Decentralised workflows and software agents

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This paper argues that the combination of software agents with existing workflow management systems can facilitate the degree of co-ordination and collaboration required to make virtual enterprises a reality. It describes the use of software agents in the: setting-up of decentralised workflows; reactive and proactive redistribution of work during process failures; promotion of interoperability between workflow management systems; visualisation and monitoring of decentralised business processes.

An implementation is described which uses a number of industry standard components, such as the Agent Communication Language defined by the Foundation for Intelligent Physical Agents, the Common Object Request Broker Architecture, JAVA[1] and the Process Interchange Format.

1 Introduction

It has become generally accepted in business that process (as opposed to functional) management is an essential element of world-class management [1], [2]. An early manifestation of this trend was the widespread adoption of Business Process Re-engineering (BPR) [3] techniques. Because re-engineering renders previously tacit processes explicit, it becomes possible to develop process centric information systems, which are often described as workflows [4]. The Workflow Management Coalition (WfMC[2]) [5] defines workflow as

"The automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules." [6].

Workflow management systems are software systems used to define, create and then manage the enactment of workflows.

The workflow market space is expanding. Ovum estimates (see Table 1) a 30% per annum growth in the value of worldwide workflow expenditure between 1998 and the year 2000.

	1998	**1999**	**2000**
Products	1,080	1,240	1,340
Services	3,564	3,844	4,020
Total	**4,644**	**5,084**	**5,360**

Table 1 Worldwide workflow expenditure ($M) by type (Ovum estimate REF)

The principal benefits associated with current generation workflow management systems are as follows. They:

- Capture policies, procedures & practices;
- Ensure consistent, uniform operation;
- Control the hand-off of work between people, departments, or systems;
- Facilitate work tracking and audit;

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[1] JAVA is a registered trademark.

[2] WfMC is a non-profit international organisation of workflow vendors, customers and users.

- Support visualisation of business processes;
- Enable the changing of business rules;
- Measure/capture performance and cost;
- Manage workloads by role.

BT has already embraced workflow technology in order to improve its own business processes. The number of BT workflow projects either completed or nearing completion is growing steadily, with many more in the pipeline [7].

The three key phases of business process management are provisioning, enactment and compensation. Provisioning is the act of resourcing the business process, i.e. finding individuals, departments and/or other enterprises willing and able to perform some or all of the individual activities that the process is made up of. Enactment is the running of the business process, i.e. providing service to live customers. Compensation is the problem solving phase, i.e. handling exceptions as and when they occur.

Fig 1 shows a simple business process definition (i.e. a representation held within a workflow management system of what is intended to happen in the real world). The business process is resourced manually, via negotiation between the managers of a number of departments or enterprises that 'own' resource capable of performing the various activities. Typically, Service Level Agreements (SLAs) are produced to detail the provisioning agreements.

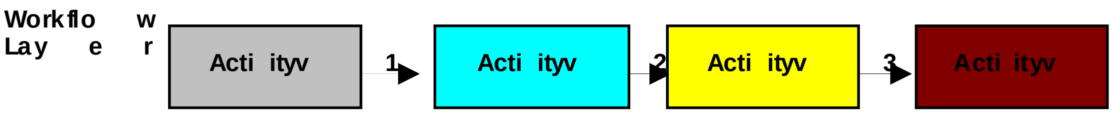

Fig 1 Simple business process definition

Once resourced, the process is enacted and work distributed in accordance with the SLAs. In theory, this work distribution can be achieved using a single workflow management system, which passes electronic representations of incoming work items from one activity to another. In practice, once inter-organisational (and increasingly, intra-organisational) boundaries are crossed, difficulties relating to work item tracking and audit trails, and interoperability have to be tackled, as multiple workflow management systems are likely to be involved.

1.1 Workflow and the Virtual Enterprise

The simplest form of a virtual enterprise is a collection of individuals collaborating to achieve a common goal, given shared access to information and an over-arching co-ordination structure. A good example would be the dynamic creation of a supply-chain, combining multiple suppliers and consumers in support of a final product. In corporate terms, a virtual enterprise can be a collection of geographically disparate departments, and/or business alliances. In a business climate where virtual enterprises have become increasingly common as organisations seek new ways of delivering value to their shareholders and customers, the majority of current generation workflow management systems represent islands of automation that provide inflexible tactical solutions. They tend to enact static process descriptions, which are time-consuming and thus expensive to modify. Also, they cannot easily be linked to other workflow management systems, as both the emergence and take-up of interoperability standards has been tardy. Hence existing workflows tend to be centralised, in the sense that the entire business process definition is held within a single workflow management system, rather than being spread across a combination of two or more workflow management systems, based on different vendors' workflow products.

Decentralised workflow supports ad-hoc collaboration and co-ordination between disparate workflow management systems. It is a vital tool for supporting dynamic virtual enterprises, as it enables existing (sub) process definitions to be combined to create new processes to rapidly meet emerging market opportunities. In such a scenario, individual departments can be viewed as service centres, able to contribute their skills to multiple, composite workflows. Such collaboration requires co-ordination between a number of workflows, as the output of a sub-process operated by one department forms the input to a sub-process operated by another department. Unfortunately, there are a number of problems that impede the development of decentralised workflow:

- Organisational issues

Effective co-operation between organisations requires the exchange of meaningful information (e.g. bills, orders, catalogues etc.). One key problem with transferring information between organisations is that they use different information models with different associated semantics (i.e. meanings). The semantics are not explicitly represented and invariably remains tacit in the minds of users and developers. This is often referred to as the ontology problem. This problem can be resolved by establishing industry standards, for example EDIFACT [8], although these are difficult and time consuming to produce. Alternatively, supporting the explicit representation of semantics in an ontology (which can then be exchanged between cooperating parties) offers a more flexible approach to information exchange between organisations. [9] explores this issue of heterogeneous information integration in more depth in this journal.

- Workflow interoperability and work item management

Workflow management systems themselves present some obstacles to interoperability. Sheth [10] points out that "currently disparate technologies for workflow automation or process management…will need to be integrated". Integration is problematic due to issues concerning interoperability standards. The WfMC is defining a number of workflow standards, which include jFlow [11], a workflow management facility. However, WfMC standards have a gestation period measured in years, not months, and their adoption by workflow product vendors is far from universal. A recent initiative by the Internet Engineering Task Force to introduce a lightweight, internet-based workflow interoperation standard (SWAP, the Simple Workflow Access Protocol [12]) appears to have stalled. Even if jFlow, SWAP and other relevant standards were agreed today and implemented by workflow product vendors tomorrow, the vast majority of existing workflows would continue to operate in splendid isolation for some time to come.

At the level of an individual workflow management system, the removal of a work item from a workflow and its asynchronous re-insertion can cause problems, as issues such as current state, whereabouts and expiry of timers need to be managed in the absence of the work item. Work item audit trails are also an issue in such cases, as partial audit trails will exist on a number of workflow management systems, but no one system will hold the full trail.

- System and technical challenges

Workflow management systems may expect to be actively queried for process statistics or work movements. Alternatively they may generate events signifying the movement of work through an activity, and expect these to be caught and handled by other process elements. Either way, centralised monitoring and control of decentralised workflows is currently problematic, as there is a need to build an end-to-end view of the process, so that work item progress can be tracked, and sub-process/activity/task level performance measures (such as queue length, throughput) displayed. This implies the need to obtain and integrate both static and dynamic process information from multiple, disparate sources. Again, ontology and interoperability issues are key.

- Compensation (Exception Handling) strategies

Many workflow management systems do not enable the flow of work to be managed in a proactive way, resulting in a backlog of unprocessed work. Dynamic compensation strategies are required to ensure that quality of service is not adversely affected when unexpected exceptions occur. There are two cases that need to be addressed, namely exceptions which requires activities to be performed which are outside of the scope of the process definition (i.e. unforeseen exceptions, or mass customisation of existing processes), and automated management of resources to support fluctuations in demand (i.e. load balancing).

The remainder of this paper describes how, based on previous work [13], a means of overcoming these barriers to decentralised workflow has been devised.

2 Software Agents and Decentralised Workflow

This paper proposes the use a layer of software agents to: manage the interoperation of disparate workflow management systems; supply extra information services for business process managers; retain users' confidence in the workflow tools they are already familiar with; protect investment in existing workflow technology.

Nwana [14] identifies three properties of a software component that identify it as an agent.

- It should be *autonomous*, that is, it is in control of a set of responsibilities independent of human advice.
- Agents should be *collaborative*, that is able to work together in order to solve a problem.
- Intelligent agents should *learn* from their experiences and adapt over time as their operating conditions change.

An *agent workflow system*, then, is a set of agents that manage the flow of work through a business process. Two forms of agent workflow systems, agent based workflow and agent-enhanced workflow, are discussed below.

2.1 Agent based workflow

Agent based workflow systems have been developed by a number of teams [15], [16], [17] and [18], each offering their own particular enhancements and features. In agent based workflow, the software agents take full responsibility for process provisioning, enactment and compensation (see Fig 2), with each agent managing and controlling a given activity or set of activities. However, these tools do not appear to have been adopted and are not, at the time of writing, in common usage. In addition, a move to agent based workflow is likely to incur high re-engineering costs, and the resulting step change in technology will create extensive training requirements.

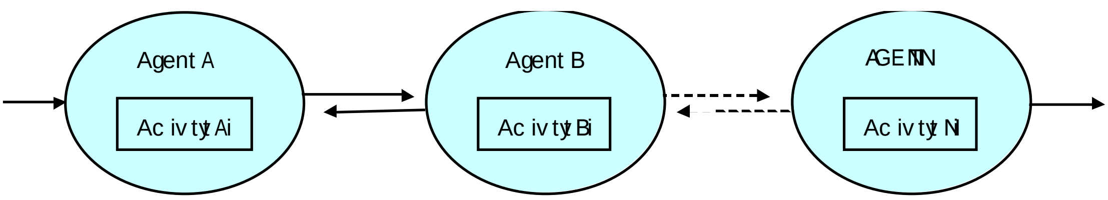

Fig 2: Agent Based Workflow

2.2 Agent-enhanced Workflow

This paper promotes the enhancement of third party workflow management systems by software agents, providing mechanisms for handling and repairing workflow failures [13], while retaining the user's confidence in the workflow tools they were familiar with. It demonstrates the feasibility of constructing workflow interoperability mechanisms, based on agents as proposed by [19], and shows that the agent layer can interface workflow management systems to other software tools to provide further functionality, such as process monitoring and control.

This approach is called *agent-enhanced workflow*, in contrast to the more common agent based workflow. Agent-enhanced workflow is achieved by combining a layer of agents with a commercial workflow management system (as per Fig 3). The agent layer is given responsibility for both the provisioning and compensation phases of business process management, whilst the underlying workflow management system handles process enactment.

Note that in both Fig 2 and Fig 3 arrows represent information flows, and encapsulation represents ownership and control of an activity definition (the real world activities are performed externally, by people or other computer systems).

Within the agent layer, each agent is responsible for one or more service offerings, where a service offering is some combination of workflow activities and the resources that are contingent upon them. Such a collection of software agents is referred to here as an agency. Within the agent layer, each agent is responsible for one or more service offerings, where a service offering is some combination of workflow activities and the resources that are contingent upon them. A collection of software agents is referred to here as an agency, the "workflow agency" is the whole agent layer, while agents offering a particular service by collaboration or simply through the abilities of the processes that they manage would be referred to as (for example) the "accounts agency" or the "correspondence handling agency".

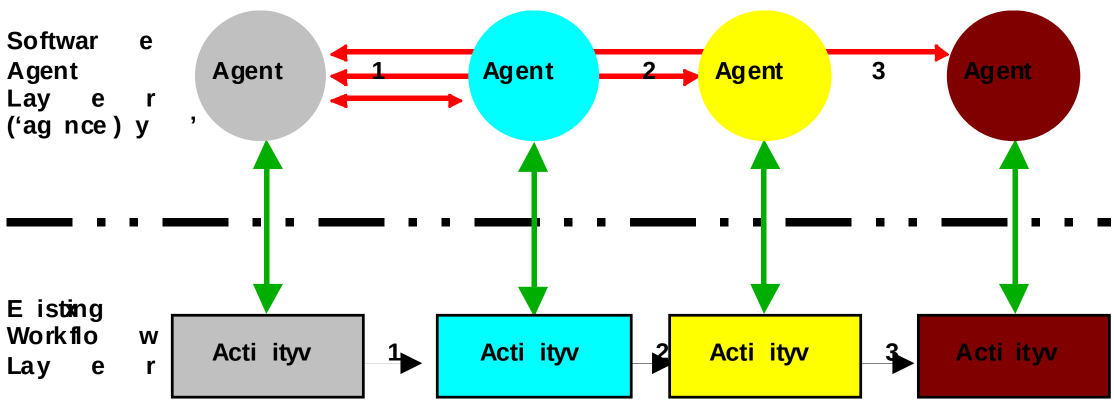

Fig 3 Agent-enhanced workflow

Agent-enhanced workflow operates as follows: External demand (e.g. yesterday's mortgage applications) is expressed as a goal (e.g. 'process all yesterday's mortgage applications') for an agency to achieve. Within that agency, the software agents collaborate to decompose the goal, contracting out sub-goals to other agencies as necessary. Thus a provisioning plan is formed via this backward chaining[3] approach, which involves many agents spread across one or more agencies (see Fig 4) negotiating to supply and consume business services, and exchanging contracts (in the

[3] C.f. the technique of solving a maze by starting at the end and working backwards to the start.

form of electronic SLAs) when agreements are reached. Each SLA describes the responsibilities of both parties in terms of volume and type of work, price, timescales etc. The provisioning plan is both a process definition and a resource schedule - resources are reserved as the plan is formed - and equates to a decentralised workflow. That is to say, the plan combines a number of sub-processes hosted on disparate workflow management systems.

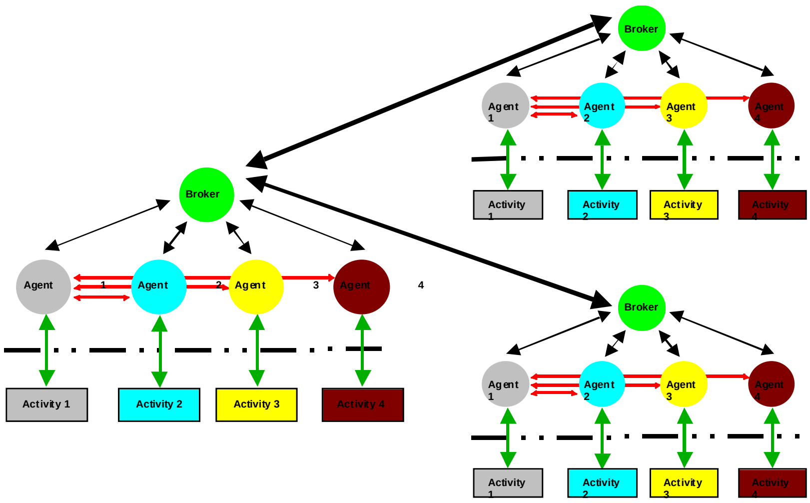

Fig 4 Decentralised workflow management using software agents

The software agents enact the plan, causing work items to be created, processed, routed and destroyed in the underlying workflow management systems, as and when appropriate. When a sub-goal has been achieved by a given agency (e.g. checking the credit rating of a batch of applicants), the partially processed work is handed-off to the next agency, and so on, until completion.

2.3 Business benefits of Agent-enhanced Workflow

There are four major impediments to decentralised workflow: organisational issues; work item identification and management; system and technical challenges; compensation strategies. Agent-enhanced workflow addresses these impediments as follows:

- Organisational Issues

Agent-enhanced workflow offers a solution to this problem by demanding that the members of the agent layer subscribe to a common ontology. The common ontology acts as a shared semantic representation which is then mapped to the local semantics of each of the inter-operating systems. PIF, the Process Interchange Format [20], forms the basis of the shared ontology that the agents use to communicate process definitions, statistics etc.

- Work Item Identification and Management

As the agent layer is responsible for devising, monitoring and revising the provisioning plan (i.e. which items of work should be routed where, and when), it is natural that the removal and re-insertion of work items should be managed by that layer. Work item audit trails are also managed at the agent layer, by combining audit fragments from the various workflow management systems into a coherent whole.

- System and Technical Challenges

An end-to-end view of decentralised business processes is provided via the Visualisation and Monitoring System (VMS), an external agency that exists to provide common services to other agencies.

The VMS also provides a contract compliance view, by comparing the performance of each agency with the terms of the various SLAs that it is a party to, and highlighting any discrepancies. Knowledge of an agency's contract compliance behaviour is used to support learning and predictive behaviour in itself and/or other agencies.

- Compensation strategies

Individual software agents can react to process failures by monitoring queue lengths for each workflow activity that they are responsible for. If a pre-defined threshold is exceeded, the software agent negotiates to both offload unprocessed work items, and to reduce the rate at which work is being presented to the activity for processing.

As well as this reactive response to process failure, the software agents can behave proactively. Consequently, new plans for the distribution of work are formulated automatically before a process failure becomes apparent to the customer.

2.4 Agent-enhanced workflow technology

The technologies adopted to tackle the major impediments to decentralised workflow are described below.

- Organisational Issues

PIF is a frame-based language which defines a core of process-centric entities (such as *activity, decision, timepoint*), and relations between them (such as *creates, modifies, performs, successor*). PIF is intended to support the exchange of business process models across different formats and schemas. The authors of PIF recognised the likely need to extend PIF to suit individual domains, and introduced the concept of a partially shared view (PSV), i.e. a third-party addition to PIF that supports as much sharing as possible with other PSVs. The PSV concept was adopted, and a number of additional entities were created (such as *software agent*, *statistic* and s*ervice level agreement*) that inherit attributes from the core entities.

Conceptually, the conversion from PIF core and the PSV entities to JAVA was straightforward, as PIF entities can be mapped to simple JAVA classes. In practice, each agency had access to a copy of the JAVA class files representing the PIF entities, and generated instances of those classes as required.

All inter-agency (and agency to VMS) communication uses FIPA Agent Communication Language (ACL) [21]. The VMS uses FIPA ACL to request that each agency send a description of any of its sub-processes that are contributing to the overall business process. When an agency receives a request to describe its sub-process, it obtains a process description via a query to its workflow layer and converts the process representation into instances of the JAVA PIF classes. It then inserts those JAVA instances into a FIPA ACL message as the content part, and sends the message (using IIOP) to the VMS. The VMS then assembles the various sub-process definitions using the precedence information contained within each, and displays a graphical representation of the process.

The VMS performs centralised progress monitoring, using the FIPA ACL communicative acts *request-when* and *request-whenever* to obtain information from the various agencies. Upon receipt of either message from the VMS, an agency's broker formulates and asserts a goal (e.g. ‘get the activity statistics for activity X’) which causes an agent to make one or more simple statistics calls to its underlying workflow management system (in keeping with the conditions contained within the *request-when* or *request-whenever* message), The result is passed back to the broker and sent back to the VMS using FIPA ACL, with PIF as the content language.

- Work Item Identification and Management

The common ontology (based on PIF) that exists within and across agencies greatly simplifies the task of tracking work items as they move between workflows.

- System and Technical Challenges

The use of a common ontology greatly simplifies inter-agency communication. The results of any query from an agent to its workflow layer or an external (e.g. MIS) system is passed to the agency's broker, which converts it to PIF format. The information is transmitted to other brokers using FIPA ACL. The JAVA-based agents are implemented using BT's Zeus agent building toolkit [22]. The interface to workflow utilises Syntegra's WAPI[4] written in C, which was distributed using the JAVA Native Interface and CORBA-2. The broker agents are implemented using JAVA and CORBA-2. The connectivity mechanism between the agent and workflow layers is shown in Fig 5.

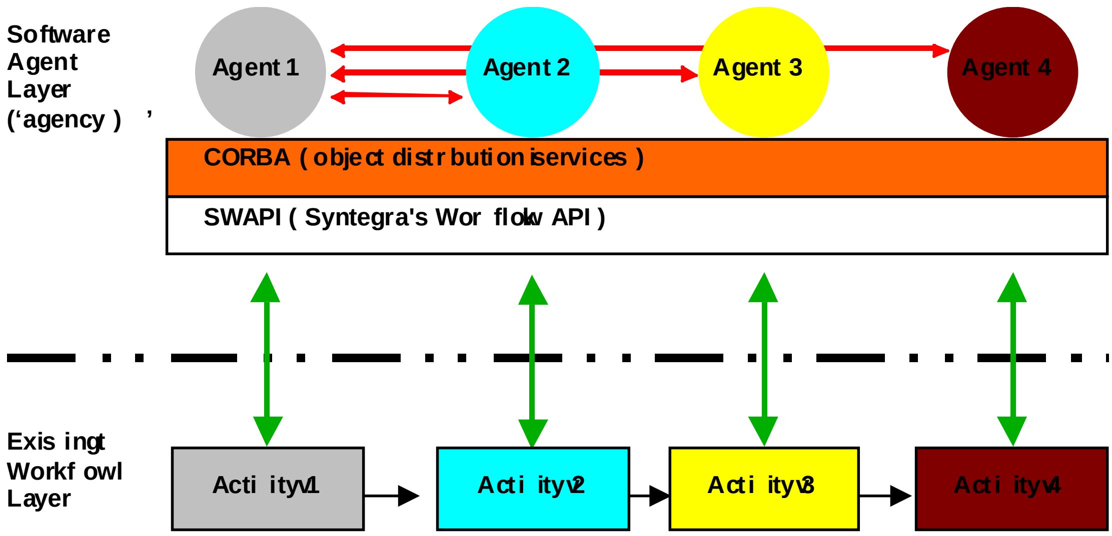

Fig 5: Agent to workflow connectivity

- Compensation strategies

Proactive compensation was achieved by using Support Vector Learning (SVL) [23] to provide each agent with the ability to predict the flow of work that it would receive, based on the history of the flow of work received to date. SVL is a new technique which has grown out of the efforts to understand machine learning at a theoretical level. The use of SVL techniques enabled the software agents to effectively predict when a failure was likely to occur. As a result, new plans for the distribution of work were formulated automatically before a failure transpired.

Fig 6 shows the output from one such proactive agent. The predicted backlog of work (dashed line) leads the actual backlog (solid line) by a predefined time period, N epochs. At point 1, a backlog is predicted. At point 2 (N epochs later) an actual backlog of work occurs. At point 3, the predicted rate of growth of the backlog is adjusted, based on a larger data sample. At point 4, the predicted backlog exceeds a predefined quality threshold, and the provisioning plan is revised, via re-negotiation between the software agents. The predicted backlog falls to zero at point 5. The actual backlog reaches zero at point 6 (again, N epochs later).

[4] The essence of this product is that it provides a common API to a number of workflow engines.

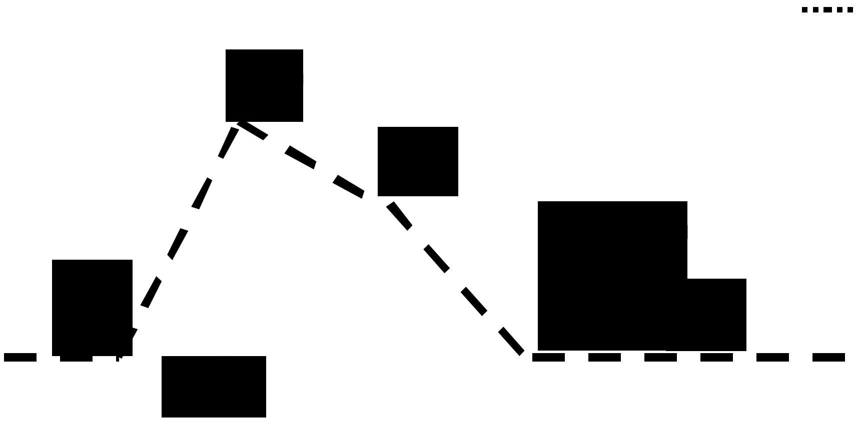

Fig 6: Queue size prediction

3 Conclusions

This paper describes an agent-enhanced workflow architecture that uses industry standard middleware tools (CORBA, JAVA) to interface software agents to third-party workflow management systems. It shows how broker agents, using standard interaction protocols such as *fipa-request-when* and *fipa-request-whenever* coupled with a PIF-based content language, can be used to facilitate workflow interoperability.

There were a number of candidate process description languages, but PIF was chosen because of its extensibility and ease of conceptual mapping to JAVA. In practice, the use of PIF as a common ontology (coupled with facilities to automatically translate the results of workflow queries into PIF), facilitated the use of the VMS agency to provide visualisation and monitoring services, such as an end-to-end process view, and contract compliance (a comparison of the contracted and actual performance of an individual agent or an agency as a whole). With the recent introduction of an XML version [25], PIF may now find widespread acceptance within Web-based e-Business applications.

FIPA ACL proved that it was capable of both supporting ‘workflow agency to workflow agency’ communications, and ‘visualisation and monitoring agency to workflow agency’ communications. The experiences of using the specifications were fed back into FIPA, for incorporation in future versions.

The use of Support Vector Learning techniques enabled the agents to differentiate between a cyclic flow of work with peak values that exceed a failure threshold but would not cause a failure in the long term, and an actual trend that would eventually lead to failure. Future work will involve generalising the learning algorithms so that they can easily be adapted to work with a wide range of software agents and domains.

In summary, agent-enhanced workflow provides a workflow co-ordination and collaboration mechanism for provisioning virtual processes, automating the redistribution of work due to failed processes and smoothing the hand-offs between organisations, as well as support for visualisation and monitoring of decentralised business processes. The next step is to examine some of the non-functional aspects of the technology in trials where performance, scalability, usability and coverage can be examined.

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