AMBIENT-ORIENTED MODELING OF INTELLIGENT CONTEXT-AWARE SYSTEMS

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Abstract: The paper presents an approach for modeling intelligent IoT context-sensitive systems. Ambient-oriented modeling allows for the tracking of processes in the area under consideration, taking into account dynamic environmental changes. The main concepts and characteristics of the approach are considered. Described is the formal System of Context-aware Ambients (CCA) supporting the approach. The application of CCA modeling in a Virtual Physical Space (ViPS) is demonstrated.

Keywords: Ambient-oriented modelling, CCA, context-aware systems, IoT, ViPS

1. INTRODUCTION

The development of society under the Fourth Industrial Revolution determines the need to create new Cyber-Physical Spaces (CPS) that provide dynamic interaction between the real world and the virtual world [1]. These systems take account of changes in the physical world and adapt this information to the goals, desires and needs of the individual users.CPSs enable the physical world to merge with the virtual world by integrating computational and physical processes by facilitating the close integration of computing, communication and control in their operation and interaction with the environment in which they are located [4]. Software IoT architecture includes various types of active and passive components - mainly agents, but also services, modules, ontologies. It is convenient to use intelligent, autonomous, contextually-informed or context-sensitive components.The development of such environments requires the creation of new approaches, models, abstractions, methods and technologies to integrate the individual components of the system. Due to hardware and software complexity and heterogeneity, the construction of IoT applications is associated with serious risks. It is inappropriate, inefficient and financially disadvantageous to directly develop such systems, which determines the need for a preliminary modeling and prototyping process of the developed system.Choosing the adequate modeling approach is of particular importance. The paper presents an appropriate approach to modeling IoT systems, known as Ambient-oriented Modeling (abbreviated AOM). We will present the modeling of services that take place in Virtual Physical Space (ViPS) which can be adapted to build IoT applications in various domains. This type of modeling is based on the concept of context. A widely accepted is Dey's definition [2, 3], according to which context is any information that can be used to categorize the state of an entity - a person, place or object that is considered to be related to the interaction between user and application, including the user and application itself.

The article is structured as follows: in the second section, the basic concepts are discussed; the third section briefly discusses widely used formalizations for AOM; fourth section presents the ViPS architecture; a CCA-model of typical demonstration service is discussed in the fifth section.

2. AMBIENTS. AMBIENT INTELLIGENCE AND IOT

An Ambient is an identity with the following characteristics [9]:

- Narrowness - limited location, where action is happening;
- Inclusion – one ambient can be included in other one. Thus, ambient hierarchies can be created;
- Mobility - an ambient can change its location in the ambient hierarchy. If it contains other ambients in itself, it moves along with its entire hierarchical structure.

For modeling purposes, an ambient will be presented as a structure with the following elements:

- Identifier (name) - a mandatory element that serves to identify and control access.
- Corresponding multitude of local agents (threads, processes) - these are computational processes that work directly in the ambient and in a sense control it. The plurality of adjacent sub-ambients in turn have identifiers, agents and sub-ambients. Thus, there is the possibility of recursively building different complex Ambient-structures.

Ambient Intelligence (AmI) makes the daily information space of users more "sensitive" to their problems and peculiarities by adding sensors and effectors to interact with both the environment and the people in it. All these devices are connected through a suitable computer network. The main features of AmI technologies are the following [10]:

- Sensitivity - Recognize objects and subjects in the environment and react to their behavior;
- Adaptability - adjust their behavior according to the specific situation.
- Transparency - the technologies used are invisible to consumers;
- Universality - one of AmI's ideas is to be present anywhere, where available information allows the system to respond more adequately to emerging events;
- Intelligence - methods of artificial intelligence are used.

The basic idea behind AmI is that the applications in the space, using dynamic data from the real world and background data accumulated over time, can make decisions for the benefit of users in it [11]. Typical examples are personal assistants who, depending on the situation, are able to provide proactive help or exercise restraint. Sensible requirements to them can be the ability to recognize the user, to know the preferences and aims, to show empathy to the moods and emotions of the users, etc.

The convergence of AmI and IoT [12, 13, 14] aims to build space in which intelligent Web-enabled objects collaborate to exchange their own data and services - thus providing comprehensive services to consumers. According to the AmI and IoT vision, the devices are widespread in the space in the form of sensors, actuators, smart devices, active labeled objects or mobile robots. These devices are interconnected and can always and anywhere be accessed through a variety of small mobile devices. Compared to classic web services, AmI and IoT provide not only computing and software resources but also various levels of control of physical devices and events[15]. Using IoT and AmI technologies, the number of consumer support services is steadily increasing. These services are dynamic due to frequent changes occurring in the space.

3. AMBIENT-ORIENTED MODELING (AOM)

There are different formal systems that are used for ambent-oriented modeling. Basic formalism is π-calculus [16], which presents a type process-calculations. A basic concept in π - calculus is the channel, as one channel being able to "move" through other channels. Processes of motion are modeled as the movement of channels that refer to these processes, so there is no clear indication in the π -calculus that the processes themselves are moving. However, the basic concepts of π -

calculus are the basis for creating a number of other formalizations. In [17, 18] there are versions of the π -calculus, expanded with primitives, allowing migration between named locations. Join-Calculus [19] is a reformulation of the π -calculus with a more clear idea for locations of interactions. An important extension of the π -calculus, known as Ambient Calculus (AC), is presented in [20] where the mobility paradigm is adopted. Ambients are hierarchically structured, agents are limited to ambients, and ambients move under the control of agents. New paradigm is the movement of self-contained nested environments that include background data and real-time computing, as opposed to more commonly used techniques that move individual agents or objects. The successor to AC is the Calculus of Boxed Ambients (CBA) [21].

Calculus of Context-aware Ambients(CCA) extends the CBA with new constructions to enable mobile ambients to respond to changes in the space in which they are running [22]. Consequently, mobility and awareness of context are of particular importance. To represent the properties of CCA processes, a logical language is used, in which the contextual expression plays a major role. Contextual expressions are used in CCA to ensure fulfillment of a certain opportunity only under certain conditions of the environment, ie. in a certain context.The formal semantics of the CCA expands the CBA with the following characteristics: the ability to perform processes only while ensuring the conditions in a particular context; processes abstract processes through context mechanisms; CCA can fully implement π -calculus modeling by providing much better opportunities for context-aware ambient modeling.

CCA Ambients are treated as an identity that is used to describe an object or component - a process, a device, a location, etc. Each Ambient has a name, a boundary, and may contain other ambients within itself, and be included in another ambient. There are three possible relationships between two ambients -parent, child and sibling. Each ambient can communicate with other ambents around it. Ambients can exchange messages with each other. The process of messaging is done using the handshaking process. The notation "::" is a symbol for sibiling ambients; "↑" and "↓" are symbols for parent and child; "<>" means sending, and "()" - receiving a message. An ambient can be mobile, i.e. to move within the surrounding environment. There are two ways to move: inwards and outwards, which allow ambients to move from one location to another. The CCA can distinguish four syntax categories: locations α, opportunities M, processes P and contextual expressions k.

Locations are basic parameters for Ambients. The location α can be: "↑", meaning a parent ambient; "n↑" is used for a specific parent named n; "↓" refers to child ambient, and "n ↓" denotes a specific child ambient named n; the sign "::" is used to show a sibling Ambients, and "n ::" indicates a specific sibling ambient named n. Every ambient can also use an empty string to turn to itself.

Opportunities can use in various aspects such as the opportunity moving allows of Ambient to move around in and out. The opportunity calling of process α<y> coupled to x in space α is realized by substituting each fact parameter from the list y with its corresponding formal parameter. Ambients can exchange messages, and by the opportunity α<y> one ambient can send a list y of names to location α, and by the opportunity α(y) another ambient will receive a list of variables y of location α. The opportunity "del n" allows deleting ambient n if it is empty. This feature is allowed only for parent of the removed ambient.

Processes are a basic syntax category in CCA modeling. Process 0 does nothing and ends immediately. The process P | Q indicates that the process P is performed in parallel with the process Q. The process (νn) P expresses that the range of the name n is limited to the process P. The doubling sign is “!”, So the process “!P” is a process that can to create a new copy of the process P, i.e. !P = P |!P. The process n [P] denotes an Ambient named n, and P is the process that describes the ambient behavior. The pair of brackets "[" and "]" define the boundary of the Ambient.

Contextual expression defines the condition that must match with the surrounding environment of the performed process. The contextually guaranteed pre-condition “k?M.P” is a process that waits and does not realize the opportunity M, which will be followed by the P process, while the environment does not satisfy the contextual condition k. The using of the contextually guaranteed pre-condition is one of the two main mechanisms for realizing contexts in CCA. The second mechanism is related to the process abstraction $x\Delta(y).P$, which means the connection between the name x and the process P as y is a list of formal parameters. Thus, the name x may be associated with more than one process in different Ambients. Calling the process abstraction x is realized by αx <z>, where α is the location in which the process abstraction is defined, and z is the list of actual parameters that are associated with the corresponding formal parameters.

4. VIPS (VIRTUAL PHYSICAL SPACE) AS IOT APPLICATION

The idea of an IoT ecosystem is based on the notion of “things”, that are the basic building blocks of the space. They provide connection and interaction between physical and digital worlds in the Internet. Every "thing" must provide sensory information and to have computational and processing capabilities. All these capabilities define it as an autonomous, active structure that can share knowledge and information with other planning and decision-making environments to achieve for personal or shared purposes. In addition, the "things" should be able to communicate seamlessly across a network as form a "things" hierarchical network structure.

In accordance with this concept, the ViPS architecture provides virtualisation of real objects that can be adapted to a specific domain. In aspect of software technologies, this means creating digitized versions of physically real objects that can be defined and digitally interpreted. Thus, ViPS architecture reflects and represents in the digital world an essentially identical model of the real physical world in which processes, users and knowledge in a particular area interact with each other in a dynamic, personalized and context-sensitive way. Modeling "things" takes into account factors such as events, time and location. The analytical sub-space (AS) provides tools for the preparation of domain-specific analyzes supported by four structures. ONet is a hierarchy of ontologies that present the main features of things in the defined domain. ENet models different types of events and their characteristics (identification, conditions for occurrence and completion) that are representative of the domain of interest. TNet provides the opportunity to present and work with temporary aspects of things, events, and locations. In ANet the spatial characteristics of "things" and events can be modeled as ambient stricture. The work with these structures is supported by specialized interpretators based on the official specificatios as Interval Temporal Logics (ITL [5]), CCA [6], and Event Model (EM) [7]. Inferences and conclusions made by model interpretation use background knowledge and domain documents stored in Digital Libraries Subspace implemented as open digital repositories satisfying DSpace specification.

The operative assistants, implemented as rational intelligent agents, provide access to the resources of both sub-spaces and accomplish interactions with personal assistants and web applications.

Guards (GA) act as a smart interface between the virtual world and the physical world. They provide Physical World state data obtained from IoT Nodes that are transferred to the virtual environment of the space through an appropriate interface. There are many IoT nodes that access to sensors, "things" and sensor-moving devices found in the physical world.

Due to the complexity of the system, it is difficult for users to work with it. The access to ViPS is controlled and personalized. Personal assistants (PA) that work on behalf of users and are aware of their needs will prepare scenarios for meeting customer requests and manage and control their performance by interacting with ViPS's middleware software. Public information resources are available through appropriate web applications.

5. CCA-MODELING AN EXEMPLARY TOURIST SERVICE IN VIPS

Let's look at ViPS space, that provide information and services related to the tourist context. In DL Subspace is structured information related to touristic objects in a particular domain. Analytical Subspace (AS) provides tools for the preparation of tourism-specific analyzes through its four core structures: ONet provides a network of ontologies supporting information on various aspects of tourist sites - Renaissance houses, embroidery, traditional costumes, crafts, etc .; ENet provides the appropriate services such as visiting tourist sites, providing information on timetables for touristic ships, buses, airplanes, etc .; TNet guarantees the temporal aspects of the services provided, and ANet allows modeling of the spatial characteristics of the "things" and events such as route generation, etc. The PTA will act as a personal tourist guide. It communicates with the user through his personal mobile device. Each component of the space will be represented in the model by a specific operational Specialist Assistant (SA). Guards (GA) will provide the link with the physical world and will take care of the tourist's safety during the performance of services. In order to model the services in this space, it is necessary to present the considered components as an ambient structure (Fig. 1)

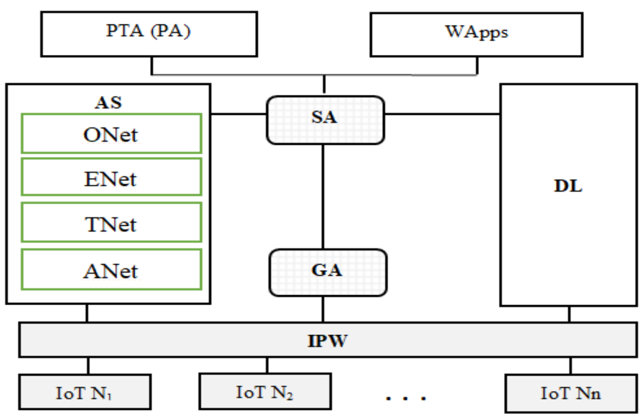

Fig.1. ViPS Ambient Structure

CCA-Modeling Ambients:

- Personal Touristic Assistant (PTA) - Ambient, representing a special type of personal assistant that provides communication with the environment and provides user-friendly services to individual tourists
- WApps (WEB Applications) - Ambient, providing connection to external information systems (eg related to meteorological forecasting, information on sea water in the Black Sea region, etc.)
- AS (Analytical Subspace) with sub-ambients ONet, ENet, TNet and ANet
- DL (Digital Libraries) - Ambient providing the information related to the particular domain.

- SA (Specialist Assistants) - Ambient providing communication in the system. This ambients contains a hierarchy of ambients presenting operational assistants that guarantee the work of individual components in space.
- GA (Guard Assistants) - ambient- structure of the guards in the space
- IPW (Interface Physical World) - Ambient providing communication between the physical and the virtual world.
- IoTN (IoT Nodes) - ambients representing different physical units-sensors and "things" delivering information from a dynamically changing environment (eg temperature sensors, etc.)

Tourist is located in the region of Burgas and wishes to visit the island of Saint Anastasia. Will consider the following scenario for interaction between participating ambients: The PTA sends a message to the SA to search for information about the touristic objects in the around area. SA sends the request to DL, from which it receives a list of touristic objects near the tourist. The tourist chooses to visit the island of Saint Anastasia and the PTA sends a request to the system for verification of island visit opportunity. SA directs the request via the AS to ENet, where it is determined whether some ship will go to the island in the next 1 hour interval, whether there are tickets and whether the museum is open. If so, the PTA sends a purchase ticket request to the ENet ambient that manage executing of the service. Upon successful completion of the service, the PTA sends a request to generate a route to the port. The message is transmitted via AS to ANet, where a list of possible routes is generated according to the current location of the tourist. After choosing a particular route, the PTA sends it to TNet for execution. In dynamic mode GA tracks changes in the environment - temperature, humidity, rainfall, etc. and in the case of storms, low temperatures, etc. sends a warning message to the PTA. This information is collected from a variety of sources - from IoTN through IPW, as well as from external applications (eg, web sites for forecasting).At the scheduled time of departure of the ship, ENet launches the event and the remaining ambients in the space begin two-way communication to provide the tourist with the necessary information during his trip. The PTA sends a request to the DL- ambient to search for information related to the tourist sites of the island. SA directs the request to the DL and receives general information or a notifying message from there. It then transmits the request through the AS to the ONet and from there it receives structured information about the individual objects, that the user is expected to visit on the island (eg information about the type and architectural features of the buildings). Information is sent to the tourist via his PTA.

The CCA model of the presented service can be described through the processes of the participating ambients as follows:

$$P_{PTA} \cong \begin{pmatrix} !SA::<PTAi, location, getTourObjs>.0\,| \\ !SA::(ListTourObjects).0\,| \\ !SA::<PTAi, location, visitIsland>.0\,| \\ !SA::(OK, InfoPW).0\,| \\ SA::<PTAi, buyTicket>.0\,| \\ !SA::(OK).0\,| \\ SA::<PTAi, location, getRouteToPort>.0\,| \\ !SA::(ListRoutes).0\,| \\ SA::<PTAi, location, Route>.0\,| \\ !SA::(Navigator).0\,| \\ SA::<PTAi, getMoreInfo>.0\,| \\ !SA::(mainInfo, specificInfo).0 \end{pmatrix}$$

$$P_{SA} \cong \left(\begin{array}{l} !PTA::(PTAi, location, getTourObjs).DL::< PTAi, location, getTourObjs > .0 \mid \\ DL::(PTAi, ListTourObjects).PTA::(ListTourObjects).0 \mid \\ !PTA::(PTAi, location, visitIsland).AS::< PTAi, location, visitIsland > .GA::< PTAi, location, visitIsland > .0 \mid \\ AS::(PTAi, OK).!GA::(PTAi, InfoPW1, InfoPW2).PTA::< OK, InfoPW > .0 \mid \\ !PTA::(PTAi, buyTicket).AS::< PTAi, buyTicket > .0 \mid \\ !AS::(PTAi, OK).PTA::< OK > .0 \mid \\ !PTA::(PTAi, location, getRouteToPort).AS::< PTAi, location, getRouteToPort > .0 \mid \\ AS::(PTAi, ListRoutes).PTA::< ListRoutes > .0 \mid \\ !PTA::(PTAi, location, Route > .AS::< PTAi, location, Route > .0 \mid \\ AS::(PTAi, Navigator).PTA::< Navigator > .0 \mid \\ !PTA::(PTAi, getMoreInfo).AS::< PTAi, getMoreInfo > .DL::< PTAi, getMoreInfo > .0 \mid \\ AS::(PTAi, specificInfo).DL::(PTAi, mainInfo).PTA::< mainInfo, specificInfo > .0 \end{array}\right)$$

$$P_{AS} \cong \left(\begin{array}{l} !SA::(PTAi, location, visitIsland).ENet \downarrow < PTAi, location, visitIsland > .0 \mid \\ ENet \downarrow (PTAi, HasShip, HasTicket, OpenMuseums).!SA::< PTAi, OK > .0 \mid \\ !SA::(PTAi, buyTicket).ENet \downarrow < PTAi, buyTicket > .0 \mid \\ ENet \downarrow (PTAi, OK).SA::< PTAi, OK > .0 \mid \\ !SA::(PTAi, location, getRouteToPort).ANet \downarrow < PTAi, location, getRouteToPort > .0 \mid \\ ANet \downarrow (PTAi, ListRoutes).SA::< PTAi, ListRoutes > .0 \mid \\ !SA::(PTAi, location, Route > .TNet \downarrow < PTAi, location, Route > .0 \mid \\ TNet \downarrow (PTAi, Navigator).SA::< PTAi, Navigator > .0 \mid \\ !SA::(PTAi, getMoreInfo).ONet \downarrow < PTAi, getMoreInfo > .0 \mid \\ ONet \downarrow (PTAi, specificInfo).SA::(PTAi, specificInfo).0 \end{array}\right)$$

$$P_{ENet} \cong \left(\begin{array}{l} AS \uparrow (PTAi, location, visitIsland).AS \uparrow < PTAi, HasShip, HasTicket, OpenMuseums).0 \mid \\ AS \uparrow (PTAi, buyTicket).AS \uparrow < PTAi, OK > .0 \end{array}\right)$$

$$P_{ANet} \cong \left(\begin{array}{l} AS \uparrow (PTAi, location, getRouteToPort).0 \mid \\ AS \uparrow < PTAi, ListRoutes > .0 \end{array}\right)$$

$$P_{TNet} \cong \left(\begin{array}{l} AS \uparrow (PTAi, location, Route).0 \mid \\ AS \uparrow < PTAi, Navigator > .0 \end{array}\right)$$

$$P_{ONet} \cong \left(\begin{array}{l} AS \uparrow (PTAi, getMoreInfo).0 \mid \\ AS \uparrow < PTAi, specificInfo > .0 \end{array}\right)$$

$$P_{DL} \cong \left(\begin{array}{l} !SA::(PTAi, location, getTourObjs).SA::< PTAi, ListTourObjects > .0 \mid \\ !SA::(PTAi, getMoreInfo).SA::< PTAi, mainInfo > .0 \end{array}\right)$$

$$P_{GA} \cong \left(\begin{array}{l} !SA::(PTAi, location, visitIsland).WApps::< PTAi, location > .IPW::< PTAi, location > .0 \mid \\ WApps::(PTAi, InfoPW1).IPW::(PTAi, InfoPW2).SA::< PTAi, InfoPW1, InfoPW2 > .0 \end{array}\right)$$

$$P_{WApps} \cong \left(!GA::(PTAi, location).GA::< PTAi, InfoPW1 > .0 \right)$$

$$P_{IPW} \cong \left(\begin{array}{l} !GA::(PTAi, location).IoTN::< PTAi, location > .0 \mid \\ IOTN::(PTAi, InfoPW2).GA::< PTAi, InfoPW2 > .0 \end{array}\right)$$

$$P_{IoTN} \cong \left(!IPW::(PTAi, location).IPW::< PTAi, InfoPW2 > .0 \right)$$

6. CONCLUSION

The paper examines the possibilities of an intelligent context-aware modeling approach, known as ambient-oriented modeling. The approach is particularly suited to supporting the development of IoT applications. The application of the approach to developing a particular model through CCA is demonstrated. The model presented in the article is just one of the elements of the overall model of ViPS. In order to test the architecture proposed in this paper, a prototype is developed to support e-learning at the Faculty of Mathematics and Informatics of Plovdiv University [6,24]. Some experiments have been conducted for IoT monitoring of water in large open water basins. New domains are sought, e.g. smart cities and intelligent touristic guides [25].

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