

# Net-mobile embodied agents

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## Abstract

The Talking Heads experiment currently being conducted at Sony CSL Paris implements a network of mobile cognitive agents. Each node of the network consists of a workstation with two digital cameras through which the agents can perceive the world. When installed on a node, agents construct classifications of what they 'see' through the cameras and interact with each other to develop a simple language for communicating their representations to each other. Travel between the nodes takes place over the Internet, using standard communications protocols.

## 1 Introduction

The evolution of computer technology has seen the development of three distinct phases of computer use. Initially, computing resources were centralised and located on monolithic mainframe computers to which access was strictly controlled. This phase was succeeded by a second in which significant amounts of computing power became available on personal computers and workstations, creating a situation in which resources were distributed. In the third phase, with the growth of the Internet these distributed resources can now be interlinked, providing for exchange of data and use of shared resources.

Some key questions concern the way these distributed resources can be used. The availability of significant processing power on client machines has changed the balance of resource use. The growing popularity of languages such as JAVA, for example, testifies to a strong tendency to capitalize on the power of client machines in order to improve response time and reduce server load by transferring to the client computation that would previously have been performed on the server.

Client-based computation also makes sense when specialised resources – particularly control or perception mechanisms that provide interfaces to the real world – are located at a specific place. This type of situation makes it desirable to consider models in which intelligent agents are transferred between locations. Where network connections are slow or unreliable, transferring an agent 'on-site'

to use resources may offer a better alternative to trying to operate the resource remotely across the network. Such agents need to be not only mobile but also adaptive, in order to cope with heterogeneous resources: in a world in which the variety of possible resource types is effectively unlimited and the protocols for manipulating them may be difficult to pre-define, an agent that can dynamically adapt to the local situation and assimilate the facilities available will offer a clear advantage.

The Talking Heads experiment is a distributed real-world experiment based on a network of sites equipped with cameras. Software agents move between these sites via the Internet. On arrival, they use the available facilities to inspect the world and build representations of what they see. At the same time, they interact with each other to develop a shared language for communicating their representations of the world. This language is evolving and dynamic, allowing it to adapt to changes in the world and the addition of new sources of information.

## 2 The agents

The agents used in the Talking Heads experiment draw on our previous work in the evolution of language (see [KSM98], [SM98]). Each agent consists of three processing modules:

- A perceptual module that can perform simple segmentation of visual images, dividing the image into distinct regions and extracting basic information – color, size, shape, location etc. – about each region.
- A discrimination module that can compute the characteristics necessary to distinguish one image segment from the others based on the extracted properties of the segments (see [Ste96a]).
- An associative memory that stores associations between computed discriminations and the tokens (words) used to represent them.

Both the discrimination module and the associative memory are initially unconfigured. As the agent interacts with the world and with other agents, it constructs a network of categorizers which it uses to compute discriminations between observed objects. In the same way, the associative memory learns a set of associations between these discriminations and the tokens that the agent's peers use to express them.

## 3 The guessing game

The agent's learning takes place in the context of a formalised interaction which we call the *guessing game*, an instance of a general class of such interactions that we term *language games* (see [Ste96b]). The game takes place when two agents

install themselves at a site and use the cameras at that site to inspect the world. Each agent performs a segmentation of the scene that it perceives, and one agent – designated as the speaker – computes a discrimination between a selected scene region and other identifiable regions in the scene. Based on that discrimination, it recovers a word token from its lexical memory (or invents a new token if none exists), and communicates this to the second agent. The hearer uses its own lexicon to retrieve a meaning (a discrimination) and applies this discrimination to the scene to identify one region. If it is able to successfully identify the scene region chosen by the speaker, the game succeeds. If it fails – because, for example, it does not know the word used, or has a different understanding of the word which does not allow it to successfully pick out the intended target – both agents engage in a repair process which can involve refinement of their discrimination structures, learning of new tokens and adjustment of association scores. Through these interactions, the agents in the population converge on a shared lexicon of symbols representing distinctive properties of objects in their world.

## 4 Teleportation

The Talking Heads network consists of multiple sites in different physical locations. Agents travel between these sites over the Internet, a process referred to as 'teleportation'. The agent's 'consciousness' – that is, the emergent data structures that constitute the unique knowledge of the agent – is transmitted using the standard HTTP protocol.

The present network uses a star topology in which all agents pass through a central server. The server is a reactive device which responds to requests from the clients – to upload an agent or data, or request a download of any waiting agents – but does not itself initiate exchanges. This configuration was chosen to allow monitoring for experimental purposes, but the system could also be implemented to allow peer-to-peer exchanges, or exchanges via an adaptive network of clients and servers whose architecture might evolve in response to changes in facilities available or meta-knowledge about the state of the network.

## 5 Results

A Talking Heads network has been implemented by researchers at Sony CSL Paris working in collaboration with researchers from the Artificial Intelligence Laboratory of the Vrije Universiteit Brussel. At the time of writing, the first two client sites – at Paris and Brussels – are already in operation, and we plan to add an additional four sites to the network by the end of the year. A central server located at Paris manages the movements of the agents and provides facilities to monitor the progress of the interactions between agents and the development of

their language. Client software is based on the Babel environment developed at Sony CSL Paris (see [McI98]), while the server software has been implemented using the MySQL database system and PHP3.

The experiment has been conceived from the outset to be publicly-visible and accessible. Through the Web site at <<http://talking-heads.csl.sony.fr>> Internet users may follow the experiment and even construct and teach their own agents. At the same time, a client site has been set up at the Laboratorium exhibition in Antwerp. Laboratorium is a collaborative project to explore and express the relation between art and science. The presence of a Talking Heads site allows ordinary users to influence the outcome of the experiment and submits the system to the kind of pressures and validation which can only occur from use in a real-world environment.

## 6 Conclusions

The growth of the Internet with its combination of client stations offering significant computational power and a high degree of interconnection between these resources means that a model of computation based on mobile processes is desirable and feasible. In applications dependent on specialised resources concentrated in a particular location, such a model is not merely appropriate but actually essential. The Talking Heads experiment embodies some of the key features of such a model, including robust protocols for transfer of knowledge between locations and adaptive agents that can adjust to conform to local conditions and facilities.

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