrot Software's online programs [16]. All of these are intended for patients that have English as their native language.

4. A DEDICATED CLOUD-BASED REHABILITATION PLATFORM

4.1. OBJECTIVES

The proposed dedicated cloud-based platform is desired to be an innovative computer-supported therapy and recovery solution, especially developed for the Romanian language and cultural particularities, as an aid in the rehabilitation of neurological patients with different types of aphasia symptoms, using a series of *fully-customizable modules of exercises*. The purpose is to *substitute* the presence of a speech-recovery therapist, while using the same principles of *speech and language therapy* (SLT), the method that currently represents the best option for aphasia rehabilitation [17]. It is aimed to be accessible to patients using *mobile devices*, both in the clinical setting and also remotely, based on the new generation of *cloud-computing concepts*. It is intended that the results be monitored and adjusted accordingly by clinicians, providing a modern, more accessible and cost-efficient method of speech therapy.

The application is desired to have a friendly user interface, making it easy to use for both clinicians and patients and it is intended to be able to manage a *potentially unlimited number of patients*, monitoring their evolution and allowing the clinician to adapt their therapy at any given moment.

4.2. THE MODULAR SYSTEM FOR EXERCISES

To put in practice these goals, the application will provide a *predefined set of treatment modules*, established by experimented medical staff and based on scientific methods. Each module will be divided into different *levels of difficulty*. For each of these modules, a large number of exercises will be provided, designed for the Romanian language and aimed at improving the patients’ speech and

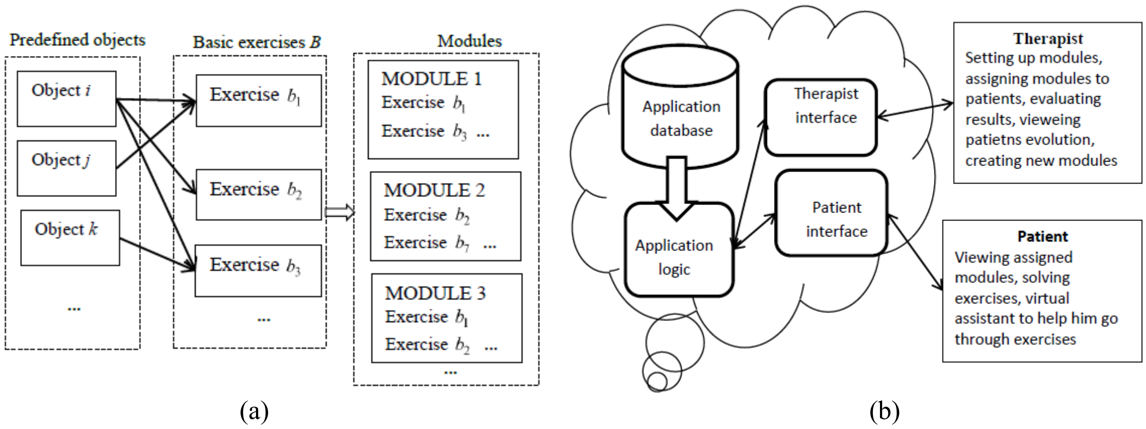

Fig. 1 – The modular system for building exercises and modules, with objects recorded as visual symbols and written and spoken words: a) and the cloud based architecture b).

language rehabilitation concerning:

- image and sound recognition,
- image association,
- image and sound similarities,
- word recognition,
- word association,
- verb and actions recognition,
- semantic classification of words,
- identification of objects,
- transcription of letters and words,
- solving arithmetic operations,
- typing words,
- color identification.

For each treatment module, the clinician can add new exercises using objects from a predefined set of objects, recorded as visual symbols and written and spoken word (Fig. 1a). Moreover, the clinician will also be able to define new treatment modules.

4.3. THE CLOUD-BASED ARCHITECTURE

The application will be deployed in a cloud-based architecture, with a central server for the application, and both the therapists and the patients connecting to the server through internet enabled *mobile devices* (for the patient) or *portable computers* (for the therapists) (Fig.1b).

The patients interface will be optimized for touch enabled mobile devices, in order to provide ease of access even for those patients that are not computer savvy.

The application will also contain a *statistics module*, allowing therapists to have an overall image of the results produced by the treatments they have set up. The statistics module will also provide a graphical and tabular evolution of patient scores for a certain type of exercise or module. Based on these figures, an ultimate outcome of the project will be establishing some connections between certain aphasia symptoms and diagnosis, and successful therapy schemes. Thus, when a similar patient is identified, the corresponding treatment and exercises will be used, leading to a more rapid recovery. Each therapist will have access to the default modules and exercises, to the modules and exercises defined by him and to modules and exercises shared with him by other therapists. Also, each therapist will have access to his own patients but no to other therapists' patients.

4.4. THE REHABILITATION PROGRAM

The use of the application is preceded by a selection of a lot of patients with aphasia, based on criteria such as:

C1. a clinical neurological examination,
C2. testing the ability to understand language, speak, read, write,
C3. calculate and recognize musical signs (notes) matched for age,
C4. sex ratio,
C5. etiology of aphasia (stroke, tumor, head trauma, demyelination, infectious disease, dementia) and
C6. subtypes of aphasia (expressive, receptive, anomic and global).

Each patient in a lot will benefit from a specific medical treatment in order to organize a *scientific, computerized, speech rehabilitation program* sustained on visual, auditory and interactive skills (repeating, answering, reading, writing, and calculating).

When establishing the treatment scheme for a specific patient, the therapists can visually combine (drag and drop) exercises from different modules and difficulty degree, or from the custom exercises created by the therapists themselves, according to each patient's specific needs. The *scores* obtained by the patient during his treatment, his overall progress and a set of predefined parameters, like total time needed to solve an exercise, are monitored and stored in the database of the application. Thus, at any time, the therapist can view the results of the conducted therapy and check on the progress and improvements made by the patient. Based on these previous results, it will be easier to decide upon the continuation of the treatment. Throughout the use of the application, a *virtual assistant*, encouraging him in doing the exercises, will accompany the patient.

A large database of patients with different forms of aphasia will be constructed, which will have a great impact on the study and rehabilitation of aphasia.

4.5. THE LOGICAL MODEL

The logical model of the rehabilitation program has two components: a structural part, referring a formalization of data and information and the logical procedure managing the interaction of the patient with a specific treatment module.

4.5.1. Formalization of data and information

The formalization of data and information regards the lots of patients and the modules containing exercises. Given a set of patients $P=\{p_i\}_{i=1}^{N}$, each patient p_i is evaluated according to the *selection criteria* C1:6 in section 4.4 and placed, by the therapist, in one of the subsets composing the partition $P=\overset{\circ}{\cup}_{k=1:K} P_k$. Obviously, patients from distinct subsets may share some evaluation results following the selection. The structure of the lots of patients is the decision of the therapist, despite the fact that a semi-automatic selection procedure can be built as support to this purpose.

Consider an indexed set of *basic exercises* $B=\{b_j\}_{j=1}^{J}$. Each b_j is created by the therapist (Fig. 1a) and stored in the database for configuring different modules. For each partition subset P_k, a set of modules $Mod_k=\{mod_m\}_{m=1}^{M_k}$ is active at a given moment, with the therapist responsible for controlling the structure dynamics.

A module $mod_m=\{ex_{jn}^m : j\in I_m, n=1:N_m\}$ is an ordered set of *therapeutic exercises* ex_{jn}^m, where $I_m\subseteq\{1:J\}$ is a subset of indexes of corresponding basic exercises and n is the ordering index in the module: ex_{jn}^m precedes $ex_{j(n+1)}^m$ and is preceded by $ex_{j(n-1)}^m$.

A *therapeutic exercise*, as component of the module $mod_m\in Mod_k$, is defined as a tuple: $ex_{jn}^m=(b_j, N_{mj}, T_{mj}, diff_{mj})$, where $b_j\in B$ is the chosen basic exercise, N_{mj} is the maximal number of repetitions of b_j in a time interval of length less or equal to the value T_{mj}, estimated by the therapist to be necessary to reach success and $diff_{mj}$ is the associated degree of difficulty established by the therapist. Observe that N_{mj} and T_{mj} together model the recommended *intensity* of the exercise.

4.5.2. A procedure for scoring a therapeutic exercise

The therapeutic exercises are repeated by the patient the imposed number of times, and each exercise performance is evaluated, in order to compute the *score* associated to the dyad patient-exercise. Also, the selected exercise has to be repeated in a time interval no longer than the specified limit.

For a selected therapeutic exercise ex_{jn}^m, consider the variable $cont\in\{0:N_{mj}\}$, defining the counter of exercise repetitions. The patient's response to the exercise, *response_*b_j, during the current cycle repetition, can be correct, incorrect, or it may not be sent in time.

If patient's response is received in time, then it is compared to the correct solution by the evaluation function $eval:\{response\_b_j\}\rightarrow\{0,1\}$, with 0 for failure and 1 for success. The history of patient's response evaluations is updated, at each cycle, with the current evaluation and stored in the variable *value*.

The computed final score is $SCOR=value\cdot diff_{mj}/N_{mj}$ and the variable *timer* is the current output of a clock measuring the time for the allowed maximal interval T_{mj}.

The interaction patient-exercise begins with the signal `start_`b_j sent by the system to the patient. If an exercise cycle is carried out and *response_*b_j is received, then the current performance is evaluated and a new cycle starts.

The therapeutic exercise ends normally if the total number of cycles N_{mj} is reached. If the allocated maximal time interval T_{mj} runs out and the exercise is not ended, then the execution is aborted and the partial results are stored (Fig. 2).

Procedure `score(`ex_{jn}^m`)`

```
Input: b_j , T_mj , diff_mj , N_mj .
Output: cont, timer, SCOR .
begin
    cont =0, value = 0
    start timer
    while ( N_mj -- cont)>0
        cont = cont + 1
        %to the patient
        send start_b_j
        wait_ response_b_j
        %from the patient
        if receive response_b_j
          value = value + eval(response_b_j)
          %from the clock
        elseif timer == T_mj
          break
        end
    end
    stop timer
    SCOR = value · diff_mj / N_mj
    disp('cont , timer , SCOR ')
end
```

After finishing all the therapeutic exercises in the module, $ex_{jn}^m\in mod_m$, $n=1:N$, the patient is re-evaluated by the therapist who interprets all the output results `score(`ex_{jn}^m`)`, and according to this evaluation, the therapist eventually reconfigures a new module, or launches an already elaborated module of therapeutic exercises to be executed. Alternatively, if the mean score is too low, the therapy is interpreted as inefficient and a decision is taken accordingly by the clinician.

4.6. THE PROJECT STEPS AND SOME ASPECTS REGARDING THE RISKS ASSESSMENT

The design of the cloud-based architecture and the implementation of the rehabilitation program will be developed in three main steps: (1) the specification of the user requirements and of the system architecture and, in parallel, the construction of the lots of patients; (2) the design and development of the prototype, its integration and deployment, implying also the accepted interface prototype and the functional testing of the alpha version; (3) the evaluation of the results of the computerized platform on the selected lots of patients, dissemination and exploitation of the application.

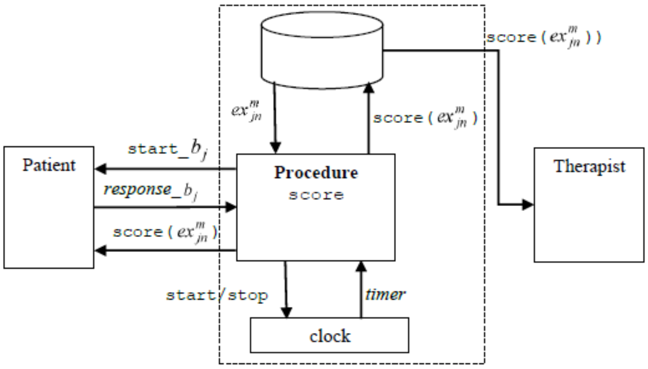

Fig. 2 – A simplified view of the information exchanged by the procedure `score` with the users.

During the entire project lifecycle, a constant assessment and evaluation of risks is required, implying continuous monitoring and communication between partners and stakeholders.

Using, as tool, the classic SWOT (*strengths*, *weaknesses*, *opportunities* and *threats*) analysis, several possible project risks have been identified, with their specific risks levels and associated back-up solutions, aimed to minimize those risks levels (Table 1).

Table 1

Estimated risks and associated back-up solutions

Risk / *level*	Back-up solution aimed to minimize the risk level
the specifications for the module requirements can be inadequate / *low*	the clinical and informatics skills and experience of the participants will prove adequate in preventing it
the software partners can misunderstand the medical requirements / *low*	the active participation of the software partners in user requirements definition
the patients may present an inability to use the therapeutically devices / *medium*	performing the patient's interaction through an intuitive interface based on touch-input
the mobile devices may be subject of generational change and obsolescence / *low*	the fact that the new technologies are friendlier to the patient user
delays in testing and development may appear / *low*	involving the main stakeholders early in the project, informing them about the project's steps and advantages
lack of interest to commercialize the system / *medium*	involving the main stakeholders early in the project, informing them about the project's steps and advantages

5. CONCLUSIONS

Although other countries developed computer programs for the recovery of the aphasic patient, these programs cannot be used in Romania, due to language barrier, as the Romanian language has a complex vocabulary and grammar and the rehabilitation has to be made in the native language of the patients.

It is worth mentioning that the mere translation in Romanian of existing software and/or tests is not a viable option in this case, due to the structural linguistic differences in word phonology (different phonemes and combinations of phonemes) and word forms (different lengths, syllables) that require distinct cognitive processing and should be adapted to the native language of the patients.

The proposed project of a cloud-based aphasia rehabilitation architecture uses a *Direct Treatment Model* to implement the principles of aphasia rehabilitation – intensity increase, multiple forms of stimuli and gradually increase in difficulty.

The structure comprises an application database, application logic and interfaces with the therapist and the patients, respectively. The treatment will be customized for lots of patients and for each patient in a lot, and will consist of intensive repetition of exercises from specially built modules. The modules can be reconfigured according to the particular treatment in progress. Each exercise in a module is characterized by *intensity* and by the *level of difficulty*. A scoring procedure for the evaluation of patients' response to exercises is proposed, as part of the application logic. As part of the risk assessment and communication strategy during the project's lifecycle, several back-up solutions aimed to minimize the estimated risks levels have been formulated.

Future research regards the implementation of the application.

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