Intelligent Agent-based Framework for Project Integration Management

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Abstract - The dynamism required in the continuous aggregation of the results of all subsidiary planning activities in a project into a consistent document (the project plan), the effective and progressive elaboration of such a document with updates, the continuous communication requirement during project execution activities coupled with the computational effort required for various ongoing performance evaluation analysis and the constant coordination of changes across the entire elements of a project is definitely overwhelming to the project manager using conventional Project Management Information System. This paper proposes the exploitation of the dynamism of intelligent agents to support project integration management, a core knowledge area of project management. Using the Belief-Desire-Intention (BDI) agent architecture this paper defines an intelligent agent based framework to support project integration management.

Key Words: Intelligent Agents, Project Integration Management.

1. Introduction

Artificial Intelligence (AI) is currently applied in many fields. One of such fields is project management. Project management is the application of knowledge, skills, tools and techniques to project activities to meet project requirements [PMBOK]. Project management is accomplished through the application and integration of its processes: initiating, planning, executing, monitoring and controlling [PMBOK]. A sizeable number of research works [1,2,3,4,5,6,7] have approached the subject matter of applying AI/Expert system (ES) to project management. These efforts address various areas including knowledge-base project schedule planning, using ES to analyze and control project schedule, intelligent project estimate validation, intelligent quality prediction model of risk allocation in construction contracts etc.

This paper focuses on the application of intelligent agent concepts in project integration management. However the proposed framework is not meant to be viewed as an effort to replace the project manager with artificial entities, rather is conceived to be an intelligent tool to assist the project manager. It is intended to enable the project manager to focus less on too many details and focus on the pig picture while the complex details of ensuring effective coordination of information across the project scope is left to intelligent agents.

The rest of the paper is organized as follows. Next section gives background information on intelligent agents. Section 3 provides the definition of project integration management and stresses the need to apply AI techniques to it. Section 4 provides background information on BDI architecture. Section 5 presents the design of the proposed agent framework, stating the underlying scheme for the construction of its BDI structure. Finally section 6 concludes the paper.

2. Intelligent Agents

The concept of intelligent agents belongs to the field of artificial intelligence (AI), a branch of computer science [14, 15]. The idea of intelligent agents was introduced in the mid-1950s [15]. Agent technology has constituted a remarkable field of research interest for about a couple of decades or more. Agent systems have been used in various applications such as workflow, scheduling, optimization, distributed systems, groupware, air traffic control, automated manufacturing, space shuttle, robotics [9,12,13]. However the exact nature of an agent has been the subject of extensive debate within the research community, in the sense that there is little agreement about the definition of what an agent could be and what architecture is most suitable to use [9,10,11]. Though there is not a universally accepted definition of intelligent agent, there is a broad consensus that agents should have the property of autonomy. They may also have other attributes, such as social ability, reactivity, pro-activeness, rationality and mobility, etc [15, 16].
In the way of presenting a definition in this paper, agents can be defined as autonomous entities that act within an environment, that is, agents are free to choose their own actions [17]. An agent is often referred to generally as an entity (piece of software) that accomplishes some tasks on behalf of its user. Agents may react to stimuli from their environment and are also capable of changing their environment. Pro-activeness is the ability of the agent to pursue goals and persist in trying to achieve its set goals. Autonomy is the ability of the agent to act without necessarily being told to take particular actions. The agent social attribute means its ability to team up with other agents towards the actualization of some goals. Situated in an environment the agent influences and is also influenced by its environment. The agent perceives its world through sensors and affects its world via actuators.

A number of different approach have been reported for modeling agent oriented systems[18,19,20,21,22,23]. One of such agent modeling paradigm reported in the literature as a mature and commonly adopted architecture is the BDI (Belief, Desire, Intention) model. The BDI agent architecture is adopted in the definition of the agent based project integration management framework carried out in this paper.

3. Project Integration Management and the need for AI techniques

Project integration management is one of the project management knowledge areas [PMBOK]. The project management knowledge areas describe project management knowledge and practice in terms of its component processes. Project integration management includes the processes required to ensure that the various elements of the project are properly coordinated [PMBOK]. Project integration management includes the following major processes [PMBOK]: Project Plan Development- taking the results of other planning processes and putting them into a consistent, coherent document. Project Plan Execution- caring out the project plan by performing the activities included therein. Overall Change Control - coordinating changes across the entire project. These processes interact with each other and with other project management knowledge areas.

In the course of project integration management, the project plan is progressively elaborated by updates and controlled and approved through integrated change control, which together recursively overlaps with project plan execution processes requiring extensive (depending on project complexities) and dynamic coordination of information to direct the various technical and organizational interfaces in the project. Change request could unexpectedly emanate from stakeholders, previous project assumptions may have been proved wrong (requiring alterations somewhere), a project task may have been delayed requiring update to project schedule etc. Hence it could be safely said that the relationships existing among the iterative and overlapping processes that constitute project integration management are not linear. It is well known that handling situations involving non linear interactions are best addressed using intelligent techniques. This paper approaches this problem domain by reasoning within the context of intelligent agents.

A real time project integration management framework based on AI concepts is most appropriate for instance to enable the project team identify variances (in cost, budget, schedule etc.) or potential risk early, before they become serious threats to success. Early and real-time (or near real-time) notification of serious variations in project elements will definitely help in avoiding serious errors that might lead to costly rework of deliverables.

4. The BDI Agent Architecture

The underlying principles of the Belief-Desire-Intention (BDI) architecture were established in the mid-1980s based on the philosophical work by Bratman[24,25]. As reported, the foundation of this agent architecture is based on the premise that a rational entity must have three cognitive structures: Beliefs, Desire, and Intentions. These structures are often referred to as the agent's mental attitudes.

Beliefs represent the agents knowledge of the world or the information it has about the state of the environment. The agents beliefs may be implemented as a variable, a database, a tuple, a set of logical expressions, or some other data structure[18]. Beliefs can also include inference rules that allow forward chaining to lead to new beliefs[26]. Desire (understood to be more or less synonymous with goals) represents the motivational state of the agent, that is, what the agent is trying to achieve. However it is argued in the literature that Desire if represented all, have only a transient representation as a type of event. The desire has been referred to as the agents information about objectives to be accomplished, or priorities associated with various current objectives, either of which are thought to be generated instantaneously or functionally, and thus not requiring any state representation [18]. Goals play a central role in some of the properties of rational systems as described by BDI theories. Goals are essentially a partial state of the world which the agent has decided to achieve [27]. In computational terms, a goal may simply be the value of a
variable, a record structure, or a symbolic expression in some logic [24].

A typical BDI agent [28, 29, 30] has a so-called procedural knowledge constituted by a set of Plans which defined sequences of actions and test steps to be performed to achieve a certain goal or react to a specific situation [31]. plans which can be viewed as special form belief represent the information about the means of achieving certain future world states and options available to the agent [30, 18]. Looked at another way, plans are sequences of actions that an agent can do to achieve one or more of its intentions [26]. Intentions represent the deliberative state of the agent, that is, which plans the agent has chosen for eventual execution. Events are triggers for reactive activity by the agent, and may update beliefs, trigger plans or modify goals [26]. Events can be generated externally by other sources or internally by the agent or other agents. Internal events are those that are created by the agent itself. This allows other plans that the agent may have to be invoked. External events are those which are not created by the agent and may be created by either the environment or by other agents. When an event is perceived, the agent may choose to execute certain plans.

5. The design of the framework

The framework consists of a number of cooperating intelligent agents designed to ensure dynamism in the capture of the vast details (e.g relating to change request, performance reports, information on authorized work etc.) that is continuously generated by the processes required in project integration management. This enables the dynamic communication of project information and work instruction to project team members e.g. via automated e-mail, sms, alerts etc. This intelligent infrastructure possesses the dynamism to intelligently react to changes (e.g. in project scope, budget, schedule etc.) in the environment thereby ensuring proper synchronization of information between the different project integration management processes in real-time. This provides reliable and consistent update of required communication to project stockholders. The major components of the framework are independent agents, each providing unique services for successful project integration management. Based on the requirement for project integration management and the communication and synchronization requirement within the framework, the following agents are identified for the system: Plan Development Agent, Project Execution Agent, Change Control Agent and Interface Agent.

5.1. Defining the BDI structure for the framework

For the description of the complete BDI (agents mental attitude) to assign to the agents identified, the software development process to capture system requirement in the sequence of Intentions, Desire, and Belief [24, 32, 33] is utilized. This model specifies that goals are extracted from system requirements, Plans (Intentions) from activity diagrams, and beliefs (data moving in the environment) from data flow diagrams. In the case of the proposed framework, from overall requirement for project integration management, the goals (outputs from each constituent process in project integration management) are discovered, then the intentions (project management activities that should be executed when certain goals are reached) are identified, and the beliefs (information from subsidiary project planning activities, informational output from other project integration management process) that will be necessary for each goal to be completed are extracted. From this the completed BDI structure to assign to each agent in the framework is defined.

5.2. The Plan Development Agent

Fig.1 (inspired by [34]) shows the BDI structure of the Plan development Agent. The agent is shown alongside other agents in the framework to clarify data exchanges (that also alter the agent's mental attitude) between the agents. It also shows overlap of processing activities among the agents as required for successful project integration management. Beliefs: the beliefs of the plan development agent are (1) the beliefs as indicated in fig.1 - this beliefs stem from other subsidiary planning activities in the project (2) project management plan update - this stem from the execution of intentions (plans) in the Project Execution Agent and the execution of intentions in the Change Control Agent. Intentions: the possible intentions of the Plan Development Agent are as indicates in fig.1. The set of plans to execute embodies procedural knowledge involved in the control of project scope, control of schedule, performing quality control, controlling cost etc. The agent can exploit inference rules within a knowledge-base while deliberating on these activities. The execution of the plans in the intention list is to ensure verification, control and update actions that ensure the coherent coordination of all subsidiary planning processes and resulting documentations. The intentions are sets of algorithms that are iteratively processed as project planning activities are carried on. These activities are executed when goals are reached. Goals: The goal the
Plan Development Agent is trying to achieve is the project management plan.

The project plan being a document that is progressively elaborated by updates and controlled and approved through integrated change control process [PMBOK], means that the Plan Development Agent has to continuously observe (or probe its environment) for the next percept. The agent will continue to process its belief, execute actions iteratively in order to achieve its intentions based on a set of algorithmic steps in its intention structure. For instance, during the planning process of project integration management, to achieve the intention control scope, the agent would have to execute steps (algorithms) to ascertain whether inputs from subsidiary planning activities are within the project scope.

Furthermore a scope change would mean update to project plan (hosted in Project Management Information system - PMIS). This means the agent would have to update its beliefs, computationally which entail executing steps to update the project management plan. The agent sends instructions to update an external PMIS. The agent is motivated by the attainment of its goals. The attained goal further constitutes events that trigger deliberation (intention execution) in the other agents in the framework. The goals/intentions further create/update the agent beliefs (referring mainly to the updates to the project plan).

5.3. The Project Execution Agent

Fig. 2 shows the BDI structure of the Project Execution Agent. Like fig. 1 it shows overlap of processing activities
among the agents as required for successful project integration management.

**Beliefs:** referring to fig.2, the data(arrows) entering the agent constitutes its beliefs. These include: Project management plan, Approve change request, signals from the enterprise/performing organization coming via the interface agent.

**Intentions:** the possible intentions (change control, schedule control, perform quality management etc.) are indicated in the figure.

**Goals:** work performance information, deliverables, project document updates, change request, work performance information (indicated by signals moving out of the agent).

The Project Execution agent continuously probe or query the project management information system (i.e. the environment in order to obtain belief from its store or from other agents.) as project execution advances. If the agent arrives at project integration management goals, that is finds **deliverables, project document updates** made, etc, it commits to the execution of some intentions. For instance if the agent arrives at the goal **deliverable**, the agent executes the steps in the intention **perform quality control**; possibly if the agent arrives at the goal **work performance information** for example, the steps in the intention **control scope**, **control schedule**, **control cost**, **perform quality assurance** are executed. Based on such executions, a change request might be sent to the **change control agent**. Execution of steps in the intention **report performance** might entail the agent sending messages to the **interface agent** to send e-mail to project stakeholders, comparing work output information with baselines to measure the variance, updating the key performance indicator document etc. Based on the appropriate goal being reached, the execution of steps in the intention **control cost** might entail running algorithms to verify whether expended cost are within the variance as specified in the **cost management plan**(a subsidiary project management plan[PMBOK]).

![Agent based Project Integration Management Framework](image)

Fig.2. BDI structure of the Project Execution Agent

### 5.4 The Change Control Agent

**Goals:** project management plan update, project document update, change request **Beliefs:** project management plans, change request, enterprise/organization assets/factors, information from the execution of intention within other agents in the framework. **Intentions:** perform quality control, documentation, escalate change request to change control system.

The change control agent monitors its environment continuously for events. If its beliefs change, for instance if there is a change request, it commits to the execution of its set of intentions. Change request can come from other agents (from execution of intentions by the **plan development agent** or **project execution agent**, from the environment (from the project team or stakeholders). The change control agent does not approve changes. It needs human input. The **change control agent** routes any change request to a Change Control System (CCS). The CCS is in this case an external system. This is the performing organizations change control system. In some organizations the CCS is called the change control board or the technical review board. This is a group of people responsible for approving or rejecting changes to a
project. The routing of the change request to the CCS for approval might take the form of file update, database entry, or e-mail etc. If the agent perceives an approved change event from the CCS the agent executes intention steps to update the project plan, update the project baselines. This might have the effect of triggering the execution of steps in the intention perform quality control.

5.5 The Interface Agent

This agent manages user interaction with the framework i.e. handles message commutation between the framework and external entities. For instance it enables the project manager to assign support task to the framework.

Conclusion

This paper has focused on the task of explicitly representing the complex iterative and overlapping information interchanges and processing among the Project Integration Management processes in the form of BDI structure, providing the basis for the development of agent based systems to support project integration management. The work is still subject to further development especially in the area of collaboration and negotiation protocols for agent-agent interaction (and possibly human agent teaming technique), leveraging with project management principles and practice. Further step in this research would be to further develop the framework towards full implementation.

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