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Modelling Software Agents: Web-Based Decision Support System for Malaria Diagnosis and Therapy

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Background and Purpose: The aims of our research as presented in this paper consist of formalizing the design of software agents and demonstrating its practicability in a web-based medical decision support system specifically for malaria diagnosis and therapy to assist healthcare professionals at medical consultation in order to optimize the quality of care of the patients with the malaria disease.
Methods: The Software Agent System proposed is a functional model based on a contractual specification as the awareness of an agent in pursuing its goals and executing tasks. The agents are designed according to the requirement for an effective diagnosis and delivering the therapy strategies for malaria as per the supplied sign-symptoms and laboratory test results.
Results: The contribution of our work is mainly the contractual specification, a λ contract. As we demonstrate in the scenarios presented as results, the contract ensures the behaviour of the agents in achieving their goals and executing tasks.
Conclusions: The Software Agent System is adopted to cope with a complex and dynamic domain such as medicine and specifically the web-based medical decision support system for malaria diagnosis and therapy of the Optimization of Malaria Treatment (OMaT) system. Our proposed functional model facilitated the implementation of the SA. Specifically, we point out the fact that a λ contract can ensure the consistency and the credibility of the reasoning of the software agent.

Keywords: Software Agents, Functional Model, Contractual Specification, Medical Decision Support

1 Introduction

The healthcare problems facing developing countries are great. For a long time, malaria is one of the most challenging infectious diseases caused by the parasite called Plasmodium and localized in areas of Central and South America, Asia and Africa. Malaria should be considered a potential medical emergency and should be treated in time. Delay in diagnosis and treatment is a leading cause of death. Thus, the technical capability to perform a correct and a timely diagnosis, with an appropriate treatment of the malaria infection in an ill patient is of critical importance in endemic regions, specifically in rural or isolated areas.

Medical decision support systems [1-4] based on eHealth and mHealth can be used to serve the unserved. [5]

The eHealth revolution in Africa is the main and most suitable vehicle for optimizing the quality of care and reducing the large amount of death being caused by infectious diseases such as malaria where specialists are not available.

"*Developing the advanced care services raises new challenges in terms of modelling, infrastructures, supports tools, and the very understanding of telecaring networks and its operating rules.*" [6]

As stated in [7], "*software agents are a computer software technology that provides a powerful new method for solving complex problems and implementing complex systems*". Also in [8], "*the motivations for the use of agents in the medical domain consist of the multitude of aspects that the agents can analyze during the diagnostics elaborations and the realization of different medical tasks. Agent-based approaches may integrate and extend different problem solving technologies.*"

Our study, as presented in this paper, consists of formalizing the design of software agents and demonstrating its practicability in a web-based medical decision support system specifically for malaria diagnosis and therapy to assist healthcare professionals at medical consultation in order to optimize the quality

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of care of the patients with the malaria disease. The contribution of our work is mainly the contractual specification, a λ contract, as the awareness of an agent in pursuing its goals and executing tasks.

2 Materials and methods

The core piece in our research remains software. Software is a term employed for the various kinds of programs for the operations of computers and related devices. It is covered in software engineering that is a Computer Science discipline dealing with the studies of the methodologies to design and to build software. The process of software development is to translate requirements into code.

A piece of software which performs a given task using information learned from its environment to act in a suitable manner so as to complete the task successfully, is a called a software agent. The environment includes humans, computers, devices, operating systems, computer applications, databases, networks, and virtual domains.

"*Several researchers are working towards the standardization of agent technologies and in the realization of development environments to build agent systems. Such development environments provide some predefined agent models and tools to make easy the development of systems.*"[9]

In the point of view of medical software development, we pay attention to the software requirement specification standard IEEE 830-1998 [10] and medical software design standard IEC 62304 [11].

We also refer to the potential and application of agents in healthcare environment that have been discussed in [12-16]. Mainly, we take in account the survey of agent-based intelligent decision support systems to support clinical management and research, presented by Foster et al. [17].

Our Software Agent System is adopted to cope with a complex and dynamic domain such as medical industry. Specifically, our software agents, developed under the project "Optimization of Malaria Treatment" (OMaT) [18], are focussed on a web-based medical decision support system for malaria diagnosis and therapy. They are designed according to the requirement as described in the consensus guidelines [19] and protocols for the management of malaria [20] for effective diagnosis and delivering the therapy strategies for malaria as per the supplied sign-symptoms and laboratory test results.

2.1 Functional model of software agents (SAs)

In the following lines, the functional model of the software agent is presented to provide an overview of the system.

Definition 1: Software agent (SA)

Software agents are a set of computational entities that exists in the form of a set of programs or components that runs on a dedicated server and can interact with external components. They act with minimal intervention from humans. They can require special and punctual collaboration with other embedded agents in pursuing their goals and executing tasks.

SAs are divided into two parts: code component ζ and data component K. Code component can be activities, services and applications that may act both as callers and as called. Data component is a content provider. It is passive and only receives calls. Code component is a set of actions that can perform on the data component.

Software agents pursue goals or carry out tasks in order to meet their design objectives. The main objectives related to the SA which acts in the OMaT system are to provide an interaction mechanism with a healthcare practitioner (HCP) and to generate diagnosis and to suggest treatments. This is the general context of use of our SAs and their specialization.

In doing so, this is considered as a multiple objective-constrained optimization problem. The purpose, on the one hand, of the optimization problem is to evaluate a solution alternative according to multiple criteria. On the other hand, the constraint in the objective optimization problem means that if O is reachable the f(c) is supported by some proof system. Thus, we define a λ contract as our proof system.

SA is defined as the following:

$$\text{SA: } \left\langle \zeta, K \right\rangle \qquad (1.1)$$

where ζ is set of code component, K is a set of data component.

The specification of the SA is the following:

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$$SA ::= c_0 \mid c_1 \rightarrow c_2 \mid c_1 \leftrightarrow c_2 \mid c_1 © c_2 \qquad (1.2)$$

where

(i) c_0 a stand alone application.
(ii) $c_1 \rightarrow c_2$, denotes that the application c_1 calls the application c_2, in other words it means the application of c_1 followed by the application of c_2.
(iii) $c_1 \leftrightarrow c_2$ means that the application of c_1 can be run in parallel with that of c_2.
(iv) c* is the complement of the application c.
(v) $c_1 © c_2$ means that the application of c_2 is embedded to that of c_1.
(vi) | denotes the alternative states of the system.

Definition 2: Code component

A code component ζ is defined as:

$$\zeta(\varphi, \kappa, \nu) = (d_n, t_n) \qquad (2.1)$$

where ζ is a code component that performs φ actions with the set of input value *v* concerning a particular patient in a data component *K*. ζ returns information regarding disease *d* and therapy strategy *t* on the basis of following relations:

$$\Delta : 2^{(k,v)} \rightarrow D, \text{ (many-to-one relation)}, \quad (2.2)$$

$$D = \{d_1, d_2, \ldots, d_n\}, \; d \in D$$

where D is a set containing treatable diseases and/or types of malaria, *d* is the diagnosed symptom and/or species of Plasmodium; and,

$$\Gamma : D \rightarrow \mathrm{T} \text{ (One-to-one relation)}, \qquad (2.3)$$

$$T = \{t_1, t_2, \ldots, t_n\}, \; t \in T$$

where T is a set containing different therapy strategies, t is a suggested therapy.

Definition 3: Action

Action is defined as a composition of a set of atomic tasks. Consider the following action structure:

$$A ::= \varepsilon \mid a_0 \mid a_1a_2 \mid a_1 \rightarrow a_2 \mid a^* \qquad (3.1)$$

where

(i) ε is the empty action or a standard alone action.
(ii) a_0 denotes a finite or countable infinite number of basic actions that needs further construction.
(iii) a_1a_2, the concatenation of actions a_1 and a_2 means the action of a_1 followed by the action of a_2.
(iv) $a_1 \rightarrow a_2$ means that the action of a_1 can be replaced by that of a_2.
(v) a* is the complement of the action a.
(vi) | expresses alternative state of the system.

Definition 4: Optimization

The purpose of the optimization problem is to evaluate alternative solutions according to multiple criteria.

$$\begin{aligned} &max\{f_1(c)=o_1\} \\ &max\{f_2(c)=o_2\} \\ &\ldots \\ &max\{f_k(c)=o_k\} \qquad (4.1) \end{aligned}$$

where *f(c)* is the objective function, *o* is the highest objective function value.

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Definition 5: λ contract

The achievement of the goal pursued by the agent with awareness is sustained by a proof system called a λ contract.

The idea of a contract is borrowed from those related to human activities where there are commonly two parties; a provider, which performs some task for the other, a client.

The model of the contract used is developed in [21]. Thus applying to software agents, a contract leads to the interaction between applications or functions into an application. Ideally, a contract should cover all essential functional and non-functional aspects of an application.

The specification of a contract can contain in general the following pieces of information:

a. Operation semantics describe each operation using: - Informal text, - pre/post condition, - invariant

b. Interface protocol provides the constraints on the order in which operations may be called.

c. Service level covers guarantees regarding the qualities or non-functional requirements such as: timing constraints, network availability, data safety for persistent state, capacity, security and performance. This information can be introduced in one of the following basic element of the contract:

Request-response protocol

Data-field
Execution-information
Message
Message-client
Message-provider
Context
Results

The request-response protocol is transactions divided into two parts, contracted and contractor, one for requests and the other for responses. Transaction data-fields are used for performing two kinds of data-fields: the execution information that controls the execution of the transaction, and the message addressed to the contracted or the contractor. Furthermore, the request-response protocol, in the SA, facilitates easier integration of non-functional requirements with functional requirements. The context determines actions performed by the agent. The result is the achievement of the goal pursued by the agent.

3 Results

We had the objectives to formalize the design of software agents and to demonstrate their applicability to a web-based medical decision support system. This was possible by the prototype that we designed and implemented under the name “OMaT” [22].

The prototype was developed using PHP, XML, HTML, JavaScript and CSS as front end and raw files, MySQL and NoSql data base as the backend. The proposed solution in the form of web applications includes a generic medical decision support system and is expected to assist healthcare professionals at medical consultation and decision of the patients with the malaria disease. It contains five basic components that constitute the main menu: newCase Agent, openCase Agent, iLaboratory Agent, GIS Agent and Knowledge Repository (KR) Agent.

We describe only the component newCase to point out the use of our model, specifically the contract. The component newCase is a succession of sub-components namely: newCase1, newCase2, newCase3, and newCase4. The newCase1 sub-component allows the HCP to supply first information on the clinical examination. The newCase2 sub-component generates a report of clinical diagnosis and allows the HCP to supply secondly information on the laboratory test. The newCase3 sub-component generates the report of diagnosis, the symptomatic report and the report of therapy strategies. It also allows the HCP to write his own medical prescription based on the reported information. The newCase4 sub-component allows the HCP to download a file in the form of an electronic medical record (csv format), to print the medical decision report, and to receive it in an email.

In the following, we emphasise the use of the contract by pseudo code-based PHP to illustrate the implementation of different agents acting for the medical decision support.

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3.1 Usage scenario of the λ contract by the software agents

The specification of the OMAT system is:
OMAT ::= Login → Menu
Menu ::= newCase | openCase | iLab | GIS | KR
newCase ::= newCase1 → newCase2 → newCase3 → newCase4
newCase1 ::= newCase1 | GIS | KR
newCase2 ::= newCase2 | iLab | KR
newCase3 ::= newCase3 | KR
newCase4 ::= storage | print | sendEmail
where GIS is a Geographic Information System, KR is a Knowledge Repository and iLab is a Remote

1° Contract to guarantee action of calling another Agent
newCase1 Agent side:

```
<?
# OMAT SYSTEM
# newCase1 AGENT
## Request-response protocol
  session_start();   //Set a self control of the system
while(($userNameSystem=$userNameInput) and
  ($passWordSystem=$passWordInput))
  {
    count++; // Try again
    if ( count>5)
      {
           echo "Login Failed!";
           echo "<script>window.close();</script>";
           exit;
      }
  } endwhile
## Context
  Input Values in newCase1 form
// Enter Patient Profile Data: Sex, Age, Weight,
   Country, …,
 // Enter Signs/ Symptoms Data
    ...
## Results
   // Submit data value to newCase2
  Submit();
      ...
?>
```

2° Contract to guarantee action of calling another Agent and to express optimization problem
newCase2 Agent side:

```
<?
# OMAT SYSTEM
# newCase2 AGENT
## Request-response protocol
session_start();   //Set a self control of the system
while(($userNameSystem=$userNameInput) and
($passWordSystem=$passWordInput))
{count++; // Try again
 if ( count>5)
{ echo "Login Failed!";
  echo "<script>window.close();</script>";
  exit;}
} endwhile
// verify required information posted by newCase1
if(empty($_POST['listOfInputValue']))
{ // Missing some information
  $errors = "These values are required:".$listOfValuePost;
  setcookie('$errors ', $Errors);
  // Return to newCase1
 echo "<script>window.location='../newCase1.php'</script>";
  exit;
}
...
  $patientStatus; $signSymptoms;
## Context
function checkTestSymptom($hypothese) {
  switch($signSymptoms)
   {
     case 1: $hypothese="Uncomplicated Malararia"
     case 2: $hypothese="Complicated Malararia"
     case 3: $hypothese="Others diseases"
   }
   }
function checkTreatSymptom() {
  switch($patientStatus)
  { //Following symptoms/signs
  case 1: $treatSymptom= typeofTreatSymptom1;
        ...
  case m: $treatSymptom= typeofTreatSymptomm;
  }
}
...
// Input Values in newCase2 form
     ...
// Laboratory test
// Possiblity to call iLab
## Results
// Generates a Clinical Diagnosis Report
// Submit data value to newCase3
Submit();
...
?>
```

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4 Discussion

The software agent system is adopted to cope with a complex and dynamic domain such as medicine and particularly the web-based medical decision support system for malaria diagnosis and therapy of the OMaT system.

Our clinical decision support system for the treatment of malaria is based on consensus guidelines and protocols for the management of malaria. Thus, our system only deals with information theory and medical practice identified in advance, limited and structured so for its efficiency and completeness. This constitutes the knowledge base of the software agent.

The proposed functional model facilitated the implementation of the SA. Specifically, the λ contract ensures the consistency and the credibility of the reasoning of the software agent.

Experiments on a set of test cases were performed. The results observed in our experiments were satisfactory. The system can generate diagnosis based on signs/symptoms and can advise treatment automatically in real time.

To demonstrate and to illustrate the application of our functional model, we presented two agents: the newCase1 agent and the newCase2 agent. The newCase1agent allows the HCP to supply the first information on the clinical examination. Based on the information supplied by the newCase1 agent, the newCase2 agent can analyse it and can generate a clinical diagnosis report. This will allow the HCP to supply other information for the purpose of the laboratory test.

The "Contract 1° expresses on line 24 the definition 1 where the newCase1 agent calls the newCase2 agent. The "Contract 2° expresses on lines 6 to 23 the definition 1 where the called newCase2 agent reacts to the call of the newCase1 agent. Also, the "Contract 2° expresses on lines 27 to 40 the definition 2 where the newCase2 agent acts and generates a clinical diagnosis.

Our system uses a request/response protocol in which it can receive information from the user or other agents and can respond or react.

The quality of the system depends on the reliability of the information entered, protection against handling errors and lack of dangerous results. Therefore, the human - machine interface that we have proposed is quite responsive and easy to use to facilitate the work. A click allows the user to enter data.

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