Collaboration Patterns Ontology for Human-Machine Decision Support

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Keywords: Human-Machine Decision Support, Collaboration Pattern, Collaboration Patterns Ontology.

Abstract: Collaboration of humans and machines when they complement capabilities of each other is becoming increasingly relevant. Recurring problems often arise in the collaboration process. Collaboration patterns that provide reusable efficient and proven solutions for recurring problems is a means to facilitate organization of joint activities for specific collaboration goals such as decision support. Existing studies on collaboration patterns make it clear that collaboration faces problems of diverse classes. The paper proposes a holistic view on human-machine collaboration relatively to the decision support domain where a human-machine environment processes a task that the user deals with as a decision support problem. During task processing, humans and machines use collaboration patterns when they intend to achieve goals for which the patterns propose solutions. A collaboration patterns ontology supports the choice of a kind of pattern that the collaborators can use to accomplish a specific goal. The present research provides models for organization of pattern-based collaboration and contributes to the problem of human-machine decision support suggesting a pattern-based decision support process.

1 INTRODUCTION

Nowadays, role of machines (software intelligent agents, smart devices, robots, etc.) as a collaborative partner of humans has become pivotal. Collaborating, humans and machines complement capabilities of each other and produce better results. This partnership enhances human decision-making. When humans work in collaboration with machines, they harness the power of the machine's capabilities to enhance their decision-making and problem-solving processes (IABAC, 2023).

Collaboration, like other forms of work, often faces problems that can occur repeatedly. Christopher Alexander (Alexander et al., 1977) mentioned this fact in the 70s with relation to problems recurring in architecture. He introduced a concept of design pattern as a description of a problem, which occurs over and over again, and a proposal for a reusable solution for this problem. In architecture, the design patterns have not found a widespread usage, but the idea behind these patterns has attracted attention of other domains including collaborative design, collaborative software development, collaborative decision-making, and others.

Motivation to address to collaboration patterns in the context of human-machine decision support is that the patterns propose efficient and proven solutions and therefore pattern-based decision support help make better decisions.

Multiple studies on collaboration patterns describe patterns developed for specific collaboration problems from different domains. The problems vary from organization of collaboration environment to collaborative solving particular tasks. This makes it clear that collaboration faces problems of diverse classes. The present research proposes a holistic view on human-machine collaboration. It integrates various kinds of existing collaboration patterns into a human-machine decision support environment to solve recurring problems occurring in collaboration processes. An ontology of collaboration patterns serves as a means for context-aware choice of a specific pattern to solve a particular collaboration problem.

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Smirnov, A. and Levashova, T.
Collaboration Patterns Ontology for Human-Machine Decision Support.
DOI: 10.5220/0013057300003838

In *Proceedings of the 16th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2024) - Volume 2: KEOD*, pages 83-94
ISBN: 978-989-758-716-0; ISSN: 2184-3228

The purpose of the present research is to provide a perspective how a human-machine decision support based on collaboration patterns can be organized. To achieve the research purpose, collaboration patterns found in various domains are categorized and a conceptual model of human-machine collaboration pattern is built. This model forms the basis of a middle-level ontology for human-machine collaboration patterns. The ontology is specialized in respect to human-machine collaboration in decision support. It enables a context-aware choice of collaboration patterns aimed at accomplishment of goals occurred during the collaboration. A sample process of solving a task that the user formulates, as a decision support problem by a human-machine environment is proposed and a use case model is considered.

The rest of the paper is as follows. Section 2 introduces kinds of collaboration patterns, the conceptual pattern model, and the ontology of collaboration patterns. Then, in Section 3, the conceptual model of human-machine decision support based on collaboration patterns is outlined, task processing in accordance with this model is presented, and a use case is considered. Conclusion summarises the main research results.

2 ONTOLOGY OF COLLABORATION PATTERNS

An analysis of research on collaboration patterns underlies the development of the collaboration patterns ontology. Patterns identified in multiple domains in relation to human-machine collaboration, human collaboration and collaboration of machines are analysed. The analysis exposed five kinds of collaboration patterns. The ontology integrates these kinds of patterns based on a conceptual model representing components common for most of the pattern representations. This model provides concepts and relationships for the high level of the ontology. Further, this level is specialized in respect to human-machine collaboration in decision support.

2.1 Kinds of Collaboration Patterns

The Section describes collaboration patterns identified from the pattern descriptions found in various domains. The patterns can be divided into patterns that solve the problem of organizing collaboration, and patterns that offer a solution to a problem that arises in the collaboration process. In the former case, collaborators do not necessarily have to be involved in the collaboration activities but the patterns are referred to as collaboration ones because they provide with results that support such activities. Organization patterns, cognitive patterns, and interaction patterns represent this group of patterns. In the latter case, collaborators use patterns to solve jointly the problem they are dealing with. This set of patterns comprises process patterns and collaborative engineering patterns.

2.1.1 Organization Patterns

Organization patterns (Eoyang, 2018; Schmeil & Eppler, 2010) refer to collaboration process as collaborators' activities in accordance with principles and structure of collaborative environment. The aim of these patterns is proposing an environment for collaboration. They describe a problem solution in terms of objects, actions, rules, and steps for collaborators with roles who meet at a location to collaborate on a common goal in a given context.

A collaborative environment is organized in accordance with collaboration types, which determined by characteristics of the collaboration. Such characteristics include collaboration goal, kinds of activities, structures of partner interactions, and others (e.g., term of collaboration (long-term, short-term, others); expected use of the results from the collaboration (internal usage, transfer from one partner to the other, transfer to third parties, etc.); others). Solution proposed by the organization patterns is architecture of a collaborative environment. Elements of this architecture are collaborators, roles they fulfil, collaborators' activities according to their roles, tools supporting the activities, and other elements of information systems architectures (interface, infrastructure, etc.). Additionally, the architecture describes relationships between the architectural elements and specifies collaboration rules.

2.1.2 Cognitive Patterns

Cognitive patterns (Deokar et al., 2008; Toniolo et al., 2023; Vreede et al., 2006) describe the thinking and reasoning processes of experts. Collaboration process from the viewpoint of the cognitive patterns is putting forward ideas, proposals, hypotheses and their agreeing. The patterns' objective is to shape a scenario for the collaboration process. A solution that the patterns propose is a configuration of various cognitive patterns or pattern modelling components to organize such a scenario with respect to a specific intellectual task.

The patterns support the following semantics. Collaborators solve an intellectual task. Human collaborators fulfil the role of experts. They undertake intelligent activities. Agents provides automated support to humans, when needed. In the collaboration process, the experts can use multiple tools that afford one or more capabilities (e.g., tools supporting communications or content visualisation, etc.) Undertaking of an ordered set of intelligent activities leads to a solution of the intellectual task. Preconditions determine which kind of intelligent activity it is advisable to choose at a particular stage of task processing. The collaboration scenario represents collaborators, roles they fulfil, a sequence of collaborators' activities according to their roles, and tools supporting the activities.

2.1.3 Interaction Patterns

Interaction patterns (Barchetti et al., 2011; de Moor, 2006; Dorn et al., 2012) describe a problem solution in terms of components of communication and data management processes. These patterns consider collaboration process as exchanging and editing information, and performing procedures and tasks initiated by information messages. The objective of the interaction patterns is to compose a scenario for the collaboration process. They offer a solution in the form of a composite information pattern or pattern modelling components to organize such a scenario with respect to some collaborators' activity.

The semantics behind the interaction patterns is as follows. Collaborators interact to achieve a specific goal that arises in the process of their joint activities. Collaborators with the role of initiator send messages to the collaborators with the role of executor. The executors respond to the initiators of undertake the requested activity. An executor can forward the message to other collaborators to initiate their actions. In this case, the role of executor changes to the initiator. The goal determines the content of the messages and is contained in the content. The collaboration scenario represents collaborators, roles they fulfil, a sequence of collaborators' interactions according to their roles, and communication tools supporting the interactions.

2.1.4 Process Patterns

Process patterns (Papageorgiou et al., 2009; van Diggelen & Johnson, 2019; Verginadis et al., 2009; Vo et al., 2015) describe a problem solution in terms of activities, actions, and work tasks that the collaborators must take or accomplish to come to this solution as well as tools they can use. Collaboration process is considered as taking actions by collaborators leading to problem solution or goal achievement. The patterns aim at building a collaboration process. A solution offered is a configuration of several process patterns or a sequence of actions, which shape the workflow.

In the process patterns, collaborators take activity to achieve a goal or solve a problem. Activities and actions of the collaborators constitute the workflow. It specifies collaborators, roles they fulfil, a sequence of collaborators' activities according to their roles, and tools supporting the activities.

2.1.5 Collaborative Engineering Patterns

The collaborative engineering patterns (Barchetti et al., 2011; Gottesdiener, 2001) describe a problem solution in terms of rules for collaborative decision-making. Here, collaboration process is a decision-making process. The patterns' objective is proposing a procedure for establishing collaborative decision-making rules. A solution proposed is the procedure for choosing a decision-making rule by the collaborators.

According to the patterns' semantics, collaborators undertake activities to establish a decision-making rule. For this, they follow the procedure offered by the collaborative engineering pattern, in accordance with their roles and use communication tools if necessary.

2.2 Conceptual Pattern Model

The semantics behind the kinds of the collaboration patterns discussed above provide with ideas about a conceptual model of human-machine collaboration pattern (Figure 1). The concepts of this model are defined in the following way.

Pattern is a description of a reusable solution for a recurring problem arising in human-machine collaboration processes.

Goal is a solution intended to be found for the problem arose in the collaboration process.

Collaborator is an individual engaged in collaboration.

Human is a collaborator of human nature.

Machine is a software entity engaged in collaboration.

Activity is behavior of collaborators necessary to achieve the goal.

Role is a position of a collaborator specifying activities that the collaborator can and must be capable to undertake.

Tool is a means that supports an activity.

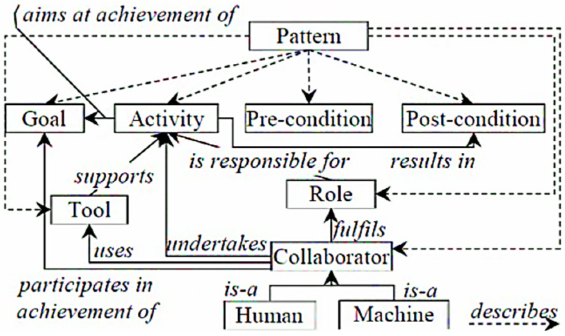

Figure 1: Conceptual model of human-machine collaboration pattern.

Pre-condition is a condition when a pattern can be applied.

Post-condition is a solution that the pattern proposes.

The conceptual model of human-machine collaboration pattern supports the following semantics. A pattern proposes a (reusable) solution for a goal achievement. A set of pre-conditions determines the possibility of pattern usage. Collaborators represented by humans and software entities (machines) participate in the goal achievement. They undertake activities necessary to achieve it, act in accordance with the roles that they fulfil, and, if necessary, use tools supporting certain activities. The activities produce outcomes some of that constitute a set of post-conditions of the pattern application. The pre-conditions do not include conditions necessary to undertake activities because these conditions do not coincide with the pattern application pre-conditions. The post-conditions represent only the activities outcomes that provide solutions (indicate the goal achievement).

2.3 Ontology

Figure 2 proposes an OWL-ontology of human-machine collaboration patterns developed based on the conceptual model (Figure 1). The ontology is implemented in the Protégé ontology editor (Musen, 2015). The part given in Figure 2 shows middle-level classes (Cabrera et al., 2015) representing relatively generic concepts and relationships relevant to the domain of collaboration pattern modelling. In this figure, the unsigned relationships coming from the class *Thing* specify the property of *has subclass*.

The ontology (Figure 3) is a specialization of the middle-level in respect to human-machine collaboration in decision support. It integrates the five kinds of the collaboration patterns and represents decision support activities according to the Simon's decision-making model (Simon, 1960, 1979). The ontology has not been fully completed yet. It does not provide complete sets of subclasses and limited to sample concepts sufficient to the discussion of the paper topic. Actually, the classification of activities, roles, and tools can be much more extensive.

Definitions of ontology concepts not given in Section 2.2 are provided below. The ontology hierarchy shows classes alphabetically. In some places, class definitions given do not follow this order to give first definitions for classes that subsequent definitions use.

Status is a stage of processing a decision support problem (a problem that the decision maker is dealing with). It can take values *new*, *projected*, *planned*, *assigned*, *in progress*, and *completed*. Status values serve as preconditions for using patterns.

Character is a nature of an activity. Character if specified by the function *f*(intellectual) → {true, false}. "True" means that an activity is of the intellectual nature; "false" reports that the activity's character is not specified, that is it can be both intellectual and non-intellectual.

Cognitive is a pattern providing a set of activities to design a process of solving an intellectual task by collaborators. The pre-conditions for pattern application are 1) the status is *in progress* and 2) in the collaboration plan (the collaboration plan is a post-condition of process plan application), the character of an activity is specified as intellectual. A

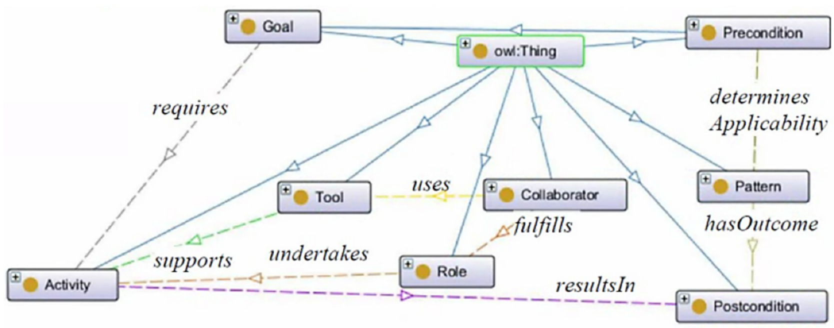

Figure 2: Middle-level of ontology for human-machine collaboration patterns.

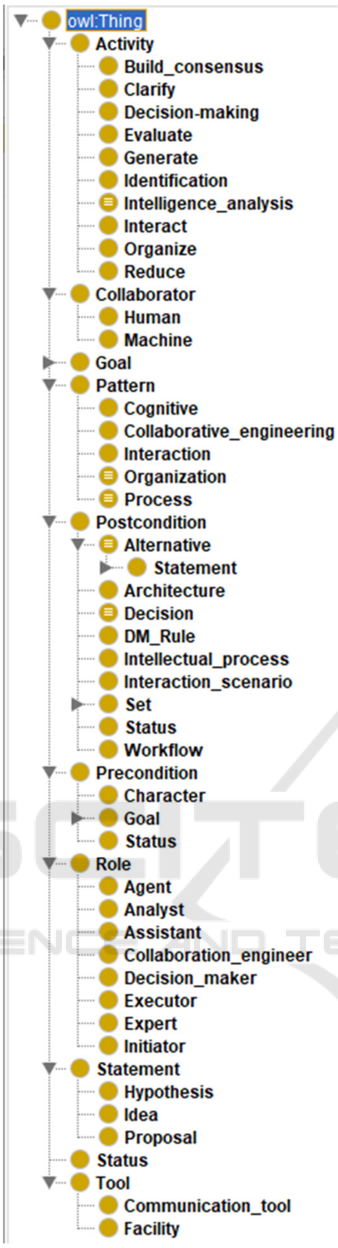

Figure 3: Ontology of human-machine collaboration patterns: asserted class hierarchy.

post-condition of pattern application is a plan for solving the intellectual task. Such a plan is a sequence of intelligent activities (e.g., generating ideas, assuring that the collaborators agree on the meaning of each other's statements, etc.) undertaking of which leads to a solution of the task.

Collaborative engineering is a pattern offering a procedure for establishing a collaborative decision-making rule. The pre-conditions for use of the pattern are 1) the status is *in progress* and 2) there is a request from one or several collaborators to make a decision. A post-condition of pattern application is a collaborative decision-making rule.

Interaction is a pattern providing tools and components of communicative acts to shape a scenario of interactions between the collaborators while their undertaking activities. The pre-conditions for use of the pattern are 1) the status is *in progress* and 2) there is a request from one or several collaborators to communicate or take activities. A post-condition of pattern application is an interaction scenario.

Organization is a pattern providing a set of architectural components to arrange a collaborative environment. The pre-condition for use of the pattern is the status has the value of *projected*. Post-conditions of pattern application are 1) architecture of collaborative environment and 2) the task status changes to *planned*.

Process is a pattern providing a workflow model for planning a goal achievement process. A pre-condition for pattern application is the status has the value of *planned*. Post-conditions of pattern application are 1) a workflow plan and 2) the task status changes to *assigned*. A workflow plan is a sequence of activities necessary to achieve the goal, roles responsible for their undertaking, collaborators fulfilling these roles, and tools needed to complete the planned activities.

Build consensus is an activity to move from having fewer to having more collaborators who are willing to commit to a proposal.

Clarify is an activity aiming at movement from having less to having more shared understanding of concepts and of the words and phrases used to express them.

Decision-making is an activity that entails identifying and choosing from alternatives an alternative that is a problem solution.

Evaluate is an activity aiming at movement from less to more understanding of the relative value of the concepts under consideration.

Generate is an activity to move from having fewer to having more concepts in the pool of concepts shared by the collaborators.

Identification is an activity on realizing a problem needs to be solved.

Intelligence analysis is an activity to make sense of information (often conflicting or incomplete) to explain an observed situation by weighing up competing hypotheses.

Interact is an activity that entails communications between collaborators or undertaking an activity by a collaborator in response to a communicative message.

Organize is an activity to movement from less to more understanding of the relationships among concepts the collaborators are considering.

Reduce is an activity aiming at movement from having many concepts to a focus on fewer concepts that the collaborators deem worthy of further attention.

Statement is a communication that expresses some meaning.

Hypothesis is a statement intended to explain certain facts or observations.

Idea is a statement describing a thought or suggestion as to a possible approach to problem solving or goal achievement.

Proposal is a statement putting forward something for consideration or discussion.

Alternative is an alternative from the set of alternatives (*Set*) presented by a statement.

Set is a set of alternatives as a post-condition of the "generate" activity.

Decision is an alternative chosen from the set of alternatives as a post-condition of the "decision-making" activity.

Architecture is architecture of collaborative environment as a post-condition of the organization pattern application.

DM Rule is a collaborative decision-making rule as a post-condition of the application of the collaborative engineering pattern.

Intellectual process is a plan for solving the intellectual task as a post-condition of the cognitive pattern application.

Interaction scenario is a specific scenario for interactions between collaborators as a post-condition of the interaction pattern application.

Workflow is a plan for goal achievement as a post-condition of the process pattern application.

Communication tool is a software and applications that facilitate information exchange between collaborators.

Facility is a tool affording some capabilities needed to complete an activity.

Agent is a role specifying activities that software agents undertake.

Analyst is a role entailing activities on analytical research and system analysis to solve problems, explain observations, make forecasts, and develop recommendations.

Assistant is a role entailing activities on providing an expert with services.

Collaboration engineer is a role entailing activities on designing a process of solving an intellectual task.

Decision maker is a role entailing decision-making activities.

Executor is a role of a message recipient, which entails activities on sending replying messages and undertaking activities initiated by a message.

Expert is a role specifying activities that humans undertake.

Initiator is a role constraining activities with the activity on sending messages to initiate interactions.

3 DECISION SUPPORT

A human-machine environment uses the collaboration patterns to recommend decisions to the user. This environment operates according to a conceptual model of human-machine decision support based on collaboration patterns (Smirnov & Levashova, 2024). It processes a task that the user formulates as a decision support problem. During task-processing, humans and intellectual agents use collaboration patterns when they intend to achieve goals for which the patterns propose solutions.

3.1 Conceptual Model of Human-Machine Decision Support Based on Collaboration Patterns

The conceptual model of human-machine decision support based on collaboration patterns (Figure 4) includes concepts introduced in the collaboration pattern ontology and concepts of *Context*, *Problem*, *Resource*, and *Task*. In the conceptual model, the concept of *Goal* has a narrower meaning.

Problem is a solution/accomplishment that needs to be found/achieved for a task/goal arose in the collaboration process.

Task is a problem to be solved as a decision support problem.

Goal is a problem arose in the course of the task processing.

Resource is an available source of aid or support that may be drawn upon when needed. *Collaborator* and *Tool* are kinds of resources.

Context is information characterising the situation of the task processing. The contextual information reports on the task processing activities, the goal of these activities, the resources involved, the roles that the collaborators fulfil, and the statuses of the task.

According to the conceptual model discussed humans and agents that are components of a human-machine environment collaborate to process jointly a task as a decision support problem. Collaboration

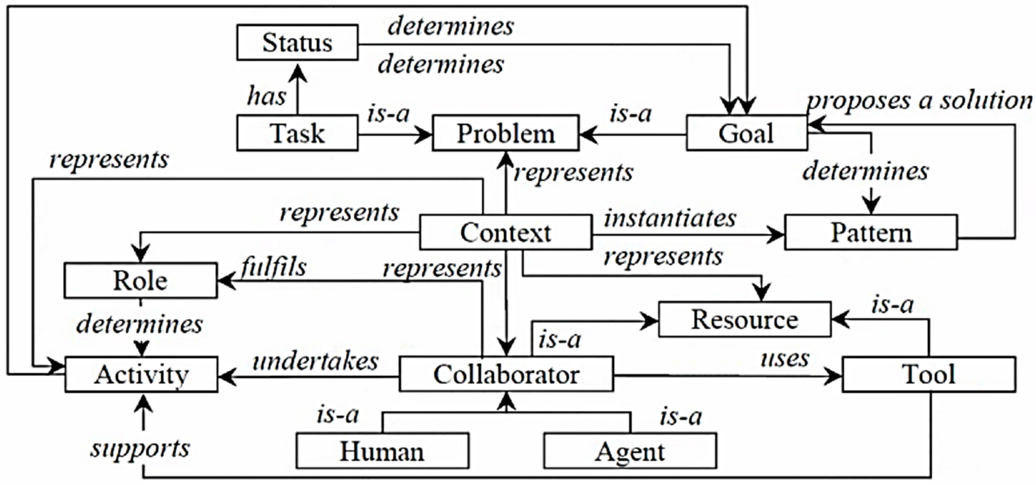

Figure 4: Conceptual model of decision support based on human-machine collaboration patterns.

patterns propose solutions for recurring goals arising during the task processing. Context provides information needed to choose and instantiate patterns. The task status and the objectives of the undertaken activities determine the current goal of the task processing. If this goal matches with a pattern goal then this pattern can be used in the given context. During the task processing, the contextual information is updated.

Kinds of activities that collaborators can undertake determine the decision support scope of the conceptual model. These activities are decision support ones and activities included in the specifications of problem solutions that the patterns propose. The *Activity* class of the collaboration pattern ontology (Figure 3) represents them.

3.2 Task Processing Using Collaboration Patterns

The human-machine environment processes the task formulated by the user. When the environment receives a task, the status of this task is assigned to *new*. This status means that the current goal is definition of kinds of activities necessary to solve the task. According to the conceptual model (Sec. 3.1), some of these activities are predefined. They are activities supposed by the Simon’s decision-making model (Simon, 1960, 1979): problem identification, the development of alternatives, evaluation of the alternatives, and choice of an alternative from the alternatives set (making a decision). The goal of the problem identification activity entails activities on task formalization and acquiring information needed to solve it. This goal as well as the goal of definition of kinds of activities are out of the consideration in the present research because no patterns offering solutions for them have been found.

After the set of activities needed is defined, the task status changes to *projected.* Further activities aimed at the task processing are supported by the human-machine collaboration patterns (Figure 5). Table 1 presents the pre-conditions when a specific pattern can be applied. In the table, task with no attribute is the task that the user formulates (task as defined in the conceptual model of decision support); intellectual task refers to any activity of the intellectual nature.

The task status of *projected* supposes that the current goal is organization of a collaborative environment, that is definition of a set of architectural components necessary to complete activities on the task processing. The organization pattern proposes a solution for this goal. The outcome of the pattern execution is architecture of the collaborative environment. As a post-condition of the pattern application, the task status changes to *planned*.

The task status of *planned* suggests that the goal of designing a plan for the task processing appears. For this goal, the process pattern offers a solution. The outcome of pattern application is a task-processing plan that the collaborators develop based on the view of the environment architecture.

Table 2 proposes an example of such a plan. In this table, *no.* means the activity number in the sequence of the activities planned. The interaction activity does not have any number because collaborators can need to interact when undertaking any activities. The tool of HMCIE refers to Human-Machine Collective Intelligence Environment (Smirnov et al., 2022), which affords a technological backing by supporting interactions between

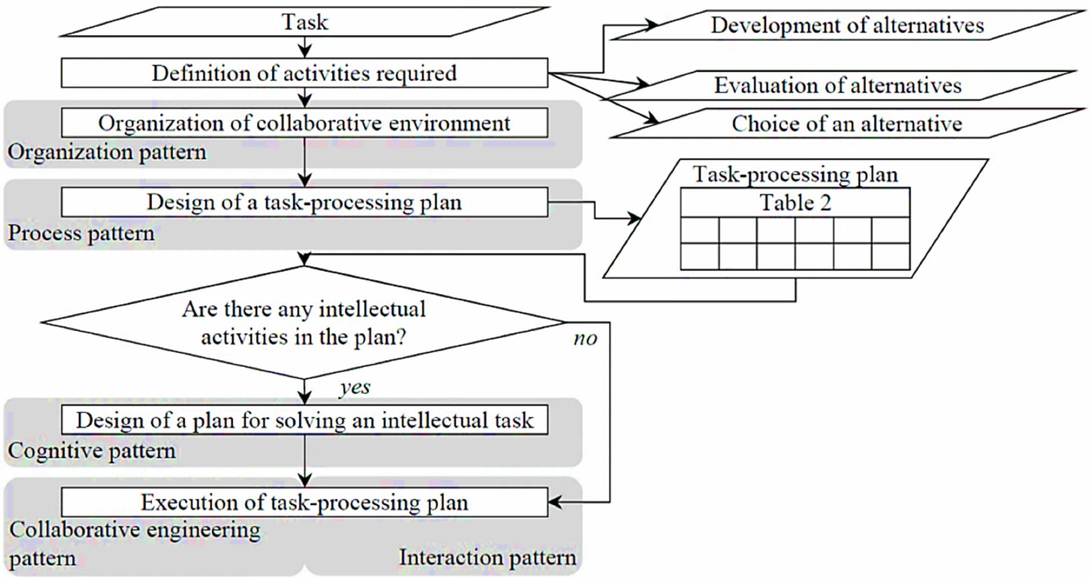

Figure 5: Task-processing based on human-machine collaboration patterns.

Table 1: Pre- and post-conditions of collaboration pattern applications.

Pre-conditions		Pattern	Post-conditions
Goal	Task status value and others		
Organizing a collaborative environment	Task status is *projected*	Organization	• Collaborative environment architecture; • Task status is *planned*
Designing a task-processing plan	Task status is *planned*	Process	• Task-processing plan; • Task status is *assigned*
Carrying out an activity aimed at accomplishment of a not-recurring goal	• Task status is *in progress*; • *f*(intellectual) → false	Not defined	Outcome from the carried out activity
Designing a plan for solving an intellectual task	• Task status is *in progress*; • *f*(intellectual) → true	Cognitive	Scenario for solving an intellectual task
Establishing a decision-making rule	• Task status is *in progress*; • Request on making a decision	Collaborative engineering	A collaborative decision-making rule
Shaping a scenario for collaborator interactions	• Task status is *in progress*; • Request on communication or undertaking activities	Interaction	Collaborators interaction scenario

Table 2: Task-processing plan (example).

no.	Activity	Nature	Role	Collaborator	Tool
1	Development of alternatives	Unspecified	Analyst	Agent	HMCIE
2	Evaluation of alternatives	Intellectual	Collaboration engineer	Human	HMCIE
			Decision maker	Human	
3	Choice of an alternative	Unspecified	Decision maker	Human	HMCIE
–	Interaction	Unspecified	Initiator	Agent, Human	HMCIE
			Executor	Agent, Human	HMCIE

collaborators, enabling collaborators interoperability, providing mechanisms for self-organization, and offering computational services that agents can use. As a post-condition of process pattern application, the task status changes to *assigned*.

When the collaborators start executing the plan, the task status changes to *in progress*.

The presence in the plan of some activities specified as intellectual (e.g., the activity on evaluations of alternatives in Table 2) means existence of the goal for solving an intellectual task. The cognitive pattern proposes a solution for this goal. For instance, to solve the evaluation task an expert fulfilling the role of *collaboration engineer* defines the sequence of activities as *organize*, *clarify*, *reduce*, *clarify*, and *evaluate*. Experts fulfilling the role of decision maker are responsible for undertaking the scheduled activities. The outcome from these activities is a set of alternatives agreed with all the experts and evaluated relative to one or more criteria.

The final activity of choice of an alternative in the task-processing plan stipulates an appearance of the decision-making goal. The collaborative engineering pattern is responsible for a solution for this goal. The collaborators follow the procedure for establishing a decision-making rule proposed in the pattern. This procedure offers a sequence of rules following which the collaborators can make a choice on a collaborative decision-making rule that they agree to use in the current circumstances. Examples of decision-making rules are majority vote, delegation, negotiation, spontaneous agreement, arbitrary, decision leader decides without discussion, decision leader decides after discussion, consensus (Gottesdiener, 2001). The result of going through the procedure proposed in the collaborative engineering pattern is a collaborative decision-making rule that the collaborators agree to use when choosing an alternative. The alternative chosen is considered the decision recommended by the human-machine environment. The delivery of this decision to the user completes the task processing process. The task status changes to *completed*.

A decision-making goal may appear not only while choosing alternatives. Any activities may need local decisions. Such a necessity is a precondition to use the collaborative engineering pattern.

Collaborators during undertaking the activities (intellectual and others) can need interactions. The interaction pattern proposes a solution how to achieve an interaction goal. This pattern offers a set of components to create an interaction scenario. The scenario describes an order of communicative acts, content of these acts, roles of the participants of the interactions, and tools supporting the interactions.

3.3 Use Case

The use case is devoted to the developing recommendations aimed at release and prevention of traffic accidents. As part of the regular inspections, the user of the human-machine environment initiates the task of developing recommendations and provides to the environment information necessary to task processing. The task status receives the value of *new*.

The list of activities necessary to solve the task as a decision support problem comprises the development of a set of recommendations for release and prevention of traffic accidents at the given site, evaluation of the recommendations from the set regarding the criteria used in the environment, and choice of a recommendation for offering the user (making a decision). Getting the list of activities changes the task status to *projected*.

The status of *projected* means that a collaboration environment is supposed to be organized and the ontology infers that the organization pattern is indented to accomplish this goal (Figure 6). This pattern is chosen to show an example of the axiomatization. Axioms for other patterns are not provided because of the space limit.

A post-condition of the organization pattern is a set of concepts and relationships that describe collaboration environment architecture. The pattern does not impose a role responsible for the instantiation of the architectural components. In the use case, the user configures the architecture. It describes:

- a set of functions:
  - activities as they are defined in the list of activities above;
  - interactions;
  - providing information;
- a set of resources:
  - a group of intelligent agents comprising:

Figure 6: Axioms for organization pattern.

Table 3: Specialization of task processing plan.

no.	Activity	Activity nature	Role	Collaborator	Tool
1	Collecting relevant information regarding the task	Not specified	Analyst	Accident analyst	HMCIE
				Signs analyst	
2	Development of a set of recommendations for release and prevention of traffic accidents	Not specified	Analyst	Recommender	HMCIE
3	Evaluation of the recommendations	Intellectual	Collaboration engineer	User	HMCIE
			Assistant	Accident analyst	
				Signs analyst	
			Decision maker	Any expert	
4	Decision making	Not specified	Decision maker	All	HMCIE
–	Interactions	Not specified	Initiator	All	HMCIE
			Executor	All	

  - accident analyst (an agent that provides information about the traffic accident site and analyses the accident reporting cards);
  - signs analyst (an agent that provides information about the road signs installed at the traffic accident site);
  - recommender (an agent that proposes criteria for evaluation of alternatives, coordinates the procedure of establishing decision-making rules, and provides recommendations for release and prevention of traffic accidents);
- a group of experts comprising:
  - decision maker;
  - FRA – a representative of the Federal Road Agency;
  - Municipal administration – a representative of the Administration;
  - Police inspector – a representative of the traffic police department;
- HMCIE tool;
- interface REST API;

- a set of roles: agent; expert; decision maker; analyst; collaboration engineer; assistant; initiator; executor.

Organization of the collaboration environment completes with the assignment of the value of *planned* to the task status. This status means that a task processing plan should be designed.

Since the recommendations are developed within a regular inspection, a plan (the example in Table 2) designed previously to solve similar tasks in the HMCIE is used. Table 3 shows the specialization of this plan to the architecture created.

The plan developed leads to changing the task status to *assigned*. The collaborators start putting the plan into actions and the task status changes to *in progress*.

At the stage of collecting relevant information regarding the task, the accident analyst provides the collaborators with the date and time of the inspection, the coordinates of the accident site, the period for which the inspection is carried out, and the reference to a collaborative meeting service. The signs analyst notifies that that at the considered location the sign "turn right" is installed at the minor road entering the major one and the signs "Bend to left" and "No overtaking" are installed at the major road (Figure 7). The accident analyst reports that the accidents of the types of rear-end or side-impact collisions are fixed at the accident site due to non-compliance of drivers with road signs. When drivers leave the minor road they violate the sign "turn right", turn to the left and due to the major road turns sharply, the view of vehicles moving on the right is difficult, which leads to collisions.

Based on the information that the analysts provided, the recommender starts activities on the development of recommendations. This agent uses the Guidelines for the release and prevention of traffic accidents (further, the Guidelines) to make recommendations. With reference to the Guidelines, it recommends to install lane delineators at the accident site.

The recommendations development activity is followed by the recommendations evaluation activity. The plan specifies the evaluation activity as intellectual. It means that a collaborator fulfilling the

Figure 7: Accident site.

role of collaboration engineer should shape a scenario of recommendation evaluation. In the use case, the user fulfils the role of the collaboration engineer. HMCIE supports the user with the cognitive pattern and with a set of possible evaluation criteria. The user specifies the evaluation scenario through a sequence of intellectual activities as Generate, Reduce and Build consensus (the ontology of human-machine collaboration patterns defines these activities). As an evaluation criterion, the user choses the criterion of advisability.

The recommendation to install lane delineators is submitted to the expert group for evaluation (the experts start their activity with *Reduce* because the activity of *Generate* was performed by the recommender). The police inspector believes that the proposed recommendation is not advisable, because if lane delineators are installed then a left turn from the major road to the minor one will be impossible, but this turn is not dangerous and is currently allowed. The others joint the inspector’s opinion. Thus, the expert group rejects the recommendation proposed by the recommender.

According to the evaluation scenario, the experts generate some more alternatives. They can also ask agents for assistance (for complex calculations, searching information, etc.) The police inspector starts the activity of alternatives generation and proposes the agent group to consider which measures can be provided for if the sigh “turn right” is removed. The recommender submits to the expert group a list of nine measures that the Guidelines provide for the collisions of the considered types on the turned sharply roads.

The experts evaluate the measures from the list (the number of the measures is reducing). As a result of the evaluation, the experts find none of the measures advisable.

The experts start developing alternatives again. The municipal administration believes that the most appropriate to equip the given crossroad with a smart crossroad system (the Guidelines do not provide for this measure). Such systems are adaptive road traffic controller used to switch traffic lights on a single (local) crossroad. The other experts support the proposal of the municipal administration. A smart crossroad system is the recommendation of the human-machine environment submitted to the user.

The use case leaves out of consideration the patterns of collaborative engineering and interaction. Collaborators apply the interaction pattern at any communications and interactions. When an interaction takes place HMCIE instantiates content of the communicative act and collaborators fulfilling the roles of initiator and executor. As well, HMCIE is the tool supporting the interactions. The collaborative engineering pattern is applied when collaborators are not aware which rule to use to make a decision. In the use case, the user provides such a rule (consensus) in the alternatives evaluation scenario.

4 CONCLUSIONS

Patterns provide reusable efficient and proven solutions for recurring problems. Pattern-based human-machine collaborative decision support is the aim of the present research. The human-machine environment uses a collaboration patterns ontology to choose an appropriate pattern when collaborators face a specific problem during their joint activities. The ontology integrates five kinds of collaboration patterns. These patterns provide solutions for recurring problems of organizing a collaborative environment, designing collaboration plans and plans for collaborative solving intellectual tasks, establishing decision-making rules, and shaping scenarios for collaborators’ interactions. Humans and software agents (machines) process a task that the user formulates to the human-machine environment as a decision support problem and apply collaboration patterns to accomplish decision support goals.

The research contributes to the problem of human-machine decision support suggesting a pattern-based decision support process. An important consequence of using collaboration patterns is that they allow collaborative decision support environments to improve their performance and make better decisions by using solutions that the patterns offer.

The shortcomings and limitations of the research concern the ontology completeness and its validity. The use case presented in the paper is very simple. It does not allow to judge about the ontology generality. As well, the potential of the ontology inference has not been fully studied. So far, it is limited to pattern offering.

The limitations shape a foundation for future research. The ontology is planned to be revised and validated using a set of application scenarios. These scenarios are expected to help to assert the ontology correctness, to identify points for possible ontology extension and provide ideas what kind of inference it should support.

ACKNOWLEDGEMENTS

The paper is due to the State Research Project no. FFZF-2022-0005.

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