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December 2002

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Abstract

This article discusses the need for a classification or profiling taxonomy for intelligent agents. The paper reviews existing classification schemes and its disadvantages. The profile can be based on n dimensions. This classification scheme is used to describe existing agents to demonstrate its benefits. All agents can be represented using this multi-dimensional matrix. Additional benefits are described. A standard taxonomy would provide a uniform framework for the consistent classification of intelligent agents. The classification system would help developers and users in the selection process and help software vendors explain their products. It would help the user evaluate alternatives and compare competitive products. The taxonomy would also help clarify and simplify the landscape for agent development and applications.

Keywords: Intelligent agents taxonomy, classification schemes, multi-attribute profile, radial chart, three-dimensional classification space

Introduction

The area of intelligent agents continues to be an important one as indicated by current research (Joshi and Singh 1999, Lieberman et. al. 2001). At present there is no consensus on what exactly constitutes an agent, or its characteristics. While change is an inevitable fact of life, it can also be unsettling. With so many different agents, it is important to ask, how can we select the best agent for a specific application? This article discusses the need for a classification or profiling taxonomy for intelligent agents. Without a classification scheme, it may be a complex task to try to select an intelligent agent for a specific application. However, by using a classification or taxonomy, and by comparing their different features, attributes, and capabilities, the selection task can be facilitated.

The significance of the use of frameworks in the area of intelligent agents has already been demonstrated (Kendall et. al. 2000, Brugali and Sycara, 2000, Lejter and Dean 1996, Lee et. al. 2000, Liang and Huang 2000). It is important to ask, why is a classification taxonomy so necessary? There are several reasons that justify our objective. A standard taxonomy would provide a uniform framework for the consistent classification of intelligent agents. There are many advantages to developing a common taxonomy, or classification system. The classification system would help developers and users in the selection process and help software vendors explain their products. It would help the user evaluate alternatives and compare competitive products. The taxonomy would also help clarify and simplify the landscape for agent development and applications.

With the rapid evolution that we enjoy in the area of intelligent agents, the taxonomy will need to be reviewed every so often and be updated. Agent software and technology are moving rapidly, so a static taxonomy would soon be out of date. Some features which are important for agents today, were not considered just three years ago. Hence developing a taxonomy that can be maintained is a challenge. A standard taxonomy would provide a common framework for developers, users, and vendors. The taxonomy would also provide a framework for future developments. A taxonomy of agents would require identifying the key characteristics of agent systems, including the characteristics of the agents, the multi-agent systems, the frameworks, and the environments (Huhns and Singh, 1998). Current taxonomies and frameworks are based on specific technologies and languages.

As languages and technologies evolve, frameworks and taxonomies must be updated. Our approach overcomes this disadvantage by implementing a framework based on the profile or the characteristics of the agent.

Review of Previous Agent Classifications and Taxonomies

Many researchers have proposed various classification schemes and taxonomies to provide a simpler way of characterizing the space of agent types rather than just one trying to depict every potential combination of possible attributes. We will review several schemes, before proposing our profile-based classification.

In a classical paper, Gilbert et. al (1995) from IBM described agents in terms of a space defined by three dimensions (or attributes) agency, intelligence, and mobility. The scope of intelligent agents is shown in Figure 1. This model was the first one to consider multiple dimensions. The classification criterion shown in Figure 2 was proposed by Nwana (1996). Nwana uses three attribute dimensions: mobility, reactivity, and autonomy. He combines the three attributes in a Venn diagram, resulting in four types of agents: collaborative-learning agents, collaborative agents, interface agents and smart agents.

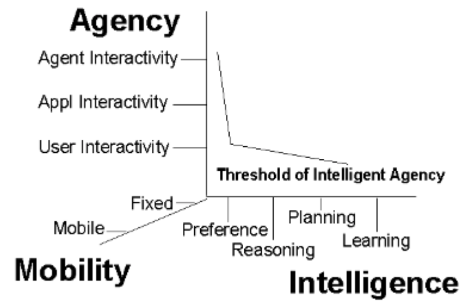

Figure 1: Intelligent Agent Scope

After proposing the previous classification criteria, Nwana describes ongoing research in seven categories: collaborative agents, interface agents, mobile agents, interface agents, mobile agents, information/Internet agents, reactive agents, hybrid agents, and smart agents. However, Nwana fails to describe the criteria used to classify an agent in any of his proposed categories. The agent topology is illustrated in Figure 3.

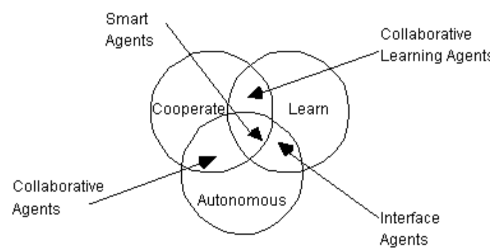

Figure 2. Nwana Classification Diagram

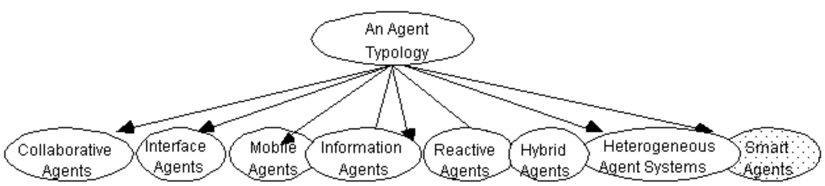

Figure 3. Nwana's Agent Topology

Franklin and Graesser (1996) proposed a taxonomy of autonomous agents based on a biological taxonomy. This taxonomy is shown in Figure 4. Below this initial classification, they suggest that agents can be categorized by control structures, environments (e.g., database, file system, network, Internet), language in which they are written and applications.

Figure 5 presents another framework based on the task the agent performs or the languages or protocols it is based on. This scheme proposed by Labrou et. al (1999) has a similar approach to Franklin and Graesser (1996) Although using the language or the agent protocol as the basis for classification is convenient for development and design purposes, languages change too often, and the framework would need to be constantly updated to reflect the implementation of agents in new languages. Languages are ephemeral; therefore, according to our viewpoint, using agent characteristics as the classification criteria would provide a more stable framework.

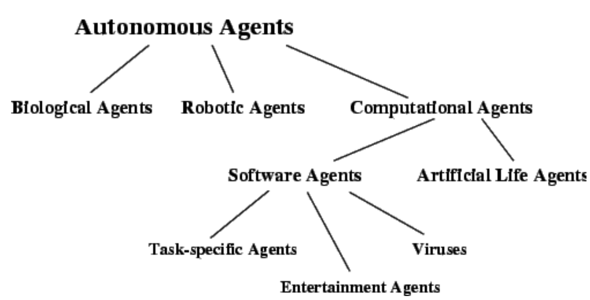

Figure 4. Taxonomy of Autonomous Agents

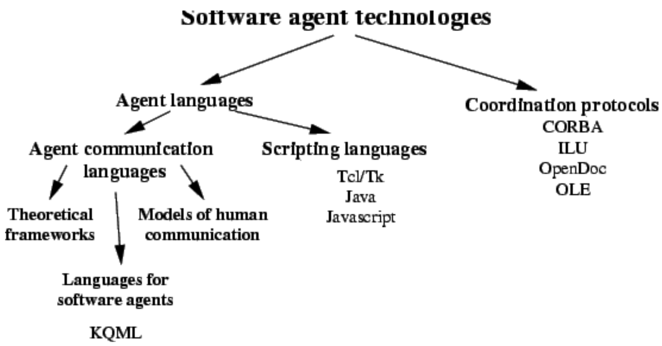

Figure 5. Software Agent Technologies Classification

The following taxonomy shown in Figure 6 has been proposed by Brenner, Zarnekow and Wittig (1997). At the highest level, three major categories of agents can be distinguished: human agents, hardware agents and software agents.

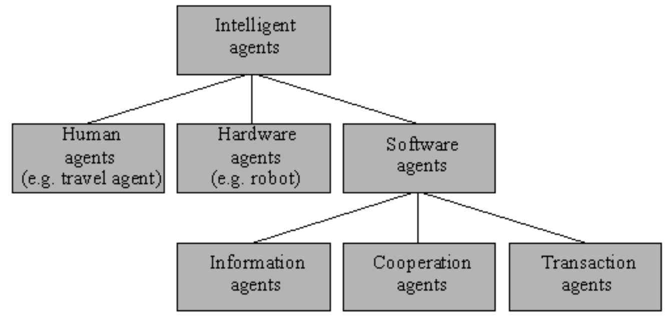

Figure 6. A Taxonomy of Intelligent Agents

Brustoloni (1991) classifies agents starting with a three-way classification taxonomy that includes regulation agents, planning agents or adaptive agents. A regulation agent reacts to inputs and it always knows what to do, it never learns nor plans. Planning agents plan using Artificial Intelligence techniques, case-based reasoning or Operations Research methods. Adaptive agents can learn.

Given so many agent attributes, Gilbert et. al (1995), Nwana (1996), Franklin and Graesser (1996), Brustoloni (1991), and Brenner, Zarnekow and Wittig (1997), have all tried to come up with a simplified framework in order to describe the space of agent types. However, the classification schemes and taxonomies that have been reviewed do not include all possible combination of potential attributes. Some models use two attributes or dimensions and classify agents in a bi-dimensional plane. Other models, such as Gilbert's (1995) and Zarnekow's (1997) use three attributes, resulting in a three-dimensional space where agents are categorized.

Zarnekow (1997) has also proposed a three-dimensional classification space. The three selected criteria are intelligence, mobility and number of agents. Notice how both Gilbert et. al. (1995) and Zarnekow (1997) agree on including intelligence and mobility as main attributes.

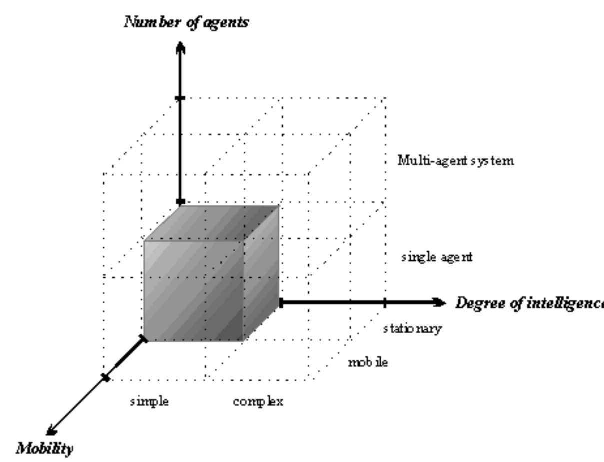

Figure 7. Three-Dimensional Classification Space

This three-dimensional representation has several advantages, it can be visually represented, and it is simple and clear. However, it is a limited and oversimplified representation because it does not take into account most of the characteristics. Zarnekow proposes that all characteristics of the previous section can be placed in the three dimensions of the matrix: reactivity, proactivity reasoning/ability to learn, and character are properties that significantly determine the intelligence of an agent. Communications capability is required in both single agents and in multiagent systems, and can be assigned to the category of the number of agents. The capability of cooperation affects both the intelligence criterion and the number of agents. Autonomous behavior influences both the intelligence and the mobility of agent. The operation of a mobile agent is useful only when it has a maximum degree of autonomy.

Tung and Jintae (1999) have designed a framework for building decision support systems using software agent technology. They have proposed a taxonomy of agent characteristics that can be used to help identify agents to support different types of decision tasks. However, their taxonomy is specific to agents for decision support, a more comprehensive taxonomy should also consider agents for information filtering, data mining and data conversion.

The Proposed Multidimensional Taxonomy

From the previous review, we can see that none of the existing models can provide a common framework for the classification of the always-evolving set of intelligent agents. Our approach to this problem is a multidimensional classification model. Zarnekow's model it is limited since it only considers three basic characteristics, and therefore three axis. A more accurate representation would assign an independent axis to every characteristic. According to Franklin and Graesser (1996), this classification scheme can be considered a matrix organization. Each characteristic defines a dimension. With n features, an n-dimensional matrix is created, so that each cell of the matrix corresponds to a collection of characteristics and provides a category.

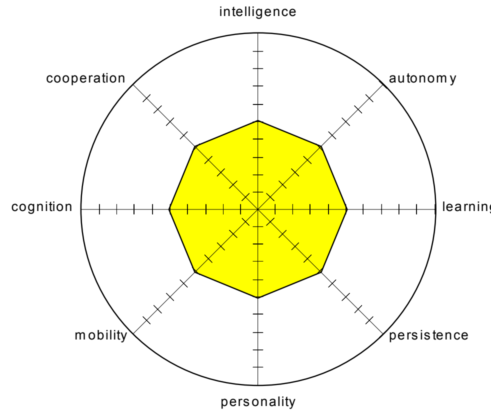

Figure 8. Multi-Dimensional Matrix

We propose a profile-based classification scheme. The profile can be based on n dimensions. We have included the eight most cited characteristics in our proposed model (Figure 8). This classification scheme can be used to categorize existing agents and even future developments. All agents can be represented using this multi-dimensional matrix. Gilbert and Zarnekow have limited the matrix to three dimensions, as a clear representation (visual) is not possible. We represent the matrix as a radial diagram. Radial Diagrams are a form of graph that allows a visual comparison between several quantitative or qualitative aspects of a situation, or when charts are drawn for several situations using the same axes (poles). A visual comparison between the situations can easily be made. We can plot the profile of an agent based around a number of characteristics (axis). Different agent profiles are reflected in the shape of the polygon drawn to link the plotted points.

The use of many axis (characteristics) does not necessarily imply that every agent will have all characteristics. In the current trend toward specialization, an "all encompassing" agent would neither be feasible, nor desirable. The number of axis (characteristics) plotted in the chart can be variable, between three and eight attributes can be plotted on each chart. Scales for each attribute are arranged radially and the points plotted on each radius are joined to generate a shape that can be visually compared with the same plot for another agent. In a comparative analysis, the desirable characteristics of a specific agent (a theoretical profile) and candidate agents can be plotted on the same chart in order to graphically demonstrate the gap between them. Similarly several agent categories can be graphically compared. Figure 9 describes the scales used for each attribute, and Figure 10 shows the integration of the scales in the radial diagram.

```
                                         INTELLIGENCE
   Preferences              Reasoning                   Planning              Learning
 - <--------------------------------------------------------------------------------> +
   Less Intelligent                                                   More Intelligent

                                           AUTONOMY
   Asynchrony Representation Data-interactive Application-interacte Service-interact
 - <----------------------------------+---------------------+-----------------------> +
   Less Autonomy                                                         More Autonomy

                                     LEARNING/ADAPTABILITY
   Fixed                                   Teachable                        Autodidactic
 - <----------------------------------------+---------------------------------------> +
   Less Learning                                                        More Learning

                                          PERSISTENCE
   Transient                                                                 Long-lived
 - <--------------------------------------------------------------------------------> +
   Less Persistent                                                     More Persistent

                                     PERSONALITY/CHARACTER
   Simple/Sloppy                                                         Antropomorphic
 - <--------------------------------------------------------------------------------> +
   Machine-Like                                                              Human-Like

                                           MOBILITY
   Static             Mobile scripts                  Mobile objects          Itinerant
 - <--------------------------+----------------------------+-------------------------> +
   Less Mobile                                                              More Mobile

                                        COGNITION LEVEL
   Deliberative                                                               Reactive
 - <--------------------------------------------------------------------------------> +
   Less Reactive                                                          More Reactive

                                   COOPERATION/COLLABORATION
   Antagonist                          Competitive                          Cooperative
 - <--------------------------+----------------------------+-------------------------> +
   Less Collaborative                                             More Collaborative
```

Figure 9. Characteristics and Scales

Each individual agent can be profiled in terms of its in this n-dimensional profile. We will use only eight characteristics (axis) for simplicity, but the model may include more or less dimensions depending on the number of characteristics to be considered. The model can also be used for representing ideal profiles for a specific application. An agent for electronic stock trading must exhibit an appropriate level of autonomy, intelligence, mobility, etc. The required (or desired) levels could be represented in a profile.

The radial diagrams can be used as a method of graphically comparing the characteristics for several individual agents. The shape formed by the radial diagrams will quickly identify agents that have similar characteristics and are particularly useful to classify or identify the characteristics for a specific agent application. Each axis represents a characteristic, the farther from the center, the higher the level of the characteristic.

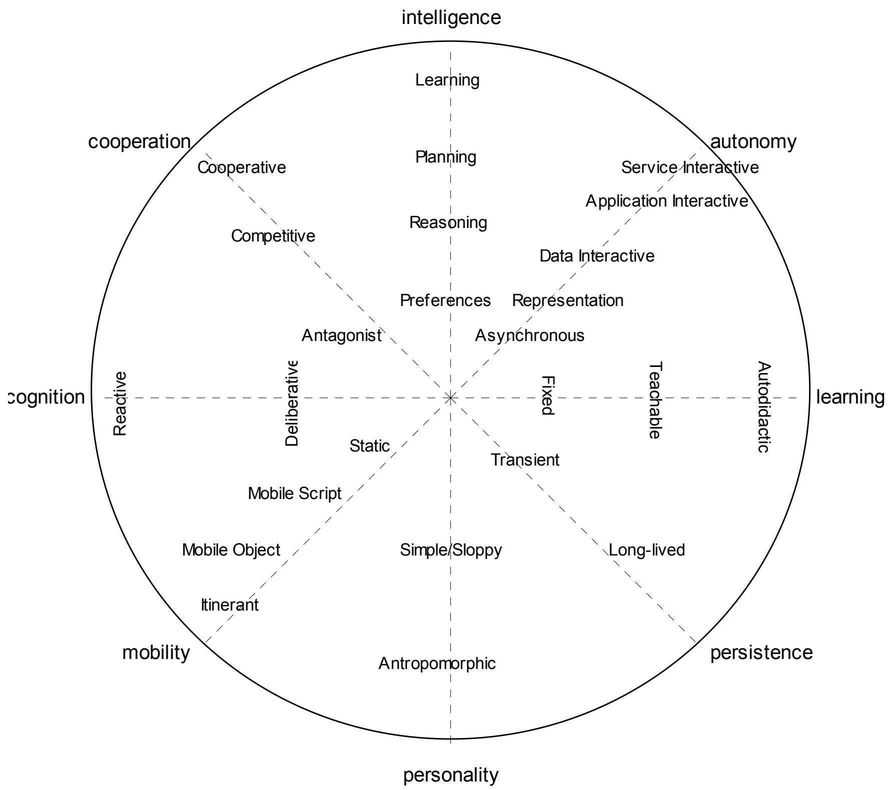

Figure 10. The Complete Framework

A Sample Application

An extensive review of currently developed agents was conducted to analyze their profile. Because of space limitations we include one sample profile classification for Aglets to show how the framework can be applied to represent the characteristics of diverse agents. We can use the scaling sheet as a report card to determine the appropriate level of each characteristic. The levels can be determined by the agent designer or the user during the agent selection process. We present the scales in Figure 11, the sample radial diagram in Figure 12 and the analysis table describing the scaling criteria.

```
                                       INTELLIGENCE
  Preferences              Reasoning            Planning             Learning
- <------- X ---------------------------------------------------------------> +
  Less Intelligent                                                  More Intelligent

                                         AUTONOMY
  Asynchrony Representation Data-interactive Application-interacte Service-interact
- <----------------------------------+-------------------- X ----------------------> +
  Less Autonomy                                                        More Autonomy

                                   LEARNING/ADAPTABILITY
  Fixed                                Teachable                        Autodidactic
- <--- X -----------------------------------+---------------------------------> +
  Less Learning                                                       More Learning

                                        PERSISTENCE
   Transient                                                             Long-lived
- <--------------------------------------------------------------------X------->+
  Less Persistent                                                   More Persistent

                                   PERSONALITY/CHARACTER
 Simple                                                              Antropomorphic
- <------------X---------------------------------------------------------------> +
  Machine-Like                                                           Human-Like

                                          MOBILITY
  Static             Mobile scripts              Mobile objects           Itinerant
- <--------------------------+-------------------------------------------X------>+
  Less Mobile                                                           More Mobile

                                      COGNITION LEVEL
  Deliberative                                                             Reactive
- <--------------------------------------------------------------------X---------->+
  Less Reactive                                                       More Reactive

                                 COOPERATION/COLLABORATION
  Antagonist                          Competitive                       Cooperative
- <--------------------------+---------------------------+---------------------X->+
  Less Collaborative                                             More Collaborative
```

Figure 11. Characteristics and Scales for a Sample Agent

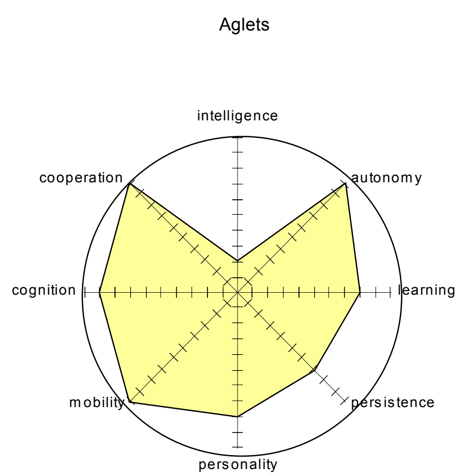

Figure 12. Radial Diagram for Aglets

Aglets (Tai and Kosaka 1999)		
CHARACT.	**RATING**	**CRITERIA**
Intelligence	Preferences	Aglets define a general-purpose mobile agent framework, but lack essential functionality such as merging and splitting.
Autonomy	Application Interactive	Aglets can be dispatched and they can perform task on behalf of the user at a remote site, without the need for user intervention.
Learning	Fixed	Aglets functions are specified as programs and modules, any changes must be re-programmed
Persistence	Long-lived	Aglets can be saved and run at a later time.
Personality	Simple	In the user interface, aglets are represented as bees, however the interface is somewhat simple.
Mobility	Itinerant	Aglets are Java objects that can move from one host on the Internet to another. They are mobile network agents that can be dispatched from one computer and transported to a remote computer for execution.
Cognition	Reactive	The aglets program code includes state information about the environment.
Cooperation	Cooperative	Agents with similar interests and goal can also interact, however inter-agent communication is limited.

Figure 13. Analysis Table

Limitations and Future Research

The main disadvantages of a multi-dimensional matrix are that it cannot be visually represented, because in the physical world we are limited to three dimensions. Another limitation is the fact that each attribute has a different scale and measurement. However, they might be integrated by using a percentage-based measurement system instead of a qualifier-based one. Ratings would be specified as percentages instead of adjectives. The profile classification model can also be used to represent ideal profiles for a specific application. An agent for electronic stock trading must exhibit an appropriate level of autonomy, intelligence, and mobility. The required (or desired) levels could be represented in a profile. Desired profiles for information retrieval agents, filtering agents, and Auction agents could be effectively represented using this classification scheme. The required agent profile could be used as a "job description" to identify potential candidates to "fill" in the job. The profile of existing agents can be compared to the required profile and the closest match can be selected.

Conclusion

Using this classification or taxonomy, by comparing their different features, attributes, and capabilities, can facilitate the selection and design of intelligent agents. A common classification framework can help designers to identify current gaps in the development of intelligent agents. Users can easily map their processing requirements to existing agent technologies and select the closest match. A profile-based classification system can evolve along with languages and technologies and provide a stable and common framework to classify current and future developments.

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