Testing Complex Business Process Solutions

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Abstract—**Today's business climate requires you to constantly evolve IT strategies responding to new opportunities or threats. While the fundamentals of IT - reliability, availability, security and manageability – are still crucial, rapid results are mandatory for business success. These business challenges can be solved by acting with agility – striking the proper balance between the introduction of leading-edge technology and the pragmatic application of IT. In this paper, we introduce a testing framework for business solutions dealing with complex and dynamic IT environments. Our framework supports test-driven development which facilitates an incremental construction of reliable business solutions that can be adapted to changes of a business environment easily. We compare our testing framework with model-driven development approaches and show how we applied our framework to an event-driven process management platform called SARI (Sense And Respond Infrastructure).**

I. Introduction

THE emergence of e-business has dramatically changed the context in which information systems are used for providing a better service to customers. With the increased rate of change possible in e-business, it has become essential that business processes can be adapted according to the changing business environment more quickly than in the past. Static processes that cannot adapt to changing needs are a liability. Enterprises are scrutinizing the effectiveness of their business and IT operations to identify opportunities for greater efficiencies. Sense & Respond [5] and Event Management [1] have emerged as disciplines to enable enterprises to manage time-sensitive and dynamic business processes which are highly integrated with information systems.

A major challenge for systems in continuously changing business environments is to keep them robust and operational for critical business processes. In this paper, we introduce a framework for testing the functionality of event-driven and time-sensitive business processes. With our testing framework we address the following issues:

- Validation of the quality and correctness of a process model
- Automated testing of business process execution within a distributed environment
- Testing side effects from modifications of a process model
- Detecting and diagnosing performance problems of process deployments
- Facilities for investigating discovered malfunctioned processing steps

Traditional business process management solutions use simulation for analyzing the quality of process models. Process simulation is a top-down approach for process reengineering programs and provides valuable insight in variations of process models. However, process simulation is only as good as the underlying assumptions for the simulation parameters. In this paper, we propose a testing framework which follows a bottom-up approach for gaining insight in existing business processes or business process solutions in development. Starting from an existing process model, we use our framework to validate it with tests bottom up. For the testing, we not only consider the description of the process model, but also runtime aspects are considered as

- Verifying the outcomes of processing steps by actually invoking services and components,
- Measuring the throughput of processing engines,
- Testing the robustness of the process management system during failover scenarios,
- Testing changes for configuration settings such as parameters for processing engine, business rules, or resource assignments.
- Creating simulation tools and mockup strategy to replace complex business environments like SAP during test scenarios

The remainder of this paper is organized as follows. In Section II, we discuss test-driven development of business solutions and compare it with model-driven development. In Sections III – V we give an overview of our testing framework for testing Sense & Respond processes, show the testing environment we used and demonstrate a testing scenario with our proposed framework. Finally, in Section VI we conclude our paper and give an outlook for future work.

II. Test-Driven Development For Business Solutions

Looking back the way software has been developed – particularly considering the last years – dramatic changes can be observed. Starting 2001 with the "Agile Manifesto" [6] agile software developing processes became commonly accepted development strategies, hence having significant impact on the way software projects are planned, managed and implemented nowadays. Agile methodologies like XP [2], Scrum [3] or Crystal [4], which formed the foundation for the

Manifesto, strongly emphasize the role of software tests by integrating them early into the software development instead of just "accepting" it as part of software production at the end of an iteration or the whole process. Parallel with the new software development processes, also new software architectures appeared on the scene, driven by the widespread usage of Internet related technologies. Particularly noteworthy are so-called Service Oriented Architectures (SOA) [9]. SOA has gained popularity as new software engineering paradigm and arose from the necessity of creating components providing clearly defined small pieces of functionality that later on can be assembled into complex (usually distributed) applications. Splitting up complex applications into smaller components and services aims not only at increased reusability but should also leverage composing and refactoring (business) processes. Evidently, this approach fit well for fast changing environments, where business systems have to continuously adapt to new business needs.

Service-oriented systems usually don't try to substitute systems that are already installed in companies; much more they try to provide an infrastructure that enables to utilize older applications as services. Taking all this into account, it appears to be obvious, that such systems often result in an operational environment with complex dynamical behavior which is hard to predict and evaluate [13]. Hence (automatic) testing of an infrastructure is a difficult issue. An additional challenge for such environments is, to bring the requirements defined by a user or several stake holders into a model that can be understood from technical architects, developers and of course testers (which is the main focus of this work).

Using models to design systems help us understanding complex problems and its potential solutions through abstraction. Selic proposes in [12] the following five characteristics of engineering models for building complex systems (see Table 1).

With our testing framework, we want to address these characteristics in different ways as traditional model-driven development approaches. Figure 1 shows a comparison of a model-driven and test-driven development of business solutions.

Abstraction: A model is always a reduced rendering of the system that it represents. By removing or hiding detail that is irrelevant for a given viewpoint, it lets us understand the essence more easily.
Understandability: Is a direct function of the expressiveness of the modeling form used (expressiveness is the capacity to convey a complex idea with little direct information). A good model provides a shortcut by reducing the amount of intellectual effort required for understanding.
Accuracy: A model must provide a true-to-life representation of the modeled system's features of interest.
Predictive: You should be able to use a model to correctly predict the modeled system's interesting but non-obvious properties, either through experimentation (such as by executing a model on a computer) or through some type of formal analysis, which depends greatly on the model's accuracy and modeling form.
Inexpensive: It must be significantly cheaper to construct and analyze than the modeled system.

Table 1: Characteristics of Engineering Models

The focal point of model-driven development is to describe business solutions ideally with models without any consideration of platform specific details (= Platform Independent Models) and automating the transformation of these models into executable software components. Model-driven development holds promise of being the first true generational leap in software development since the introduction of the compiler.

One of the biggest challenges for model-driven development is the transformation between the platform independent and platform form specific models. Roundtrips between these models are very difficult and sometimes it is even not feasible to maintain the traceability between model artifacts. In particular, the traceability links from platform specific models back to platform independent models are often missing which makes it difficult to create a true-to-life representation of the modeled system. Model-driven development approaches often only predict how platform independent models will map into an execution environment.

With our testing framework, we make this process also

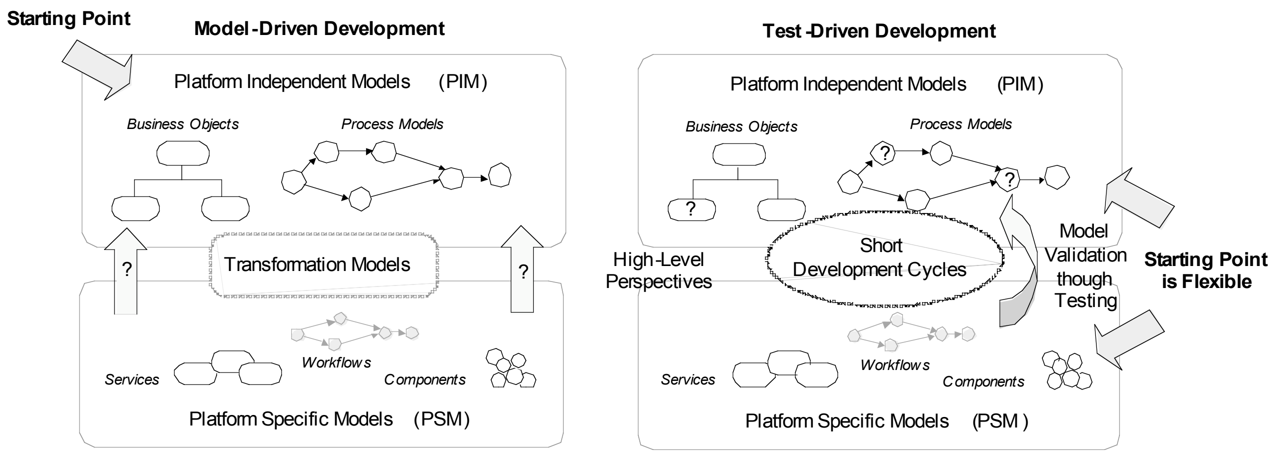


Figure 1: Model-Driven Development vs. Test-Driven Development

reversible and further consider how an existing execution environment conforms to a platform independent model. Test-driven development does not assume that all platform specific models (which include for instance also code) are generated in a top-down fashion. A software engineer can decide whether to start with a model which provides a high-level perspective of the system, or with platform specific artifacts such as software components.

A software engineer can use software tests to validate the behavior of an existing system with platform dependent and independent models. Although it would be desirable to validate all details of a platform independent model, this is often too time consuming and not cost-efficient. Software tests facilitate users to test out various aspects of the system behavior that are relevant to them. As we will show in the next sections, they can do this a various abstraction levels.

III. Testing Framework For Sense And Respond

Before we introduce our testing framework, we want to briefly introduce the target system. The testing framework is tailored to an agile business process management platform called SARI (Sense And Respond Infrastructure). We want to briefly give a overview of the SARI system in order to better understand how the testing framework was applied.

A. A Brief Introduction of SARI

SARI's main objective is to help organizations to control and monitor their business processes and IT systems in order to respond to business situations or exceptions with minimal latency. SARI is able to continuously receive, process and augment events from various source systems, and transforms in near real-time these events into performance indicators and intelligent business actions. SARI is a distributed, scalable platform, which allows modeling and executing various forms of Sense and Respond processes (see Figure 2).

The data processing is controlled by "Sense & Response loops" which can be divided into 5 stages. During the "Sense" stage events are continuously captured and transmitted to the SARI system where they are initially unified before the actual data processing starts. In the "Interpret" stage, the captured events are transformed into meaningful business information, such as key performance indicators, business situations and exceptions. The next stage is the "Analysis" of the generated business information in order to determine root causes for business situations and exceptions. The analysis has the goal to find the best possibilities to improve the current situation of the enterprise. The analysis also allows to predict the business performance and risks for making changes to the business environment. In the following "Decide" stage, the best option for improving the current business situations and determines the most appropriate action for a response to the business environment is chosen. Finally, in the "Respond" stage, the decision made has to be implemented in the business environment by communicating the decision as a command or suggestion (e.g. by e-mail), or by directly adapting and reconfiguring business processes and IT systems. During the processing in the 5 stages, business information is continuously generated and decisions are made to which a response follows. The response has an effect on the source systems (from which SARI originally might have received events) and consequently also on the performance and the success of the organization.

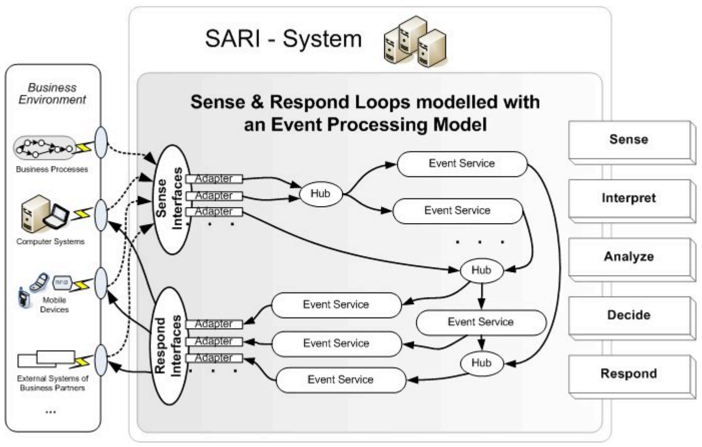


Figure 2: SARI Sense & Respond Loops [11]

Using the SOA approach, we model in SARI Sense & Respond loops with a pool of services and establish the infrastructure that enables a robust communication and interaction between them. SARI uses an event processing model (EPM) for modelling Sense & Respond loops. Similar to a construction kit, the EPM offers various building blocks which can be used to construct a Sense & Respond loop. Dependent on the requirements and the business problem, these building blocks can be flexibly conjoined or disconnected. Links between the building blocks represent a flow of events from one service to the next. Typical building blocks are event services for various data processing tasks in each stage. For more details please see [11].

B. Overview of the Testing Framework

In this section, we introduce a testing framework for Sense & Respond which was tailored to the SARI system. Our testing framework includes classes of tests with different abstraction levels (see Figure 3).

Starting with "Code & Unit Tests" at the lowest abstraction level, we use a "bottom-up" approach for testing a wide range of characteristics and functionality of the system. This is different to the "top-down" testing approaches (e.g. used for Model Driven Development [12] which uses high-level models and the customer requirements as starting point for the testing. The problem with "top-down" approaches is that a complete model and sufficient details for customer requirements have to be available in order to start the testing. On the other hand, with a "bottom-up" approach, we first test available parts of the system and we work up the ladder until we finally reach the end-to-end tests for testing a full business process. With each new abstraction level, the complexity for tests is increasing since the scope of the test scenarios is expanding.

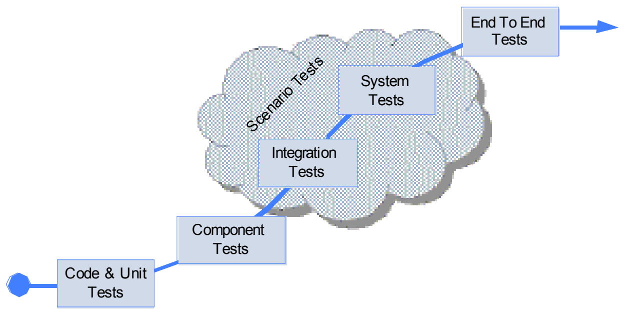


Figure 3: SARI Framework Tests

Code & Unit Tests: These are the foundation of our testing framework and ensure that each implementation unit of the application works correctly. Usually, an implementation unit consists of a class. The aim of unit tests is to ensure the correct behavior and results of implemented functionality on code level. Unit tests facilitate significantly the code changes, since they are the "insurance" for a developer that a code is working correctly. If a unit test doesn't continue to work, a developer immediately knows that a change within the system "broke" the code base.

Component Tests: SARI is a modular system and is decomposed into functional or logical components with well defined interfaces used for communication across the components. Examples for such components are Event Adapters and Event Services (see also Figure 1). Component tests only consider the interfaces of components and test typical communication scenarios with these interfaces.

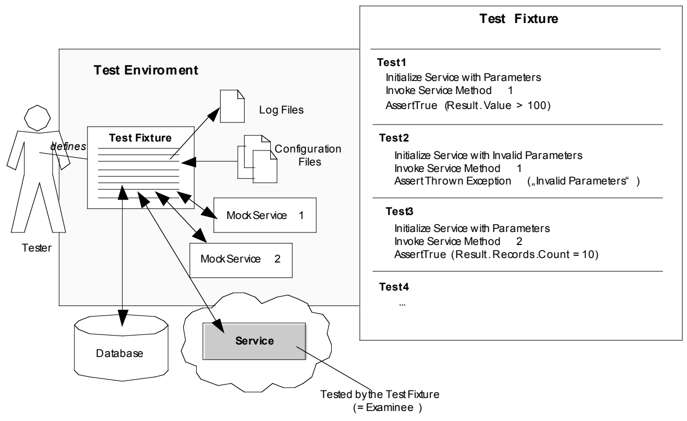
Integration Tests: The next level is to test the integration of different parts of the system. At this level of abstraction, we can observe significantly higher complexity of the test cases, due to the possible interactions of a larger number of components (which is typical for a Service Oriented Architecture).

System Tests: The previous tests focused on testing the functionality of components their interactions, however didn't consider the operational environment in which they are executed. System tests close this gap and further consider the deployment environment, the target platform as well as involved external system that the SARI system is dependent on (e.g. a database management system or queuing system).

End-To-End Tests: End-to-end tests consider complete business cases. The goal is to guarantee a proper integration with other business systems (e.g. an ERP system) besides the SARI system. All services and applications of the SARI system as well as of other business systems are taken into consideration.

C. Test Fixtures and Mock

There are two key concepts that the SARI framework makes heavy use of, namely test fixtures and mocks. In the following we want to briefly introduce these concepts. Test fixtures are a skeleton for defining unit tests and provide an environment that allows the unit tests to perform its job properly. Any part of the environment needed by a unit test besides the testing framework itself is considered a test fixture. Figure 4 shows a typical test fixture. A test fixture is used by testers to describe and implement test scenarios. Test fixtures help to mount any required system functionality or data into the test environment, such as data from a database or proxies to real system services. Sometimes, it is time-consuming to include real services into a test scenario and dummy placeholders are sufficient to perform the tests. Such placeholders are also called "mocks". The test fixture contains a list of tests (see Figure 4, right hand side) which 1) initialize the test environment, 2) invoke the tested unit (such as a service) and 3) assert the results. The last step is the most crucial one since the assertions check the current behavior of the tested unit.



```
Test1
  Initialize Service with Parameters
  Invoke Service Method    1
  AssertTrue  (Result.Value > 100)
Test2
  Initialize Service with Invalid Parameters
  Invoke Service Method    1
  Assert Thrown Exception    („Invalid Parameters“ )
Test3
  Initialize Service with Parameters
  Invoke Service Method    2
  AssertTrue  (Result.Records.Count = 10)
Test4
  ...
```

Figure 4: Test Fixture for a Service

IV. SARI TESTING ENVIRONMENT

In this section, we introduce the testing environment for the SARI testing framework. The idea of the sense and response paradigm is to capture business events, and build processing steps (following business processes) that sense situations relevant to the business. If such a "situation" takes place the system intelligently responds.

Event Service: A component for processing events. Event service have input ports and output ports which describe the interfaces for events that can be processed and that are generated as result of the event processing.
Adapter: Component for receive an event from or respond to an external system.
Hub: A component for merging and splitting event streams.
Worker Node: A computation node which executes the event services of EPMs.
Coordinator Node: A computation node which coordinates the worker nodes in order to ensure a consistent and reliable event processing.

Table 2: EPM Elements

As shown in the previous sections, SARI uses a modular approach for constructing Sense & Respond loops. This is achieved by using an EPM, which allows to flexibly conjoin and disconnect various elements (e.g. event services) of the model, dependent on the requirements and the business problem. Links between the elements represent a flow of events from one service to the next. Figure 5 shows an EPM and the deployment environment of SARI in context of our testing framework. Table 2 summarizes some elements of the SARI system that we want to use later in our discussion.

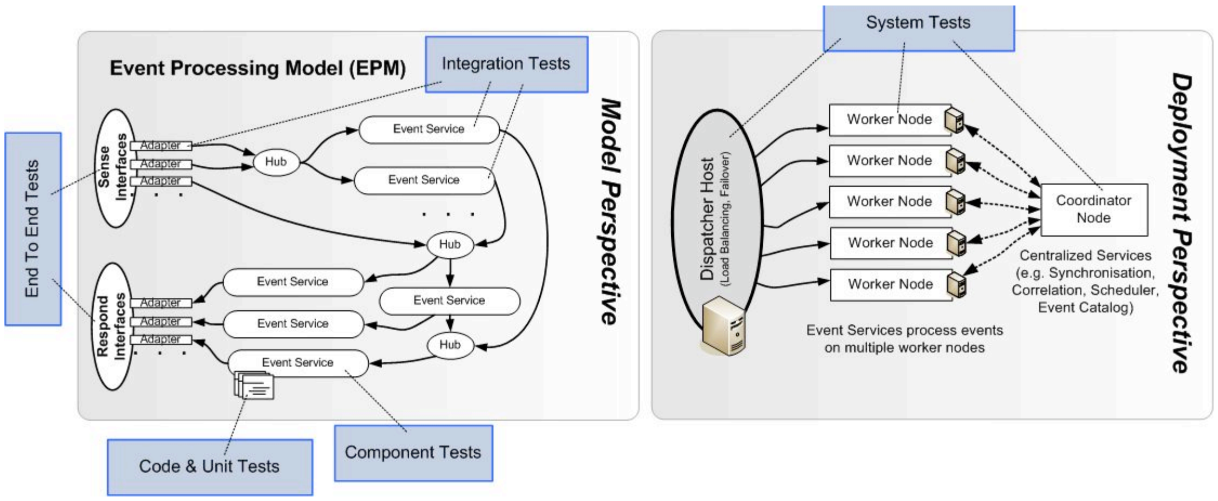


Figure 5: SARI Testing Environment

We used the testing framework NUnit [8] as a foundation for the code & unit tests, component tests, integration tests and system test. We extended the NUnit framework with comprehensive test fixture and mocks (as will be explained later) in order to support complex tests. For the end-to-end test a simulation module was developed.

Code & Unit Tests: In SARI, data is collected and received through adapters and continuously processed by event services. Each adapter and event service is a component that can consist of multiple classes. For instance, when

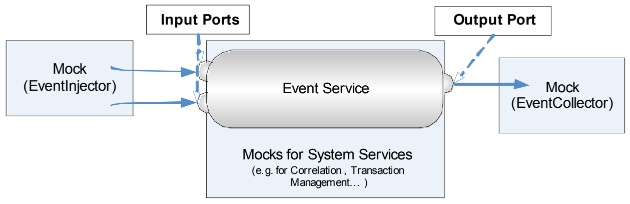


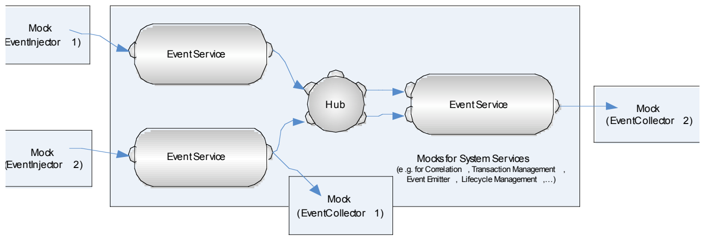
Figure 6: Testing Event Services

implementing an event services for discovering event patterns based on ECA (Event/Condition/Action) sets, a set of classes for describing the ECA sets, a class for processing the ECA sets (the ECA engine), and an event service hosting the ECA engine needs to be implemented. Code and unit tests are fully supported by NUnit; hence an extension of this testing framework was not required at this level of testing.

Component Tests: Interfaces of a component and services are validated using component tests. In SARI interfaces are defined by event types describing the structure of specific event data. The event types are used for input- and output ports of event services and adapters with EPMs. E.g., when testing an event service, a tester sends a set of events to the input ports of the event services and tests the result of the event processing by investigating the results at the output ports of the event services. Figure 6 illustrates this process. Within a test fixture - as mentioned above - a tester uses an event injector to send events to the input ports of the event service. During the event processing, the event service might use various kinds of system services (such as event correlation [10], transaction management, and queuing) which are also provided by mock objects. These mock objects are light-weight implementations of system services which results in shorter execution times for the component tests (the initialization of component tests typically occurs in less than a second). After the event processing, an event collector mock object is used to capture the events published on the output ports of the event service. The tester can use the collected events for assertions within the test fixture.

Integration Tests: An event service can depend on the results of other event services or adapters. The aim of integration tests is to consider a larger set of components and services within EPMs and test whether they work correctly in concert.

Figure 7 shows a set of dependent event services. Event



igure 7: Integration Test for Event Services

injector mocks are used to send events to the event services from a test fixture. Similar as in component tests, event collector mocks collect events from output ports of an event service. The collected events can be used for assertions within the test fixture. The difference to component tests is as follows:

- Testing of the outcome of an event processing problem including multiple event services
- Multiple event injectors and event collectors are allowed
- Additional map elements such as hubs (shown in Figure 7) or synchronization blocks
- Event services can use "external" parameters such as map parameters
- A comprehensive set of heavy-weight mocks for system services is available

With integration tests, users can test parts of an EPM or an EPM in its entireness. Integration tests include a larger set of mocks for system services. Some of the mocks are heavy-weight because they are built on top of SARI system services. Examples for such heavy-weight services are the correlation service, the event emitter for forwarding events within an EPM, and the lifecycle management for event services and adapters. The executing of an integration test takes about 5 to 10 seconds on our testing system, due to the longer instantiation times of the complex mocks for the system services.

System Tests: The SARI system is a distributed platform for event processing (see Figure 5 – deployment perspective). It includes various types of nodes that perform dedicated processing tasks. E.g., the dispatcher host performs load balancing, the worker nodes host the event services and process events and the coordinator node provides centralized services such as a timer service and synchronization. System tests allow to test the processing tasks within this complex distributed environment. Test fixtures for system tests can assert processing results for EPMs as well as system states (e.g. lifecycle state of an event services) in case of exceptional situations such as failures of a working unit. The repetition of such failure situations is extremely difficult in real-world scenarios, as the system state is difficult to preserve. Using test fixture that prepare the system state of worker nodes and other working units elegantly solve this problem since the tester has full control and access to the working units (e.g. worker nodes) and can initialize and verify the system state.

End-To-End Tests: End-to-end tests are used to test complete sense & respond business scenarios in order to verify their correct behavior from an end user perspective. In order to facilitate the testing of end-to-end business scenarios, we developed a simulator for simulating event sequences of real-world scenarios. End users can either generate events by initiating state changes in the real business environment (which result in events that are sent to the SARI system) or by using a simulator to generate the events for a test. A detailed discussion of end-to-end tests is out of scope for this paper and part of future work.

Level	**% of Defects Found**	**Costs of Defects**
Code & Unit Tests	37 %	15 %
Component Tests	11 %	8 %
Integration Tests	33 %	42 %
System Tests	5 %	11 %
End-To-End Tests	14 %	24 %

Table 3: Found Defects vs. Costs of Defects

V. EXAMPLE

In this section, we show a short example for integration tests. The starting point for our example is a simple EPM for calculating the cycle time for business activities (see Figure 8). In this EPM, the time difference between two Events *Activity Started* and *Activity Completed* is calculated and stored in a database. Additionally simple exception handling is implemented. Table 4 lists the components used in Figure 8.

SAP Adapter: Is used to deliver "*Activity Started*" events from an SAP system into the system.
MQSeries Adapter: The "*Activity Completed"* events are received from a different data source – in the example from an MQSeries messaging system.
Cycle Time Calculation Service: Receives the "Activity Started" and "Activity Completed" events and calculates the cycle time. The event service has to identify the corresponding event pairs and use their timestamp for the calculation of the metric.
Cycle Time Storage Service: Stores the calculated cycle time metrics in a database.
Exception Handling Service: Handles exception events that can be sent by the other event services if an exception situation occurred (e.g. database was not available).

Table 4: Components for Cycle Time Example

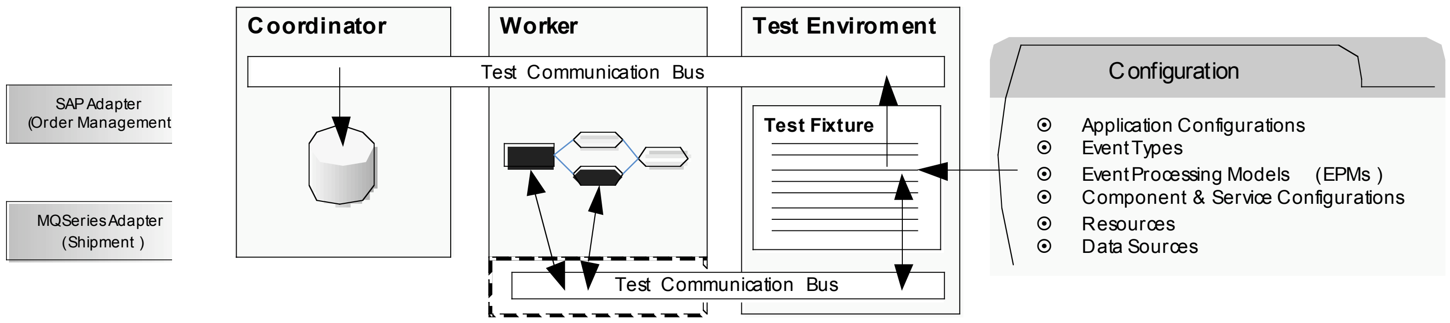

SAP Adapter (Order Management
MQSeries Adapter (Shipment)
Coordinator
Worker
Test Enviroment
Test Communication Bus
Test Fixture
Test Communication Bus
Configuration
Application Configurations
Event Types
Event Processing Models (EPMs)
Component & Service Configurations
Resources
Data Sources

Figure 9: Test Communication Bus of SARI

The following table provides some statistics about discovered defects in BPM solutions build with SARI. We measured the number of defects found and the actual costs for fixing the defects. Table 3 shows the distribution of the defects found and the costs for fixing them. The costs for fixing defects increase with the abstraction level of tests. The highest costs were caused by defects discovered by integration and end-to-end tests.

To test the proper functionality of this EPM, several issues have to be taken into consideration:

- SARI has to provide a testing environment for executing this application which includes in SARI's case worker and coordinator nodes. The test environment must be able to instantiate and control these nodes and to simulate the event processing.

- Metadata about the event types "Activity Started" and "Activity Completed" (e.g. the list of attributes for the event type) as well as the configuration for adapters and services must be deployed from the testing environment.
- The EPM has to be controllable from a test fixture such as starting and stopping the event processing. Furthermore, testers must be able to send sample events to the EPM and evaluate the results of the event processing.
- A tester should be able to reduce the complexity of external systems (such as a SAP system) by mocking these event sources.
- The EPM has to be controllable from a test fixture such as starting and stopping of the event processing. Furthermore, testers must be able to send sample events to the EPM and evaluate the results of the event processing.
- Simple definition of tests and analyzing of test results
- A tester should be able to reduce the complexity of external systems (such as a SAP system) by mocking these event sources.

Figure 9 shows the interaction between the SARI system and the testing environment in which the tests of a test fixture are executed.
During the start of a test, the Coordinator and Worker node are initialized and the configuration settings are provided. Every required configuration is stored as XML file and can be provided by testers within the test. The following implementation of a test in C# shows how a tester can provide a configuration:

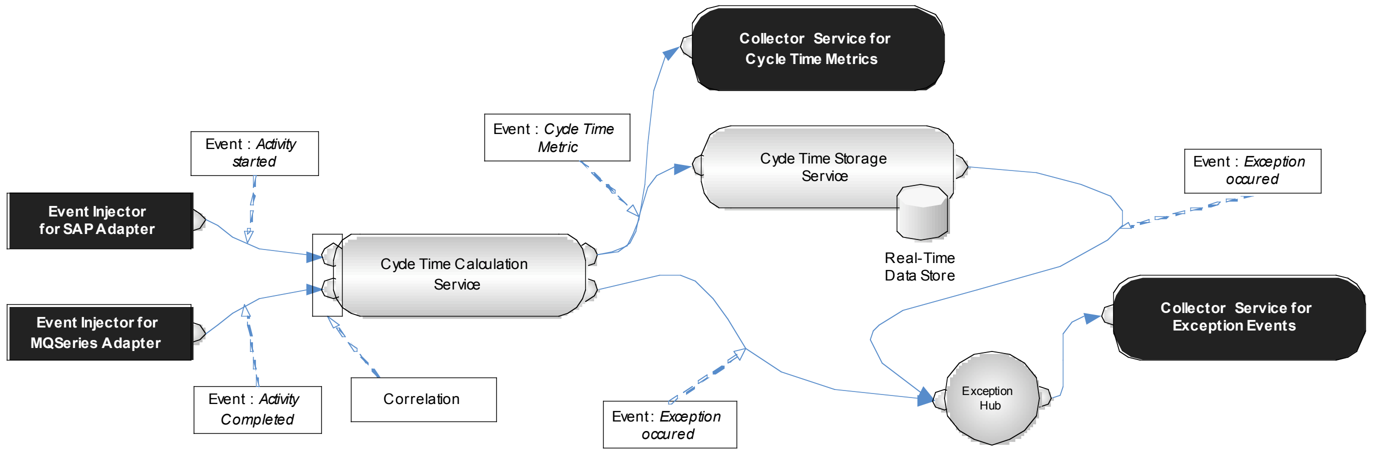
```
MyServiceTest() {
    Deployment.AddEventTypeLibrary("EventTypes.xml");
    Deployment.AddComponentLibrary("ComponentDescriptions.xml");
    Deployment.AddComponentLibrary("Resources.xml");
     ...
```

In the next step, the tester adds the application description which contains also the EPM. After providing all configuration files and the application description, the application can be deployed and started on the Coordinator and Worker node.

```
...
Uri applUri = Deployment.AddApplicationDescription("Application.xml");
Deployment.DeployAndStartApplication(applUri);
...
```

After these steps, the application is running and can be tested. For our example, we want to show how to run the test scenario without executing transactions in real business systems. By replacing the event adapters with Event Injectors, a tester can directly send events from a test fixture to the EPM. Furthermore, tester can add Event Collector services to the EPM in order to collect event that are generated during the event processing (see Figure 10).

The Event Injectors (representing test adapters) can be used to publish events generated in the test fixture instead of executing a real transaction from a SAP system. Collector Event Services can be used for collecting event processing results. The following code fragment illustrates a test of the example process:



Collector Service for Cycle Time Metrics
Event : Cycle Time Metric
Cycle Time Storage Service
Event : Exception occured
Event : Activity started
Event Injector for SAP Adapter
Cycle Time Calculation Service
Real-Time Data Store
Collector Service for Exception Events
Event Injector for MQSeries Adapter
Event : Activity Completed
Correlation
Event: Exception occured
Exception Hub

Figure 10: Cycle Time Example with Event Injectors and Event Collector Services

```
...
for (int i = 0; i < 100; i++)
{
    Event activityStarted = CreateEvent("Activity Started");
    TestCommunication.PublishEvents("EventInjector for SAP
      Adapter", activityStarted);
    Event activityCompleted = CreateEvent("Activity Completed");
    TestCommunication.PublishEvents( "Event Injector for MQSeries
      Adapter", activityCompleted);
}
  Assert.IsTrue(TestCommunication.WaitOnCallback(
      "CollectorServiceForCycleTimeMetrics", 100, TimeOut));
  List cycleTimeEvents = TestCommunication.GetCollectedEvents(
       "CollectorServiceForCycleTimeMetrics");
  // Check whether the collected events in cycleTimeEvents are correct...
  ...
}
```

The code fragment sends 100 "Activity Started" and "Activity Completed" events to the Event Injectors in the sample EPM. After sending the events, the test fixture waits with *TestCommunication.WaitOnCallback()* until 100 "CycleTime Metric" events have been received in the

Collector Event Service. After successfully waiting until the "Cycle Time Metric" events have been calculated and received, the collected events can be accessed within the test fixture and used for assertions.

VI. Conclusion And Future Work

With new paradigms for software development and software architectures companies are able to respond faster to changes of a business environment. In this paper, we introduced a testing framework which supports these paradigms by being able to test the correct behaviour of running business solutions. We compared our approach with model-driven development and showed how software tests can be used to make model assertions. Finally, we showed how we applied the testing framework for the SARI system.

The work presented in this paper is part of a larger, long-term research effort aiming to making testing an integral part for the management of business processes. Part of this work is the development of a test bed for testing, simulating and benchmarking business process solutions. One of our key ideas to improve our current testing framework is to use more abstract languages for the definition of test fixture. At the moment, testers have to use programming languages such as C# for writing tests. In future, we want to allow testers to use higher level languages for writing tests.

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