

# TOWARDS AUTOMATIC PROCESS-AWARE COORDINATION IN COLLABORATIVE SOFTWARE ENGINEERING

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**Abstract:** The dynamic nature and high degree of collaboration and communication inherent in software development projects raises various challenges for the automated coordination of tasks in software engineering environments (SEEs). To address these challenges and to enable automated coordination, adaptive process-aware SEEs are required that enhance process quality while not encumbering software development. This paper describes a synergistic approach that extends a process-aware information system with contextual awareness and integrates this in a SEE. Abstract processes and the actually executed workflows are automatically and contextually associated. In particular, intrinsic and extrinsic process activities are considered and a context-based reasoning process is used to automatically derive possible (artifact) activity relations and consequences. Thus, necessary follow-up activities can be automatically governed. Our results show support for improved team coordination, greater situational awareness for developers, and process guidance as well as process navigability for collaborating software engineers.

## 1 INTRODUCTION

Recently, a trend towards greater automation and process-centricity can be observed in various industries for achieving predictable quality and efficiency (Mutschler et al., 2008). Typically, process automation is applied in domains with foreknown and predictable activity sequences such as production, business, and logistics. In the software development domain, low-level operational and collaborative workflows typically aberrate sufficiently to make process automation especially challenging.

To enhance the automated coordination capabilities in software engineering environments (SEEs), various challenges must be addressed. Software development is project-oriented and lacks the typical production stage with repeatable activities or interactions. Process-Centered Software Engineering Environments (PCSEEs) (Gruhn, 2002) support such projects with both tooling and

processes, yet these must be tailored to the unique and diverse project and product needs (e.g., quality levels, team size, etc.). While common software engineering (SE) process models have proven to be beneficial, they are typically manually implemented (especially in small-to-medium enterprises), often remain coarse in their granularity, are documented to an often general level, and rely on humans to follow and map actual low-level concrete actions and events to the appropriate higher-level process (*process navigability*).

In this paper, the following definition of process and workflow will be used: *Process Management* deals with the explicit identification, implementation, and governance of processes incorporating organizational or business aspects. *Workflow management*, in turn, deals with the automation of business processes. Consequently, a workflow is the technical implementation of a process.

A lack of automatic process guidance and support in an SEE can result in a disparity between

the specified and the executed process and lead to unpredictable process and product quality. Furthermore, uncoordinated activities may occur, affecting process efficiency. From the process perspective, activities and workflows can be roughly separated in two categories: *Intrinsic* activities are planned and executed as part of the SE process model (e.g., VM-XT (Rausch et al., 2005) or Open Unified Process (OpenUP, 2011)). *Extrinsic* activities, in turn, are executed outside the reference process model and are thus unplanned and difficult to trace or support. For an example of *extrinsic* vs. *intrinsic* workflows, we refer to Figure 1.

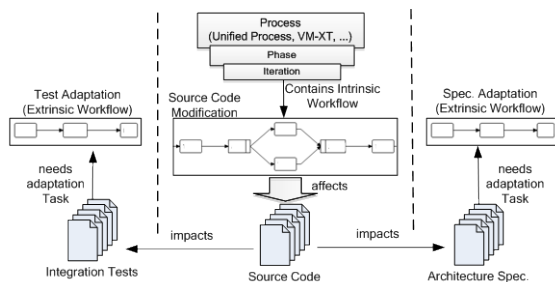


Figure 1: *Intrinsic* and *Extrinsic* Workflows.

Our previous work has described a holistic framework that applies semantic web (SemWeb) technologies to SE lifecycles (Oberhauser and Schmidt, 2007) and integrates context-awareness and PAIS technology (Oberhauser, 2010) to provide SE process support. (Grambow et al., 2010a) dealt with explicit modeling and execution support for *extrinsic* activities utilized for the automated treatment of specialized issues in SE projects. (Grambow et al., 2011) investigated consistency in the modeling of processes and workflows in SE to unite abstractly specified processes as well as the concretely and automatically supported workflows. Finally, automatic integration of quality aspects into processes was investigated in (Grambow and Oberhauser 2010; Grambow et al., 2010b).

To comprehensively support the SE process, various other aspects should also be considered: The concrete triggering and orchestration of collaboration activities is desirable. To enable configurable collaboration support, various activity dependencies should be supported. For instance, direct follow-up actions may be necessary while in other cases notification to other team members may suffice. So that *extrinsic* activities support traceability and are integrated in the SE process, they should be associated with appropriate *intrinsic* activities. In support of user contextual-awareness,

automated guidance should not only be provided for the activities in one workflow (horizontal connections between the activities), but also vertically, making the hierarchical connections between processes and workflows explicit.

In this paper, the connection of *intrinsic* and *extrinsic* activities is addressed, featuring a context-based reasoning process to automatically derive consequences of activities (e.g., impacts on other artifacts) and govern follow-up activities. Additionally, the connection between abstract processes and concrete workflows is emphasized, providing this information to the user to support *navigability* and process awareness.

The structure of the paper is as follows: the problems addressed are illustrated in the next section, followed in Section 3 with a description of the solution approach. Section 4 shows the application of our approach to the illustrated problems. Section 5 addresses the issue of the additional effort required. Section 6 then discusses related work, followed by the conclusion.

## 2 PROBLEM SCENARIO

The issues being addressed will be illustrated using two problem areas: The (horizontal) connection of *intrinsic* and *extrinsic* activities as well as the (vertical) connection of abstract and concrete process regions. *Extrinsic* workflows often involve activities triggered by, and thus dependent on, *intrinsic* activities. Thus, a coherent modeling and coordination between *extrinsic* and *intrinsic* activities is needed.

To illustrate these dependencies between *intrinsic* and *extrinsic* activities, a scenario comprising activities that imply changes to artifacts (e.g., source code or documentation files) is used. Generally, many of the activities of *intrinsic* workflows involve such changes. Artifact changes, in turn, often imply certain follow-up actions that are hitherto coordinated manually. Figure 1 depicts this scenario for a source code artifact that is part of an interface component: since the file belongs to an interface component, the applied changes possibly not only affect the unit tests of the file, but also other artifacts such as the architecture specification or integration tests. These additional activities are usually neither covered by the SE process nor governed by workflows; manual coordination can lead to impacts being forgotten and result in inconsistencies, e.g., between the source code and the tests or specifications. Even if not forgotten,

follow-up actions could benefit from automated governance and support. Furthermore, it can be difficult to determine which stakeholder should be informed about which change and when, especially considering the dynamic and diverse nature of the artifact-to-stakeholder relationship and various information needs.

The second problem regarding process integration in SE projects is to bridge the gap between the abstract high-level archetype processes and the concrete actions and workflows performed by project participants. Not addressing this challenge can hinder collaboration due to a lack of situational-awareness. This occurs especially in multi-team / multi-project environments where users often switch between projects. For a person performing a task in such an environment, it can be beneficial after such a switch to have information about the project directly available. That includes information about the project, phase, iteration, activity deadline, other activities related to the current activity, and the persons to be contacted in special situations.

### 3 SOLUTION APPROACH

This section presents the approach taken to address the aforementioned issues.

#### 3.1 Concept

The essence of our solution approach is the combination of an adaptive PAIS with SemWeb technology. A process management module is used to model both *intrinsic* and *extrinsic* workflows in an integrated way, while additional information about hierarchical dependencies and the context are stored and processed in a SemWeb-based context management module. To acquire information about the environment, low-level events that occur during SE tool usage (e.g., saving a file or changing code) are extracted and combined to derive higher-level activities such as creating a unit test. The realization of the solution approach is the Context-aware Software Engineering Environment Event-driven framework (CoSEEEK). It is comprised of modules in a service-based architecture: The *Process Management* module orchestrates SE activities for all project participants. Flexible PAISs support the coordination of activities according to a predefined process model as well as dynamic process changes (e.g., to add, delete, or move activities) in order to cope with unforeseen situations (Adams et al., 2006; Dadam and Reichert, 2009; Weber et al., 2009). For

*Context Management*, SemWeb technology was chosen due to its many advantages (Gasevic et al., 2006), especially a vocabulary including logic statements about the modeled entities and relations as well as a taxonomy for these entities. Furthermore, well-structured ontologies also enhance interoperability between different applications and agents, fostering knowledge sharing and reuse as well as enabling automated consistency checking. *Event Extraction* primarily utilizes sensors for collecting contextual state changes in external elements via events and data associated with various SE tools. These low-level atomic events and data are aggregated in the *Event Processing* module, which uses complex event processing (CEP) to create high-level events with contextual semantic value.

The combination of these modules enables CoSEEEK to automatically manage ad-hoc dependencies of certain activities in an either active or passive information distribution fashion. Active information distribution means that the system automatically assigns follow-up activities to responsible persons or teams. Passive information distribution means that the system provides retrieval capabilities and only creates notifications for users to inform them about changes. To enable such automated information distribution, a system must be capable of automatically identifying different *areas* of interest in a project. Therefore, CoSEEEK introduces different concepts for logically separating a project as illustrated in Figure 2.

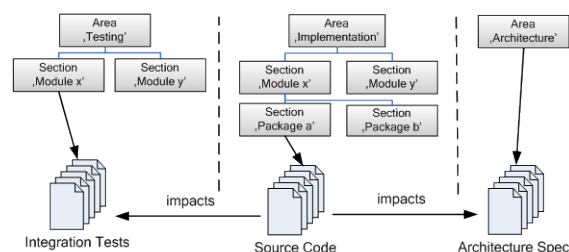


Figure 2: Area / Section Example.

Areas of a project such as ‘Implementation’ or ‘Architecture’ can be explicitly defined and further segregated into *sections*. These definitions can be tailored for projects and automatically supported. For example, to split up the ‘Implementation’ *area*, the structures of the source code can be scanned creating *subsections* of the *area* alongside the package structure of the source code.

Information distribution comprises a three-phased approach:

1. Determine projects *areas* that are affected by an activity.

2. Determine the concrete target that is affected within the *area*.
3. Determine the information recipient that is responsible for the chosen target.

The first step is configurable and can take into account various facts to determine which *areas* are affected. For the aforementioned scenario, such a configuration can be ‘Search for affected areas in case of technical issues if an activity implies a change to an artifact and the artifact is a source code artifact and belongs to an interface component’.

The second step takes the selected *areas* and the target of the applied activity as input. This target can be a concrete artifact as in the given scenario or a more abstract *section* of the project as, e.g., a module. The concrete target is then determined via relations of the different *sections*. An example for this can be implementation and testing: the testing (structural or retesting) of a module relates to its implementation. In the given example, the relation does not need to be in place for the concretely processed component, but can also be found if one exists elsewhere in the hierarchy. If there is no direct relation from the processed source code artifact, the system looks for other components the file belongs to, e.g., the module.

Once the target for the information distribution or follow-up action is determined, the responsible persons or teams must be discovered. For example, if the target of the follow-up action is a source code file with no direct responsible party defined, the overlying *sections* are also taken into account, e.g., the encapsulating module. If a team is responsible, the information is referred to the designated contact of that team for further distribution.

Finally, CoSEEEK tracks the workflow progress at different levels of abstraction (concrete workflows, iterations, phases). Thus, the collaboration of team members is promoted by providing them with context information fostering situational awareness. This is especially useful in multi-project environments where members switch between different projects. Hereby a bidirectional association between the abstract project level, the process level, and the level where concrete activities are executed is established.

## 3.2 Realization

To realize the solution approach, the AristaFlow BPM Suite (formerly ADEPT2) (Dadam and Reichert, 2009) was chosen as PAIS technology due to its correctness-by-construction principle and its process adaptability features (e.g., robust support for

ad-hoc process changes during runtime). CoSEEEK makes use of these advanced process change facilities and integrates them into its framework via the AristaFlow API. For structuring and accessing contextual information, the *Context Management* module employs an OWL-DL ontology as well as SWRL (World Wide Web Consortium, 2004) rules and SPARQL (Prud’hommeaux and Seaborne, 2006) queries. Programmatic access to the ontology is provided by the Jena API (McBride, 2002) and reasoning by Pellet (Sirin et al., 2006). For *Event Extraction*, Hackystat (Johnson, 2007) was used due to its Java support and its sensors for various tools and applications. Events are processed and complex events generated using Esper. For *Data Storage*, the tuple space paradigm (Gelernter, 1985) was implemented as an XML space based on the eXist XML database.

To support an abstract process and context model, an ontology adapting various features and concepts of the Software Process Engineering Metamodel (SPEM) (Object Management Group, 2008) was created. Certain SPEM features were omitted to reduce complexity or because some aspects are managed extraneous to the ontology in other CoSEEEK modules.

### 3.2.1 Automatic Workflow Coordination

To realize automatic workflow coordination, the system must be aware of the *intrinsic* activities and workflows that may cause the need for coordination. These workflows, which are based on the users’ *Assignments* and are part of the SE process, are created within CoSEEEK or imported from external process management tools (e.g., MicroTool inStep) in use by an organization. In this paper, OpenUP is used as a SE process model. *Assignments* concerning software development are captured by the ‘Develop Solution Increment’ workflow in that model and imply certain activities (called *AssignmentActivities* in CoSEEEK) like ‘Implement Solution’ or ‘Implement Tests’. To exemplify the governance of *intrinsic* workflows, Figure 3 shows a snippet of this workflow modeled in AristaFlow.

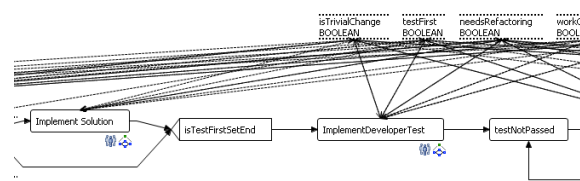


Figure 3: Snippet of an *Intrinsic* Workflow modeled in AristaFlow.

CoSEEEK features semantic enhancements of process management concepts to enable comprehensive automated workflow governance. All workflows are mirrored in the ontology using the following concepts: The *WorkUnitContainer* mirrors a workflow and the *WorkUnit* mirrors an activity. The *Assignment* and *AssignmentActivity* concepts are separated, where the *Assignment* is related to a *WorkUnitContainer* and the *AssignmentActivity* is related to a *WorkUnit* as shown in Figure 4. When an *Assignment* including the other concepts (relating *WorkUnitContainer*, *WorkUnits*, and *AssignmentActivities*) is created or imported, the procedure to detect possible impacts is invoked. The detection is based on the *AssignmentActivities* and their relations to project components like artifacts. If an impact can be detected, the trigger for a follow-up action is stored as part of the *AssignmentActivity* in the ontology to be executed after the execution of the latter. The information on affected project components is derived from the *Assignment* (e.g., ‘Change module X’) and may be coarse-grained at that point. It can be detailed later when the activity is executed because at that time the affected components become known by the system.

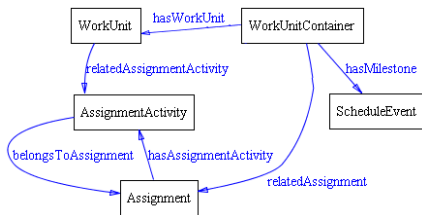


Figure 4: Ontology Section used for Navigability.

To enable automated detection of follow-up actions, different facts have to be modeled in the ontology:

- (1) The project has to be hierarchically split up into components like areas or modules.
- (2) Connections of different relating components must be established as, e.g., the fact that testing a module relies on implementing that module.
- (3) Information that can be used to clarify under which circumstances one area affects another must exist.
- (4) Different components must be classified, as, e.g., a package in the source code that realizes the interface of a component.

The concepts utilized for modeling these facts are shown in Figure 5.

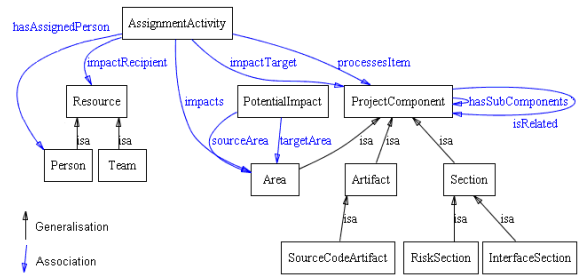


Figure 5: Ontology Section used for Workflow Coordination.

The separation of the project into logical components (1) is done by the *ProjectComponent*, which has various subclasses. In Figure 5, *Area*, *Section*, and *Artifact* are shown. An *Assignment-Activity* that is executed by a *Person* processes a certain *ProjectComponent*. A *ProjectComponent* has a responsible *Role* taken by a *Resource* that is a *Team* or a *Person*. To enable custom configurations of the possible impacts of an activity, different concepts are used: The *PotentialImpact* captures potential impacts between *Areas* (3) like ‘When a technical change happens to a component in Area a, this has an impact on Area b’. *Project-Components* of different *Areas* can be related to each other (2) like ‘Testing of module x relates to the implementation of module x’. Figure 6 illustrates the *PotentialImpact* as well as the relations (curved lines). Many of the concepts also have asserted subclasses for further classifying them (4) that are dependent on certain conditions. For example, if a *Section* is connected to problems that were detected by CoSEEEK (e.g., code problems indicated by static analysis tools), the reasoner automatically infers that it belongs to the concept *RiskSection*. The three steps of the procedure are realized using the semantic techniques shown in Table 1.

Table 1: Procedure realization for responsible party detection.

Detection Steps	Realization
1. Impact Areas	SWRL Rule 1
2. Concrete target	SWRL Rule 2
3. Responsible person	SPARQL Query 1

A concrete example for all steps is given in Section 4 along the problems defined in Section 2. As aforementioned, the presented approach features concrete follow-up activities as well as notifications about the changes. Since both procedures are very similar and due to space limitation only the more complicated case of follow-up activities is explained here. The first step, the detection of impacts on other

*areas* is realized via SWRL Rule 1 that can be custom defined to match the needs of the project or company. Therefore, the development of a GUI for easy definition of rules is planned. The rule establishes a connection called ‘impacts’ between the *AssignmentActivity* and the affected *Areas*. An example for such a starting rule is shown in Section 4. The established connection is utilized in the SWRL Rule 2 that, establishes a connection called ‘impactTarget’ between the *Assignment-Activity* and a *ProjectComponent* as shown in the following:

```
SWRL_Rule_2:
impacts(?activity, ?area) ∧
allInferredSuperComponents
(?targetComponent, ?area) ∧
processesItem(?activity,
?sourceComponent) ∧ isRelated(
?sourceComponent, ?targetComponent)
→ impactTarget(?activity,
?targetComponent)
```

The rule looks for a component in the target *area* that is related to the component processed by the activity. That component is taken as the concrete target. The rule makes use of transitivity in the defined ontology structure: The hierarchical connections between the different *Project-Components* are defined transitively and the reasoner is used to infer all sub or super components that are stored in separate relations (as used in the rule by the relation ‘allInferredSuperComponents’). Via transitivity, it is also possible to not only look for relations of the currently processed component, but also for all components above, creating multiple impact targets with another SWRL rule.

When the concrete target is determined, the responsible *Resource* is queried via SPARQL Query 1 and stored in the *AssignmentActivity*. Due to space limitations, the SPARQL query is omitted here.

After the execution of an *AssignmentActivity* with a configured follow-up action, the *Context Module* writes a “Process Start Event” (containing the relating user ID and information about the task relating to it) to the XML Space. The event is then automatically received by the *Process Module*, which starts the appropriate workflow with the tasks for the appropriate *Person*. When an activity becomes activated during workflow execution, a corresponding task becomes available for the related *Person*. The task information is encapsulated in an event in the XML Space that is automatically retrieved by a PHP-based web application that displays the task list of the respective *Person* in a

web browser or within an IDE such as Eclipse (see Figure 7).

### 3.2.2 Navigability and Situational Awareness

To provide context information for situational awareness, a set of queries to the ontology was defined. Figure 4 depicts the corresponding subset of the ontology. It shows the concrete classes for modeling the development process. All work that is done within a Project is modeled via the *WorkUnit*, *WorkUnitContainer*, *Assignment*, and *Assignment-Activity*. These concepts are used for modeling the abstract process regions (e.g., projects, iterations) as well as the concrete regions (e.g., workflows, activities) and provide a connection between them. *WorkUnitContainers* can have Milestones and *AssignmentActivities* can have relations to *ProjectComponents* as also shown in Figure 5.

By utilizing the associations of these classes, various queries become possible. For example, in an agile project that is separated into phases and iterations, one can query the milestone of the project phase in which the current iteration takes place or query the project to which the actual workflow belongs. Navigability is not only possible from the concrete to the abstract process regions, but also in the opposite direction, featuring queries such as retrieving all active activities for a project phase. The information from the ontology is provided in a standardized way using SPARQL.

For internal usage, CoSEEEK encapsulates information in events stored in the XML Space for inter-module access. For external applications, in turn, a web service interface provides access to all queries. As a direct benefit to users, *navigability* is integrated into the CoSEEEK GUI, showing all abstract concepts to which the currently processed activity belongs.

## 4 APPLICATION EXAMPLE

For validation our solution, the scenario from Section 2 is used. Prior work investigated the practicality of technical aspects such as performance with regard to CoSEEEK realization elements (Grambow et al., 2010a, 2010b).

As illustrated in Section 2, the modification of a source code artifact that belongs to the interface of a component is the target. This change can require adapting integration tests or architecture documents. Dependent adaptations usually do not appear in the

workflows belonging to SE processes and are thus *extrinsic* workflows. The given example illustrates the case for the follow-up actions regarding the tests as shown in Figure 6.

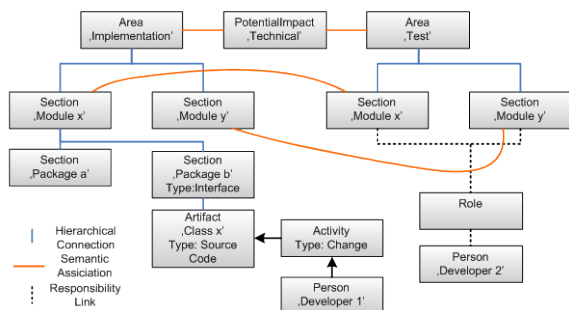


Figure 6: Application of CoSEEEK to the problem scenario.

Figure 6 shows two defined project *areas* ‘Implementation’ and ‘Test’. There is a *PotentialImpact* configured for relating technical issues from ‘Implementation’ to ‘Test’. For the implementation *area*, there are different modules with different packages. Modules x and y also appear in the test *area* and relate to the counterparts in the implementation *area* as indicated by the curved lines. Developer 2 is responsible for the tests of Modules x and y. Assume now that Developer 1 changes a class belonging to Package b, indicated by the change activity. The first step of the detection procedure for follow-up actions in this example is done by SWRL Rule 1 that takes into account the *PotentialImpact*, the fact that Package b is an interface component, the type of the activity, and the type of artifact that was processed.

```

SWRL_Rule_1:
sourceArea(?impact, ?source) ^
targetArea(?impact, ?target) ^
allInferredSubComponents(?source,
?subComp) ^ InterfaceSection(?subComp) ^
allInferredSubComponents(?subComp,
?artifact) ^
processesItem(?activity, ?artifact) ^
ChangeActivity(?activity) ^
SourceCodeArtifact(?artifact)
→ impacts(?activity, ?target)

```

The rule determines that the activity affects the test *area*. With this information the second step can be performed. As mentioned in Section 3.2.1, two different SWRL rules can be used for this. One only looks for an impact target relating to the processed component, while the other also takes into account all overlaying components. In this example, the

second rule detects an impact target: in the ‘Implementation’ *Area*, the source code file belongs to Package b that belongs to Module x, which has a relation to the ‘Module x’ Section in the *Area* ‘Test’.

After determining the concrete target, the recipient of the follow-up activity can be queried via SPARQL. In the given case, it is Developer 2.

The information about the component, the kind of change applied to it, and the user ID of the responsible person are forwarded via an event to the *Process Management* module, which starts a workflow to govern the desired activities for the respective user. This workflow can be based on a predefined workflow template or be custom built from a problem-oriented declarative definition as described in (Grambow et al., 2010a). When a task of that workflow becomes available to a user, an event is automatically distributed to CoSEEEK’s web GUI shown in Figure 7.

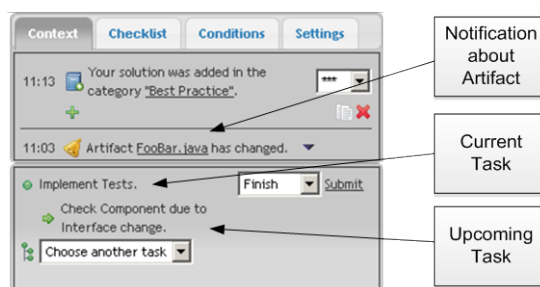


Figure 7: CoSEEEK Web GUI.

All tasks are shown at the bottom of the GUI. In order to avoid subjecting a user to information overload, only the current task and the next upcoming task proposed by the system are shown. The user may change the selection of the next upcoming task via a dropdown list. In this example, the current task is “Implement Tests” from an *intrinsic* workflow, while the next upcoming task is “Check Component due to Interface Change” from an *extrinsic* workflow. The upper part of the GUI contains information provided by the framework. Among other things, it can be used to display additional task information and notifications about components for which change notification is configured. This example shows the notification about the change of an artifact.

Automatic coordination, however, is not always necessary and not feasible in all cases. In other scenarios (see Section 2), team members could use context information to foster collaboration. For example, in an environment where persons take part in multiple projects concurrently, it might be helpful

to retrieve contextual information when switching projects. This option is provided by CoSEEEK, which shows all upper processes to which the current activity belongs.

In summary, the resolution provides collaboration capabilities via coordination of *extrinsic* and *intrinsic* workflows in a PAIS and the availability and use of context information via SemWeb technology. Activities that are often omitted and not modeled in PCSEEs are explicitly modeled and automatically coordinated via CoSEEEK. Additional support is provided for software engineers working in multi-project environments by making navigability information available and fostering situational awareness.

## 5 MODELING EFFORT

Additional modeling effort is imposed by the approach. The processes are modeled not only in the PAIS but also in the ontology. Configuration is required for how various follow-up actions should be treated. To keep the effort reasonable, some default functions and definitions are provided in the framework. The semantic enhancements to Process Management (*WorkUnitContainers* and *WorkUnits*) are generated automatically from the workflow templates of the Process Management module. To gain an awareness of project artifacts, scans are conducted on specified folders. Since the system is aware of SE tools via sensors, it becomes aware of all processed and new artifacts, and the information is acquired on the fly. An initial set of *ProjectComponents* is provided and the structure of certain *Areas* can be imported, e.g., from a folder structure or a source code package structure. Examples include the *Areas* ‘Implementation’ and ‘Test’: the system can automatically read the package structure and thus import references to all artifacts into the ontology that are hierarchically organized under various *Sections* that are created from the different packages in the source code. The names of the packages can be automatically matched to those to which they may relate. For instance, relations between ‘Test’ packages and ‘Implementation’ packages can be automatically established.

## 6 RELATED WORK

With regard to PCSEEs, (Adams et al., 2006) describe SOA-based extensible and self-contained sub-processes that are aligned to each task. A dynamic runtime selection is made depending on the context of the particular work instance. OPEN (Henderson-Sellers, 2002) is a CORBA-based PCSEE that addressed business, quality, model, and reuse issues. DiME (Koenig, 2003) provides a proprietary, integrated, collaborative environment for managing product definition, development, and delivery processes and information. CASDE (Jiang et al., 2007) and CoolDev (Lewandowski and Bourguin, 2007) utilize activity theory for building an environment supporting collaborative work. CASDE features a role-based awareness module managing mutual awareness of different roles. CoolDev is a plug-in for the Eclipse IDE that manages activities performed with other plug-ins in the context of global cooperative activities. CAISE (Cook et al., 2004) is a collaborative SE framework with the ability to integrate SE tools. CAISE supports the development of new SE tools based on collaboration patterns.

An industry approach for collaborative development is provided by the IBM Jazz / Rational Team Concert products (IBM Jazz, 2010). Jazz offers an infrastructure for distributed development including the technical basis for integration of various clients as well as data and services. It enables comprehensive project, bug, and configuration management as well as event notifications, traceability, and other software development related tasks. Team Concert is a collaborative software development environment built on Jazz technology utilizing its capabilities to provide an integrated solution for software configuration management, work item management, and build management with additional features like customizable dashboards, milestone tracking, or process templates for common processes.

In contrast, CoSEEEK offers a combination of features not found in the aforementioned approaches: workflow guidance is not only offered for activities contained in development processes (*intrinsic*), but also for *extrinsic* activities, which are not explicitly modeled within those processes. The holistic combination of all project *areas* in conjunction with SemWeb technology also enables the framework to provide intelligent decisions and thus a higher level of automation. The tight integration of PAIS technology with context knowledge not only enables the distribution of



information, but also the automated support and governance of activities in adapted workflows.

Modeling SE processes in SemWeb technologies can enhance reuse and leverage available tooling, as shown by (Liao, 2005). (Soydan and Kokar, 2006) used an ontology for CMMI-SW assessments, and (Calero et al., 2006) used ontologies for the Software Engineering Body of Knowledge (SWEBOK). CoSEEEK leverages SemWeb usage for real-time contextual-awareness in SEEs to improve SE workflows and collaboration and for supporting *navigability* and situational-awareness. The main differentiation criterion to other approaches that utilize ontologies for collaboration is the holistic integration of all project *areas* to foster synergies, and in having collaboration not be the sole focus of the framework (e.g., software quality assurance is adaptively integrated as described in (Grambow et al., 2010b)). Other approaches have collaboration via ontologies as their focus, as shown by (Wang et al., 2007) and (Yao et al., 2007). Yao et al. present a workflow-centric collaboration system whereby the main component is an ontology repository with ontologies of different abstraction levels. The process model is based on enhanced Petri nets and thus lacks dynamic adaptability. Wang et al. present an Ontology for Contextual Collaborative Applications (OCCA) that provides a generic semantic model specialized for distributed, heterogeneous, and context-aware environments. In contrast to these approaches, CoSEEEK utilizes querying and reasoning capabilities over an ontology and integrates these with process management to support automated dynamic process governance.

## 7 CONCLUSIONS

The high degree of dynamic collaboration in SE raises challenges for automated support of process awareness and guidance in SEEs. Currently, SEEs lack contextual information and integration, especially with regard to adaptive collaboration and workflows. The presented CoSEEEK approach extends adaptive PAIS with semantic web technologies and advanced event processing techniques. CoSEEEK explicitly models and manages *intrinsic* as well as *extrinsic* activities. These are coordinated, and information and activity distribution can be individually configured. A dynamic information distribution strategy enables related components to be associated even if no direct relations between the source component and the

target component exist. The responsible person for a component can also be determined if no direct responsibility is defined. The procedure neither requires rigidly predefined information channels nor does it rely on comprehensive and fine-grained predefined information on relating artifacts or responsible persons. The configuration effort to enable automated coordination is reduced by the ability to automatically import needed information and via the inference and reasoning capabilities.

*Extrinsic* activities that have hitherto typically been excluded from modeling are now guided by workflows. These capabilities enable the integration of general process models with concrete activities even if they are *extrinsic* to a particular SE process. As collaborations become more complex, support for situational awareness and *navigability* becomes vital. Manual *process navigability* through abstraction levels within the collaboration is enabled with live querying capabilities on the contextual information in the ontology.

The presented scenario demonstrated a situation where improved coordination and situational awareness were supported while providing process guidance and *navigability* for collaborating software engineers, enhancing process quality.

Automated support for coordinated collaborative software engineering, with its human interactions and continuously changing tool and process environment, will remain a challenge. Further research potential lies in the aggregation and utilization of available contextual information to increase process effectiveness and efficiency. Future work will investigate industrial usage in production environments with our project partners. For efficiency, a planned new feature will aggregate related tasks and, when a predefined threshold is reached, trigger a workflow instance with the cumulated task information. More complex task treatments can also be designated: e.g., in an agile project, emergent uncompleted tasks can be collected and stored in a backlog to inform team members at the beginning of the next iteration. A GUI for assisted definition of the SWRL rules for the first step of the procedure is also planned.

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