Agent Chameleons: Moving Minds from Robots to Digital Information Spaces

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Abstract. Agent Chameleons investigates the motivation, desire and possibility of agent migration and mutation between real and artificial spaces. The agent must be able to mutate and change its form and function depending upon the environment within which it is situated. The form inextricably dictates or constrains its behaviour and capabilities. This paper introduces the *Agent Chameleon Architecture* which supports agent migration and mutation.

1   Introduction

With the evolution of software paradigms and computing in general, new opportunities are being explored to augment the functionality and capabilities of computing. The development of agent-based systems has lead to the creation of portable computational units. This in conjunction with platforms supporting the mobility of such agents poses interesting challenges in how mobile agents can be developed and implemented without the traditional constraints of strong platform dependencies.

The Agent Chameleon Project aims to develop digital *minds* that can seamlessly migrate between physical and digital information spaces, acting as personal digital assistants freed from single platform constraints and capable of opportunistic mobility. This challenges the traditional boundaries between the physical and the virtual through the empowerment of mobile agents. Two key attributes are instrumental in achieving these *agent chameleons*; mutation and migration.

In order to achieve a strong sense of context awareness and situatedness, the agent must be able to mutate and change its form and function depending on its manifestation and the environment within which it is situated. The form inextricably dictates or constrains its behaviour and capabilities within a particular environment. The optimum form is very much dependent upon its world [19] and consequently judicious selection of appropriate forms or persona ought to empower the entity.

Within this paper an architecture and agent structure is described which supports seamless migration and mutation across platforms and within environments. This degree of agent adaptivity and mobility has not been investigated to date.

2   Objectives

The work seeks to extend from the keyboard and mouse paradigm to a notion of *personable computing* through the development of a digital *spirit* or mobile agent assistant (see figure 1), capable of migration between and *possession* of the control within various information

spaces. Such information spaces include the real world, in which the *agent chameleon* may occupy and control a physical entity such as a robot, or the virtual world, in which an agent may *possesses* an appropriate avatar. Other spaces include the Internet/intranets, together with mobile devices such as handheld Personal Digital Assistants (PDA's). Agent mutation should be driven by environmental cues, for example an agent could have a cute and cuddly appearance within a children's educational environment, but appear as a warrior within a hostile environment.
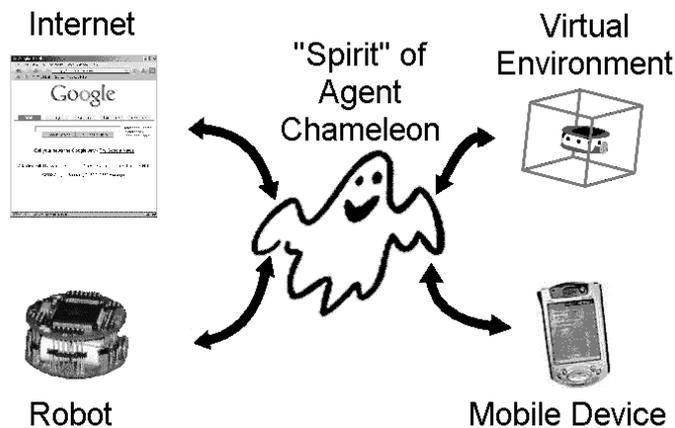

Figure 1. The agent *spirit* can migrate between and *possess* numerous platforms.

The application domain in analogous to bringing one's pet for a walk (mobile agent on a PDA device), and from time to time unleashing it to run an errand (agent travels via network protocols to other devices, performs some task, and returns). Audio, visual, and motion behaviour responses constitutes the familiarisation mechanism to facilitate consistency in persona relationships developed between the user and the agent as it migrates and mutates across information spaces.

This research aims to develop the agent's deliberative mechanisms and the framework through which it can opportunistically migrate and mutate. The objectives of the Agent Chameleons project are as follows:

a) To investigate the deductive apparatus upon which agent mutation, evolution and migration is determined;
b) To develop a mechanism to support agent chameleon migration;
c) To investigate the choice and selection of embodiment forms and mutation processes;
d) To develop proof of concept demonstrators that exercise and animate the ideas

Section 3 addresses (a) describing the deliberative agent machinery commissioned. Section 4 and 5 respectively discuss mobility support (b) and agent embodiment and mutation (c). Section 6 introduces the *Agent Chameleon Architecture* while section 7 briefly introduces a proof of concept demonstrator (d).

3 The Deliberative Agent

The term *agent* can be somewhat nebulous and contain different meanings depending on the discipline in question. We use the term in a manner synonymous with the Distributed Artificial Intelligence (DAI) community, that is, agents are characterised by the attributes of

autonomy, social ability, reactivity and pro-activity [27]. Furthermore, a stronger notion of agenthood also assigns mentalistic attitudes, that is, knowledge, belief, intention and obligation. These mentalistic attitudes can be described using the Belief-Desire-Intention (BDI) paradigm [7].

The BDI methodology constitutes an example of what has been termed practical reasoning systems [7] and is based on the notion of capturing the properties of human intentions and their function in human reasoning and decision-making. BDI architectures represent a theory, which advocates beliefs, desires, and intentions as a central motivation to agent action.

Generally, the belief of an agent is taken to represent what the agent perceives of its environment and of itself. The motivations of the agent, or desires, refer to its goals or preferences that it wishes to, but may not necessarily, fulfil. Intentions refer to a level of commitment to a state that the agent wishes to bring about and thus lead and control the agents' activities. This results in the agent acting to find appropriate ways of arriving at its intentions. A BDI architecture therefore permits the three elements of belief, desire and intention to take an active role in the cognitive processes of the agent. Examples of BDI based agents can be found in [12, 9, 10].

One Agent Oriented Software Engineering (AOSE) environment that realises a BDI architecture is Agent Factory (AF). Agent Factory is a distributed environment for the rapid prototyping of intelligent agents [20]. Originally it was implemented in SmallTalk-80, however the lack of support for SmallTalk on PDA's and Agent Factory's large size resulted in the development of a lightweight, Java based version, Agent Factory Lite (AF Lite) [21].

4   Mobile Agents

Mobile agents represent software components that travel between digital environments that are connected via some network. Furthermore the agent itself (either on a proactive or reactive basis) determines the time and destination of the migration.

Mobile agent systems generally provide one of two classes of migration:

- *Strong Migration* where the agent's object state, code and control state is captured. Upon migration this allows the agent to resume execution on the new machine from the exact point that it left off.

- *Weak Migration* where the agent's object state and code, only, are captured. Upon migration the system calls a known entry-point in the code to restart the agent on the new machine.

Mobile agent systems that utilise strong migration can be seen to be more advantageous in that the agent can migrate at any time point. Using weak migration the agent can only migrate at set points in its interpreter's cycle. However weak migration has an advantage in that there is less to be transported, the agent travels lightly as it were.

Java provides a consistent environmental structure due to its platform independent nature, and was the obvious choice for the Agent Chameleons Framework. However, as it stands the Java Virtual Machine (JVM) does not support the capture of thread states. Therefore, most commercial Java based agent systems use weak migration. JVMs have been modified in order to provide thread state capture [6], but in general the market dictates that mobile agent

systems run on unmodified Java Virtual Machines. Recent work has been conducted on trying to capture thread states without modifying the JVM [25].

Agent Factory supports weak migration (like TACOMA [16] and Grasshopper [15], unlike Telescript [26] and D'Agent [18] which offer strong migration) in that only the mental state of the agent migrates. This ensures the task of migrating an agent from a Smalltalk environment (AF) to a Java environment (AF Light) and vice versa, a much easier lightweight task. The same mental state can run on both the AF and the AF Light interpreters without modification. While AF Light is not currently compliant with the FIPA and OMG MASIF standards for agent mobility, its modular structure allows for the incorporation of such standards in the future.

5 Agent Embodiment and Mutation

The evolvable characters within the Agent Chameleons project have drawn inspiration from such work as Synthetic Characters at MIT-Media Lab [5] and work on agents as synthetic characters [1, 8, 11, 14, 22]. By evolvable character we mean a virtual character with a number of *lifelike* properties. Firstly, any behaviour that is performed should make sense, performing actions that help to achieve its goals. Secondly, it should be capable of adapting behaviour based upon experiences. Thirdly, it should be capable of conveying it's emotional state to the user, through it's appearance, posture etc. Finally, the synthetic character should be controlled by its mental state and should contribute to goal achievement.

External mutation refers to the altering of an agent's appearance as opposed to its operational functionality. The ability to alter its appearance to suit the task at hand should empower the agent. Choosing appropriate vehicles for embodiment helps to engender a sense of identity. An interesting issue is the level to which users identify with the embodiment form [2]. The embodiment is more than just material body, but it also carries a gendered, social, political and economic identity. One of the most common psychological effects of embodiment is the rendering of a sense of presence [2, 23]. Nowak and Biocca [3, 4] stressed the importance of body in achieving a sense of place, space and of another entities presence.

In addition agents may exhibit *internal mutation*, whereby behavioural refinement to unexpected situations may be based on evolutionary computation (EC) [24]. EC techniques use a distributed paradigm, which makes them well suited to adoption by distributed artificial intelligence (DAI) and multi-agent systems (MAS).

6 The Agent Chameleons Architecture Design

The Agent Chameleons Architecture can be decomposed into three primary components, namely the agent's deliberative mechanisms, the agent's migration and mutation capabilities, and the platforms that can support agent migration. We will consider each in turn.

Figure 2 illustrates the layers of the system. At the base exists the platform, that is, a Virtual Reality World, Mobile Device, Robot, etc. Above this is the native Java Virtual Machine. Beyond this resides the Java API and built on top of that is Agent Factory Lite. At present the system supports weak migration of agent mental states. This allows for the migration of these

states to wherever an agent body can be instantiated for them. In time strong migration may be supported.

6.1 Agent Deliberation

In order to achieve deliberative proactive agents we use the Belief-Desire-Intention (BDI) methodology. Agents are equipped with beliefs about their environment; such as what type of environment it is (e.g. robot, virtual environment, PDA, internet) and what the agent can achieve within this environment. In addition agents are equipped with beliefs about other environments, what constraints are in those other environments and whether they are capable of migration to those environments. A series of commitment rules help to drive the agents towards their goals. We utilise Agent Factory Lite (AF Lite), an agent prototyping environment designed and developed at UCD in part by one of the researchers (O'Hare). AF Lite provides the agents with the ability to reason based upon beliefs, desires and intentions. The AF Lite agent structure consists of a mental state, commitment rules, commitments, perceptors and actuators.
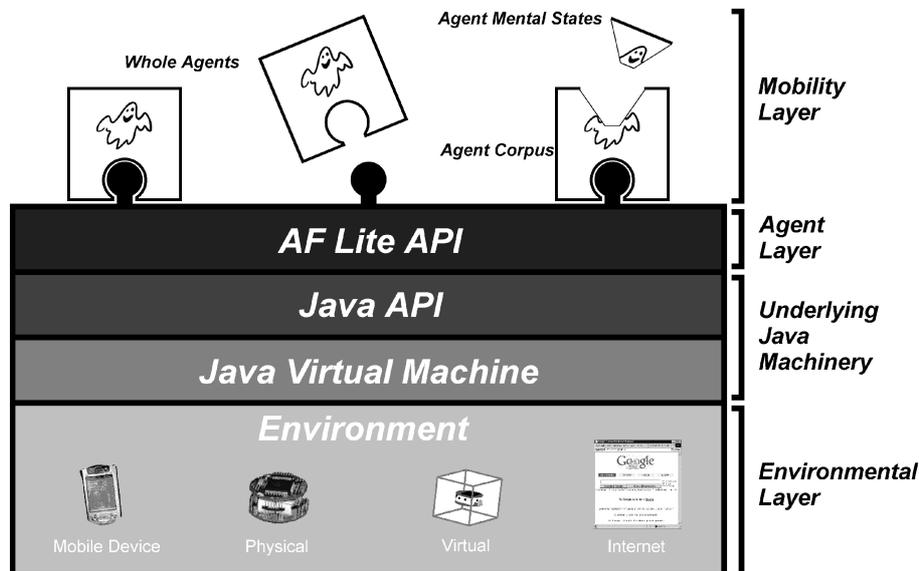

Figure 2. The Layered Agent Chameleons Architecture

The mental state consists of the agent's current beliefs, about both itself and its environment. This information is stored as a set of Beliefs. For example: `BELIEF(platform(VRWorld))` can be interpreted as 'the agent believes it is situated in a virtual reality world'. The commitment rules control the behaviour of the agent and they define under which circumstances the agent adopts a particular commitment. Commitments represent pledges to assume a course of action as a result of the interpretation of the agent's beliefs with its commitment rules. They represent the outcome of the agent's decision-making process. An agent that has the following commitment rule:

```
BELIEF(weather(rain)) & BELIEF(have(umbrella))
        ð  COMMIT(Self,Now,raise(umbrella))
```

will commit to raising an umbrella if it believes that it is raining and it has an umbrella.

Perceptors are responsible for the generation of beliefs based upon the perception of the environment, for example, a preceptor could generate a belief about environmental conditions

e.g. `BELIEF(weather(rain))`. The agent uses actuators in order to affect the environment. Actuators are triggered based upon the commitment rules adopted by the agent e.g. `COMMIT(Self,Now,raise(umbrella))` which would trigger the RaiseUmbrella actuator. In this way AF Lite agents constitute strong agents adhering to the broad BDI class of agents.

6.2 Migration and Mutation

Agent Chameleons are considered as an autonomous, mobile and social entity in the classic multi-agent systems sense. The agent has at any given instance a persona and associated with a given persona are a given set of capabilities. The migration and mutation of agents could thus be invoked in two manners. Firstly by the agent itself, reactive mutation/migration, or secondly by the enveloping environment based upon agent activity, proactive mutation/migration.

The key to this system is a method whereby the agents can migrate between the various information spaces. Ideally the agent would be able to migrate to any given machine with any given operating system without any previous support on that machine. However, presently, this is highly improbable, as the agents require somewhere to *live* on any given machine. We aim to create an Agent Chameleons environment that achieves a number of requirements.

Firstly, it provides the ability for the agents to migrate onto a destination machine. The environment is capable of accepting and activating incoming agents, and providing them with the ability to leave the environment and migrate to another. In order for the agents to locate other environments they require an address book, a list of other environment's IP addresses, port numbers and their capabilities. In addition agents need the ability to poll the various environments in their address book to see if they are active and able to accept incoming agents. The agent also needs to be able to actively seek new environments capable of housing an agent chameleon. Secondly, the Agent Chameleons environment needs to provide agents with the ability to perform their tasks within the various information spaces. For example, utilising a Khepera robot [17], the agent would be capable of moving around and using the sensors to locate obstacles such as walls. In a virtual environment, the agent would also be able to move about and sense walls, but can also fly, and/or mutate its form.

Agent Factory supports migration from one AF system to another through cloning [10]. When an agent wants to migrate it informs the destination that it wishes to do so. The destination creates an agent of the appropriate agent design. The mental state of the agent is only then copied and transmitted to the required destination. Upon receipt it is incorporated into the new agent. The old agent is then disposed of and the new agent begins execution. Currently we assume that each user has an agent interpreter pre-installed on their device, which manages the execution of the agents. Periodically AF Lite sends back updates of its mental state to the clone on the server. This acts as a safeguard in case anything causes the agent on the device to terminate prematurely. Upon resumption a roll back recovery enables the clone on the server to migrate back to the destination mobile device.

A strong sense of situatedness is required in order to facilitate the survival and mobility of the agent. An example is where the agent resides on a mobile robot platform, which is subject to battery-life constraints. Should the robot be unable to recharge itself, the agent's *body* would effectively *die*. Prior to this happening, a battery indicator informs the agent of its status

whereby it adopts a commitment and affects a migration to another location, albeit a PC, PDA, or another robot.

6.3 An Inclusive Environment

The Virtual: In order to develop the coherence and fluidity necessary to effectively link the physical and virtual domains, a computational engine as found in computer gaming is used to merge these traditionally distinct environments and facilitate the seamless migration of the digital spirit from one environment to another. This both enhances and facilitates the control of avatars based on either real-world or digital-domain sensory information. To develop the virtual environments and avatars, 3D Studio Max is currently used for high-level modelling and animation.

Preliminary proof-of-concept demonstrators were also constructed, using VRML. This system builds upon work in the Virtual Robotic Workbench [13], but has been augmented with the Agent Chameleons framework. The VRML scene is updated using the External Authoring Interface (EAI) from within a Java applet.

The Physical: For migration into the physical world, agent chameleons can *possess* robotic devices, such as K-Teams Khepera robot [17]. The Khepera robots are embedded with a small footprint JVM. The agents utilise TCP/IP protocols to migrate across networks, but light weight robots like the Khepera do not have direct access to a network, so a PC acts as an intermediate relay for communities of these such devices. This gives agents on the Kheperas the ability to communicate/migrate to entities on external networks.

The Mobile: A version of the system has also been created for use on Pocket PC based Personal Data Assistants (PDA's) such as the Compaq Ipaq. This version is based upon the Personal Java compliant Jeode JVM, created by Insignia. This version contains a simpler interface than the full VR based one, with the agents appearing as icons in a manner similar to the Microsoft Office Assistant™. These icons have a resemblance to the VR characters, so that the presence of the agent is not impeded by the reduced display and processing power of the PDA.

The Internet: In order for the agent to explore the Internet, a web-browsing server is provided. This offers a location for the agents to migrate to, from which Internet resources are accessible. Migration to other information sources like a corporate intranet, or a specific database, could similarly be supported.

7. Experiments

This research has specifically investigated agent migration across information spaces boundaries. This is a rather abstract concept and with this in mind we have initially invested effort in the creation of a simple demonstrator.

We have developed a proof of concept demonstration of migration of a physical robot from the real world to the virtual and vice-versa. As can be seen in figure 3 a physical world is extended by a virtual world depicted on the computer screen adjoined to the physical world. Small Khepera robots can navigate and explore the desk-mounted world and dock in a *robot garage* at the edge of the physical world thus removing the physical robot from vision.

Thereafter the robot seamlessly crosses into the virtual world with the synchronisation of a virtual robot continuing the trajectory of the physical counterpart into the virtual space.
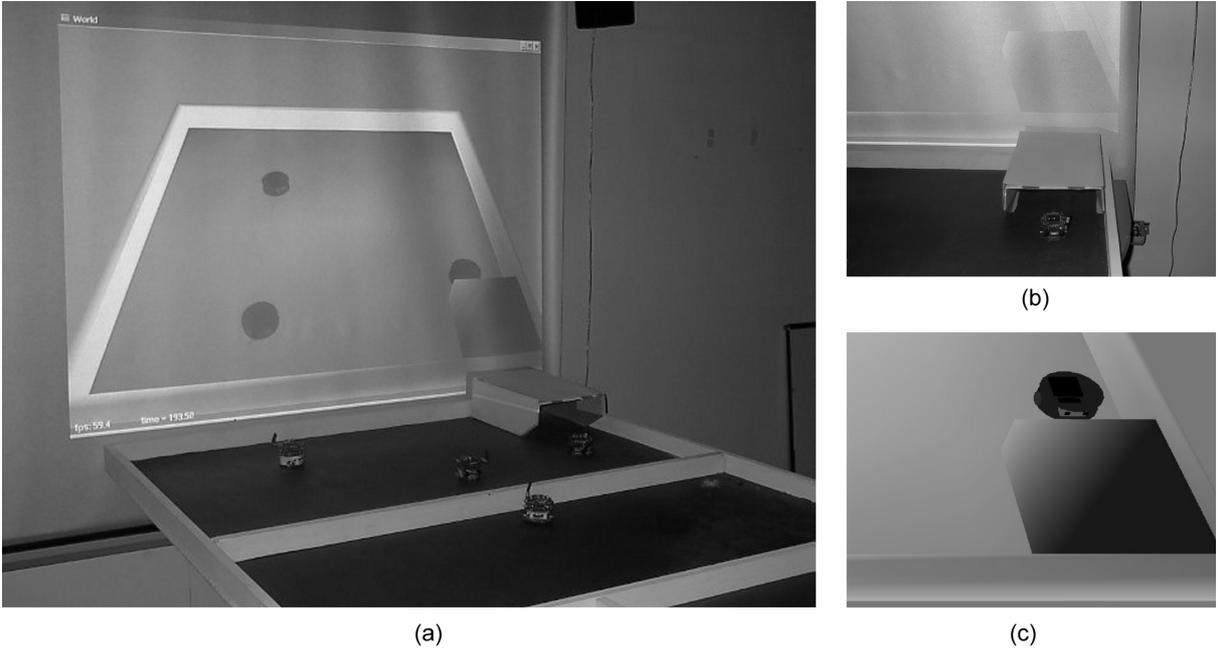

(a)

(b)

(c)

Figure 3. (a) agents can control both real and virtual and are capable of migrating between the two (b) robot enters the *robot garage* and migration to the virtual world begins (c) agent emerges into virtual world in control of robotic avatar
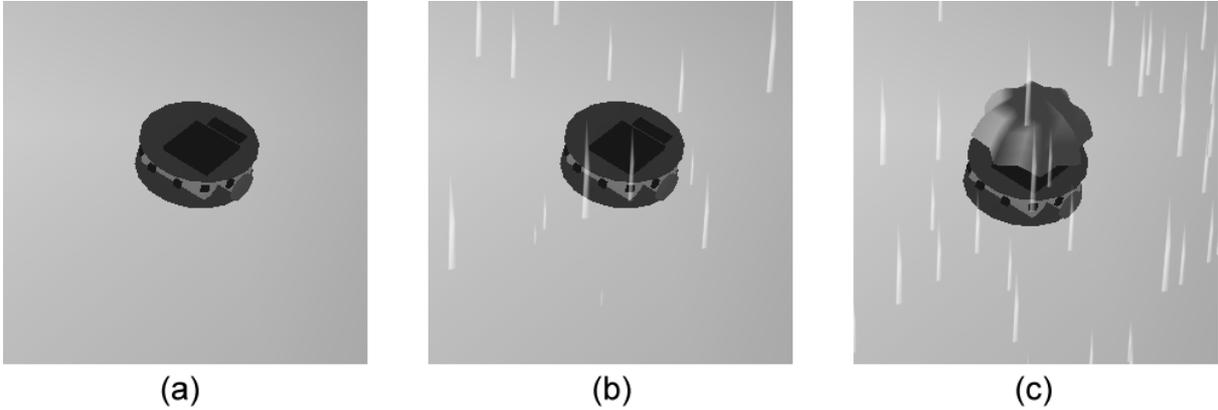

(a)   (b)   (c)

Figure 4. (a) An agent is possessing a virtual avatar (b) Environment changes trigger a mutation (c) Agent reacts to virtual weather by raising an umbrella.

7.1 Survival

The agents used in this research have been attributed basic survival instincts based on the ability of their environment to support their continued operation.

For example an agent would have a perceptor monitoring the power supply to its current environment. In the case of a battery powered platform the agent would have a commitment rule:

```
BELIEF(power(battery)) & BELIEF(battery(<5%))  =>
     COMMIT(Self,Now,migrate(123.123.123.123))
```

which states that if the system is battery powered and said battery power is below five per cent, then commit to migrating to a different device.

7.2 External Mutation

Various mutations of the virtual agent have been realised. Such mutations are underpinned by commitment rule invocation. One such example is illustrated in figure 4. In response to a change in the environmental conditions, such as a change in the weather of the virtual environment, the agents mutate their form. In this case they do so by raising an umbrella above their head.

8   Conclusion

Within this paper we have introduced the concept of Agent Chameleons. Such deductive entities reside within embodied "containers". They are autonomous, mobile and can evolve to ensure their continued existence and survival. These agent chameleons migrate and mutate between information spaces, both real and virtual, acting as our friendly assistant in the digital world of computers and networks.

We have introduced the concepts behind the Agent Chameleons Architecture, which provides the necessary computational support for: reasoning via BDI agents; mobility via weak migration and mutation based upon VR visualisation. We have presented initial proof of concept demonstrators.

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