An Agent-Based Generic Model for Human-Like Ambience

Tibor Bosse, Mark Hoogendoorn, Michel Klein, and Jan Treur

Vrije Universiteit Amsterdam, Department of Artificial Intelligence,
De Boelelaan 1081a, 1081 HV, the Netherlands
{tbosse, mhoogen, mcaklein, treur}@cs.vu.nl
http://www.cs.vu.nl/~{tbosse, mhoogen, mcaklein, treur}

Abstract. A reusable agent-based generic model is presented for a specific class of Ambient Intelligence applications: those cases addressing human wellbeing and functioning from a human-like understanding. The model incorporates ontologies, knowledge and dynamic models from human-directed sciences such as psychology, social science, neuroscience and biomedical sciences. The model has been formally specified, and it is shown how for specific applications it can be instantiated by application-specific elements, thus providing an executable specification that can be used for prototyping. Moreover, it is shown how dynamic properties can be formally specified and verified against generated traces.

1 Introduction

The environment in which humans operate has an important influence on their wellbeing and performance. For example, a comfortable workspace or an attentive partner may contribute to good performance or prevention of health problems. Recent developments within Ambient Intelligence provide technological possibilities to contribute to such personal care; cf. [1], [2], [20]. For example, our car may warn us when we are falling asleep while driving or when we are too drunk to drive. Such applications can be based on possibilities to acquire sensor information about humans and their functioning, but more substantial applications depend on the availability of adequate knowledge for analysis of information about human functioning. If knowledge about human functioning is represented in a formal and computational format in devices in the environment, these devices can show more human-like understanding, and (re)act accordingly by undertaking actions in a knowledgeable manner that improve the human's wellbeing and performance. As another example, the workspaces of naval officers may include systems that track their gaze and characteristics of stimuli (e.g., airplanes on a radar screen), and use this information in a computational model that is able to estimate where their attention is focussed at; cf. [8]. When it turns out that an officer neglects parts of a radar screen, such a system can either indicate this to the person (by a warning), or arrange in the background that another person or computer system takes care of this neglected part.

In recent years, human-directed scientific areas such as cognitive science, psychology, neuroscience and biomedical sciences have made substantial progress in providing an increased insight in the various physical and mental aspects involved in human functioning. Although much work still remains to be done, dynamic models have been developed and formalised for a variety of such aspects and the way in which humans (try to) manage or regulate them. From a biomedical angle, examples of such aspects are (management of) heart functioning, diabetes, eating regulation disorders, and HIV-infection; e.g., [3], [16]. From a psychological and social angle, examples are emotion regulation, attention regulation, addiction management, trust management, stress management, and criminal behaviour management; e.g., [17], [5], [10], [11].

The focus of this paper is on the class of Ambient Intelligence applications as described, where the ambient software has context awareness (see, for example, [21], [22], [23]) about human behaviours and states, and (re)acts on these accordingly. For this class of applications an agent-based generic model is presented, which has been formally specified. For a specific application, this model can be instantiated by case-specific knowledge to obtain a specific model in the form of executable specifications that can be used for simulation and analysis. In addition to the naval officer case already mentioned, the generic model has been tested on a number of other Ambient Intelligence applications of the class as indicated. Three of these applications are discussed as an illustration, in Section 5. Section 2 describes the modelling approach. In Section 3 the global architecture of the generic model is presented. Section 4 shows the internal structure of an ambient agent in this model. Finally, Section 6 is a discussion.

2 Modelling Approach

This section briefly introduces the modelling approach used to specify the generic model. To specify the model conceptually and formally, the agent-oriented perspective is a suitable choice. The processes in the generic process model can be performed by different types of agents, some human, some artificial. The modelling approach used is based on the component-based agent design method DESIRE [12], and the language TTL for formal specification and verification of dynamic properties [6], [18].

Process and Information Aspects Processes are modelled as components. A component can either be an active process, namely an agent, or a source that can be consulted or manipulated, which is a world component. In order to enable interaction between components, interaction links between such components are identified and specified. Ontologies specify interfaces for components, but also what interactions can take place between components, and the functionalities of components.

Specification Language In order to execute and verify human-like ambience models, the expressive language TTL is used [6], [18]. This predicate logical language supports formal specification and analysis of dynamic properties, covering both qualitative and quantitative aspects. TTL is built on atoms referring to states, time points and traces. A *state* of a process for (state) ontology Ont is an assignment of truth values to the set of ground atoms in the ontology. The set of all possible states for ontology Ont is denoted by STATES(Ont). To describe sequences of states, a fixed *time frame* T is assumed which is linearly ordered. A *trace* γ over state ontology Ont and time frame T is a mapping $\gamma : T \rightarrow STATES(Ont)$, i.e., a sequence of states γ_t ($t \in T$) in STATES(Ont). The set of *dynamic properties* DYNPROP(Ont) is the set of temporal statements that can be formulated with respect to traces based on the state ontology Ont in the following manner. Given a trace γ over state ontology Ont, the state in γ at time point t is denoted by state(γ, t). These states can be related to state properties via the formally defined satisfaction relation |=, comparable to the Holds-predicate in the Situation Calculus [19]: state(γ, t) |= p denotes that state property p holds in trace γ at time t. Based on these statements, dynamic properties can be formulated in a sorted first-order predicate logic, using quantifiers over time and traces and the usual first-order logical connectives such as ¬, ∧, ∨, ⇒, ∀, ∃. A special software environment has been developed for TTL, featuring both a Property Editor for building and editing TTL properties and a Checking Tool that enables formal verification of such properties against a set of (simulated or empirical) traces.

Executable Format To specify simulation models and to execute these models, the language LEADSTO, an executable sublanguage of TTL, is used. The basic building blocks of this language are causal relations of the format $\alpha \twoheadrightarrow_{e, f, g, h} \beta$, which means:

if state property α holds for a certain time interval with duration g,
then after some delay (between e and f) state property β will hold
for a certain time interval of length h.

where α and β are state properties of the form 'conjunction of literals' (where a literal is an atom or the negation of an atom), and e, f, g, h non-negative real numbers.

3 Global Structure of the Agent-Based Generic Model

For the global structure of the model, first a distinction is made between those components that are the *subject* of the system (e.g., a patient to be taken care of), and those that are *ambient*, supporting components. Moreover, from an agent-based perspective (see, for example, [11], [12]), a distinction is made between active, *agent* components (human or artificial), and passive, *world* components (e.g., part of the physical world or a database). Furthermore, within an agent a mind may be distinguished from a physical body. This provides the types of components distinguished shown in Figure 1. Here the dotted rectangles depict agents with mind and body distinguished within them, and the other geometrical shapes denote world components. Given the distinctions made between components, interactions between such components are of different types as well. Figure 1 depicts a number of possible interactions by the arrows. Table 1 shows an overview of the possible interactions.

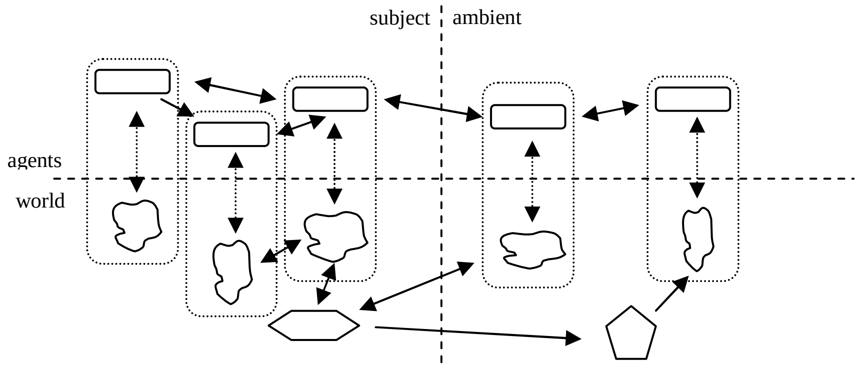

Fig. 1. Different types of components and interactions

Interaction Between Agents Interaction between two agents may be *communication* or *bodily interaction*, for example, fighting. When within the agent a distinction is made between mind and body, communication can be modelled as information transfer between an agent's mind and another agent's mind. Whether for a given application of the generic model, within agents a mind and a body are distinguished, depends on the assumptions made about the application domain. If it is assumed that communication is independent of and cannot be affected by other processes in the world, then communication can most efficiently be modelled as information transfer between minds. If, in contrast, it is to be modelled how communication is affected by other processes in the world (e.g., effects on the quality of a channel or network), then it is more adequate to model communication as bodily interaction. Obviously, also in cases that it is to be modelled how agents affect each others bodies, as in fighting, the latter is the most adequate option.

from \ **to**	*subject agent*	*subject world component*	*ambient agent*	*ambient world component*
subject agent	subject communication; subject body interaction	subject observation focus; subject action performance; subject body-world interaction	subject-ambient communication; subject-ambient body interaction	subject-ambient observation focus; subject-ambient action performance; subject-ambient body-world interaction
subject world component	subject observation result; subject world-body interaction	subject world component interaction	subject-ambient observation result; subject-ambient world-body interaction	subject-ambient world component interaction
ambient agent	ambient-subject communication; ambient-subject body interaction	ambient-subject observation focus; ambient-subject action performance; ambient-subject body - world interaction	ambient communication; ambient body interaction	ambient observation focus; ambient action performance; ambient body-world interaction
ambient world component	subject-ambient observation result; ambient-subject world-body interaction	ambient-subject world component interaction	ambient observation result; ambient world-body interaction	ambient world component interaction

Table 1. Different types of interaction

Agent-World Interaction Interaction between an agent and a world component can be either *observation* or *action* performance; cf. [11]. An action is generated by an agent, and transfers to a world component to have its effect there. An observation has two directions: the *observation focus* is generated by an agent and transfers to a world component (providing access to a certain aspect of the world), and the provision of the *observation result* is generated by the world component and transfers to the agent. Combinations of interactions are possible, such as performing an action and observing the effect of the action afterwards. When the agent's body is distinguished from its mind, interaction between agent and world can be modelled as transfer between this body and a world component. In addition, interaction between the agent's mind and its body (the vertical arrows in Figure 1) can be used to model the effect of mental processes (deciding on actions and observations to undertake) on the agent-world interaction and vice versa (incorporating observation results). Also here, whether for a given application of the generic model interaction between an agent and the world is modelled according to the first or the second option, depends on the assumptions made about the application domain. If it is assumed that performance of an intended action generated by the mind has a direct effect on the world and has no relevant effect on an agent's body, then it can most efficiently be modelled according to the first option. If, in contrast, it is to be modelled how actions and observations are also affected by other processes in the body or world, then the second option is more adequate. Also in cases that it is to be modelled how the world affects an agent body, obviously the second option is the most adequate.

The naval officer example Table 2 illustrates the different types of components and interactions for a case concerning a naval officer, as briefly explained in the introduction. The officer keeps track of incoming planes on a radar screen, and acts on those ones classified as dangerous.

subject components	**subject agents**	**subject world components**
	human naval officer	radar screen with moving planes
subject interactions	**observation and action by subject agent**	
	naval officer gaze focuses on radar screen with planes, extracts information from radar screen view, naval officer acts on planes that are dangerous	
ambient components	**ambient agents**	
	dynamic task allocation agent (including an eye tracker), task-specific agent	
ambient interactions	**communication between ambient agents**	
	communication between task allocation agent and task-specific agent on task requests	
interactions between subject and ambient	**communication**	**observation and action**
	task allocation agent communicates over-looked dangerous item to naval officer	ambient agent has observation focus on radar screen and naval officer gaze ambient agent extracts info from views

Table 2. Components and interactions for a naval officer case

Generic State Ontologies at the Global Level For the information exchanged between components at the global level, generic ontologies have been specified. This has been done in a universal order-sorted predicate logic format that easily can be translated into more specific ontology languages. Table 3 provides an overview of the generic sorts and predicates used in interactions at the global level. Examples of the use of this ontology will be found in the case studies.

Generic Temporal Relations for Interaction at the Global Level Interaction between global level components is defined by the following specifications. Note that in such specifications, for state properties the prefix input, output or internal is used. This is an indexing of the language elements to indicate that it concerns specific variants of them either present at the input, output or internally within the agent.

Action Propagation from Agent to World Component
∀X:AGENT ∀W:WORLD ∀A:ACTION output(X)|performing_in(A, W) ∧ can_perform_in(X,A,W) →→
input(W)|performing_in(A, W)

Observation Focus Propagation from Agent to World Component
∀X:AGENT ∀W:WORLD ∀I:INFO_EL output(X)|observation_focus_in(I, W) ∧ can_observe_in(X,I,W) →→
input(W)|observation_focus_in(I, W)

Observation Result Propagation from World to Agent
∀X:AGENT ∀W:WORLD ∀I:INFO_EL output(W)|observation_result_from(I, W) ∧ can_observe_in(X,I,W) →→
input(X)|observed_result_from(I, W)

Communication Propagation Between Agents
∀X,Y:AGENT ∀I:INFO_EL output(X)|communication_from_to(I,X,Y) ∧ can_communicate_with_about(X,Y,I) →→
input(Y)|communicated_from_to(I,X,Y)

SORT	Description
ACTION	an action
AGENT	an agent
INFO_EL	an information element, possibly complex (e.g., a conjunction of other info elements)
WORLD	a world component

Predicate	Description
performing_in(A:ACTION, W:WORLD)	action A is performed in W
observation_focus_in(I:INFO_EL, W:WORLD)	observation focus is I in W
observation_result_from(I:INFO_EL, W:WORLD)	observation result from W is I
communication_from_to(I:INFO_EL, X:AGENT, Y:AGENT)	information I is communicated by X to Y
communicated_from_to(I:INFO_EL,X:AGENT,Y:AGENT)	information I was communicated by X to Y
can_observe_in(X:AGENT, I:INFO_EL, W:WORLD)	agent X can observe I within world W
can_perform_in(X:AGENT, A:ACTION, W:WORLD)	agent X can perform action A within W
can_communicate_with_about(X:AGENT,Y:AGENT,I:INFO_EL)	agent X can communicate with Y about I

Table 3. Generic Ontology for Interaction at the Global Level

4 Generic Ambient Agent and World Model

This section focuses on the ambient agents within the generic model. As discussed in Section 3, ambient agents can have various types of interactions. Moreover, they are assumed to maintain knowledge about certain aspects of human functioning in the form of internally represented dynamic models, and information about the current state and history of the world and other agents. Based on this knowledge they are able to have a more in-depth understanding of the human processes, and can behave accordingly. This section presents an ambient agent model that incorporates all these.

Components within the Ambient Agent Model In [11] the component-based Generic Agent Model (GAM) is presented, formally specified in DESIRE [12]. The process control model was combined with this agent model GAM. Within GAM the component *World Interaction Management* takes care of interaction with the world, the component *Agent Interaction Management* takes care of communication with other agents. Moreover, the component *Maintenance of World Information* maintains information about the world, and the component *Maintenance of Agent Information* maintains information about other agents. In the component *Agent Specific Task*, specific tasks can be modelled. Adopting this component-based agent model GAM, the Ambient Agent Model has been obtained as a refinement, by incorporating components of the generic process control model described above.

The component *Maintenance of Agent Information* has three subcomponents. The subcomponent *Maintenance of a Dynamic Agent Model* maintains the causal and temporal relationships for the subject agent's functioning. For example, this may model the relationship between a naval officer's gaze direction, characteristics of an object at the screen, and the attention level for this object. The subcomponent *Maintenance of an Agent State Model* maintains a snapshot of the (current) state of the agent. As an example, this may model the gaze direction, or the level of attention for a certain object at the screen. The subcomponent *Maintenance of an Agent History Model* maintains the history of the (current) state of the agent. This may for instance model the trajectory of the gaze direction, or the level of attention for a certain object at the screen over time.

Maintenance of Agent Information	
maintenance of dynamic models	model relating attention state to human body state and world state
maintenance of state models *subject agent* *subject world component*	 model of attention state and gaze state of the naval officer model of state of radar screen with planes
maintenance of history models	model of gaze trajectory and attention of time
Maintenance of World Information (similar to Maintenance of Agent Information)	
Agent Specific Task	
simulation execution	update the naval officer's attention state from gaze and radar screen state
process analysis	determine whether a dangerous item is overlooked
plan determination	determine an option to address overlooked dangerous items (to warn the naval officer, or to allocate another human or ambient agent to this task)
World Interaction Management	processing received observation results of screen and gaze
Agent Interaction Management	preparing a warning to the officer preparing a request to take over a task

Table 4. Components within the Ambient Agent Model

Similarly, the component *Maintenance of World Information* has three subcomponents for a dynamic world model, a world state model, and a world history model, respectively. Moreover, the component *Agent Specific Task* has the following three subcomponents, devoted to the agent's process control task. The subcomponent *Simulation Execution* extends the information in the agent state model based on the internally represented dynamic agent model for the subject agent's functioning. For example, this may determine the attention level from a naval officer's gaze direction, and the characteristics of an object at the screen, and his previous attention level. The subcomponent *Process Analysis* assesses the current state of the agent. For instance, this may determine that a dangerous item has a level of attention that is too low. This component may use different generic methods of assessment, among which (what-if) simulations and (model-based) diagnostic methods, based on the dynamic and state models as maintained. The subcomponent *Plan Determination* determines whether action has to be undertaken, and, if so, which ones (e.g. to determine that the dangerous item with low attention from the naval officer has to be handled by another agent).

Finally, as in the model GAM, the components *World Interaction Management* and *Agent Interaction Management* prepare (based on internally generated information) and receive (and internally forward) interaction with the world and other agents. Table 4 provides an overview of the different components within the Ambient Agent Model, illustrated for the case of the naval officer.

Generic State Ontologies within Ambient Agent and World To express the information involved in the agent's internal processes, the ontology shown in Table 5 was specified. As an example, belief(leads_to_after(I:INFO_EL, J:INFO_EL, D:REAL)) is an expression based on this ontology which represents that the agent has the knowledge that state property I leads to state property J with a certain time delay specified by D. This can provide enhanced context awareness (in addition to information obtained by sensoring).

Predicate	Description
belief(I:INFO_EL)	information I is believed
world_fact(I:INFO_EL)	I is a world fact
has_effect(A:ACTION, I:INFO_EL)	action A has effect I
Function to INFO_EL	**Description**
leads_to_after(I:INFO_EL, J:INFO_EL, D:REAL)	state property I leads to state property J after duration D
at(I:INFO_EL, T:TIME)	state property I holds at time T

Table 5. Generic Ontology used within the Ambient Agent Model

Generic Temporal Relations within an Ambient Agent The temporal relations for the functionality within the Ambient Agent are as follows.

Belief Generation based on Observation, Communication and Simulation
∀X:AGENT, I:INFO_EL, W:WORLD input(X)|observed_from(I, W) ∧ internal(X)|belief(is_reliable_for(W, I))
↠ internal(X)|belief(I)
∀X,Y:AGENT, I:INFO_EL input(X)|communicated_from_ to(I,Y,X) ∧ internal(X)|belief(is_reliable_for(X, I))
↠ internal(X)|belief(I)
∀X:AGENT ∀I,J:INFO_EL ∀D:REAL ∀T:TIME
internal(X)|belief(at(I, T)) ∧ internal(X)|belief(leads_to_after(I, J, D)) ↠ internal(X)|belief(at(J, T+D))

Here, the first rule is a generic rule for the component *World Interaction Management*. Similarly, the second rule is a generic rule for the component *Agent Interaction Management*. When the sources are assumed always reliable, the conditions on reliability can be left out of the first two rules. The last generic rule within the agent's component *Simulation Execution* specifies how a dynamic model that is explicitly represented as part of the agent's knowledge (within its component *Maintenance of Dynamic Models*) can be used to perform simulation, thus extending the agent's beliefs about the world state at different points in time. This can be considered an internally represented deductive causal reasoning method. As another option, an abductive causal reasoning method can be internally represented in a simplified form as follows.

Belief Generation based on Simple Abduction
∀X:AGENT ∀I,J:INFO_EL ∀D:REAL ∀T:TIME
internal(X)|belief(at(J, T)) ∧ internal(X)|belief(leads_to_after(I, J, D)) ↠ internal(X)|belief(at(I, T-D))

Generic Temporal Relations within a World For World Components the following specifications indicate the actions' effects and how observations provide their results.

Action Execution and Observation Result Generation in the World
∀W:WORLD_COMP ∀A:ACTION ∀I:INFO_EL input(W)|performing_in(A, W) ∧ internal(W)|has_effect(A,I)
↠ internal(W)|world_fact(I)
∀W:WORLD_COMP ∀I:INFO_EL input(W)|observation_focus_in(I, W) ∧ internal(W)|world_fact(I)
↠ output(W)|observation_result_from(I, W)
∀W:WORLD_COMP ∀I:INFO_EL input(W)|observation_focus_in(I, W) ∧ internal(W)|world_fact(not(I))
↠ output(W)|observation_result_from(not(I), W)

5 Case Studies

To test the applicability of the generic model introduced above, it has been tested in three different case studies. Case study 1 addresses an ambient driver support system, case study 2 addresses an ambient aggression handling system, and case study 3 addresses an ambient system for management of medicine usage, see e.g., [16]. For all of the case studies, the generic model has been instantiated with sufficiently detailed domain-specific information to be able to perform simulations. Moreover, for each case study a formal analysis has been performed, in which relevant dynamic properties of the cases considered (such as requirements imposed on the systems) have been verified. Due to space limitations, the details of the case studies have been omitted. See, however: http://www.cs.vu.nl/~tbosse/AmI/AmI07cases.pdf.

6 Discussion

The challenge addressed in this paper is to provide a generic model that covers the class of Ambient Intelligence applications that show human-like understanding and supporting behaviour. Here human-like understanding is defined as understanding in the sense of being able to analyse and estimate what is going on in the human's mind and body (a form of mind/bodyreading). Input for these processes are observed information about the human's physiological and behavioural states and dynamic models for the human's physical and mental processes. For the mental side such a dynamic model is sometimes called a Theory of Mind (e.g., [13], [14], [15]) and may cover concepts such as emotion, attention, intention, and belief. This can be extended to integration with the human's physical processes, relating, for example, to skin conditions, heart rates, and levels of blood sugar, insulin, adrenalin, testosterone, serotonin, and specific medication taken. In this class of Ambient Intelligence applications, knowledge from human-directed disciplines is exploited, in order to take care of (and support in a knowledgeable manner) humans in their daily living, in medical, psychological and social respects. Thus, an ambience is created that uses essential knowledge from the human-directed disciplines to provide a more human-like understanding of human functioning, and from this understanding can provide adequate support. This may concern, for example, elderly people, criminals and psychiatric patients, but also humans in highly demanding tasks.

The generic model introduced in this paper is a template for the specific class of Ambient Intelligence applications as described. One of the characteristics of this class is that a high level of human-directed context awareness plays a role; see also [21, 22, 23]. The ambient software and hardware design is described in an agent-based manner at a conceptual design level and to support context awareness has generic facilities built in to represent human state models and dynamic process models, and methods for model-based simulation and analysis on the basis of such models. For a particular application, biomedical, neurological, psychological and/or social ontologies, knowledge and dynamic models about human functioning can be specified. The generic model includes slots where such application-specific content can be filled in to get an executable design for a working system. This specific content, together with the generic methods to operate on it, enables ambient agents to show human-like understanding of humans and to react on the basis of this understanding in a knowledgeable manner. The model has been positively evaluated in three case studies related to existing Ambient Intelligence applications that already are operational or in a far stage of development.

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