SAP Sailing Analytics

Architecture Overview

2012-08-03, Axel Uhl

# Introduction, Project Background and History

The SAP Sailing Analytics are a technology show-case demonstrating SAP technologies, concepts, skills and values applied to the domain of regatta sailing. They started as a small tool primarily intended to support a commentator in his job by displaying a live leaderboard for a sailing regatta with data interesting for the commentary. GPS and wind data travel from sensors to the server where the application keeps it in memory. When a request for a leaderboard is received, the data is aggregated on the fly, performing geometric computations including wind projections and involving a virtual "advantage line" orthogonal to the wind direction.

The live leaderboard started as a web application with a Java back-end responsible for the connectivity with the sensors and providing the geometry engine, and a Python process rendering the Web UI for the client's browser. The Python process issued REST requests to the Java back-end which responded with JSON documents.

The solution was first shown at Kieler Woche 2011. At the time, it was capable of displaying a single leaderboard that showed a number of tracked races in numerical form, offering columns for overall rank, race rank, rank at a mark, and values for average speed, distance traveled, gap to leader in seconds, velocity made good (VMG), estimated time of arrival at the next mark and current speed over ground. It was prototypical in many regards but regardless was considered an improvement for the commentary. The sailors liked it too because for the first time they could see numerical evidence of their choices of speed over distance.

After Kieler Woche 2011, the architecture changed. We removed the Python engine and used the Google Web Toolkit instead to render the Web UI directly in the Java process. A first new live leaderboard with this approach was shown at the IDM Travemünde 2011 and later at the MdM Hamburg 2011 events. Over time, the solution learned to manage multiple leaderboards, combining historic race analysis with live tracking. Particularly the accumulation of historic race data will require changes in the architecture in the near future to support this use case better.

A Google Map visualization, originally intended primarily for debugging purposes, matured to a useful tool used by commentators and spectators alike, combined with charts showing wind and competitor data, and of course the traditional live leaderboard. The leaderboard itself received various enhancements over time, including data about maneuvers such as tacks, jibes and penalty circles, and additional figures such as the average cross-track error which under shifty wind conditions in some boat classes may be an indicator for the risk taken by a competitor. Some of these figures turned out to be quite expensive to compute. Therefore, in a few cases we deviated from the original approach where everything was computed on the fly upon receiving a request. Instead, the more expensive calculations in live mode now happen asynchronously in the background, and client requests are fulfilled with whatever the most current result for these figures is.

The REST/JSON APIs offered by the Java back-end have been exploited by at least two additional show-case scenarios. Already in 2011, Business Objects Dashboards displayed data extracted through these interfaces in various analytical views. In 2012, the interfaces started to be used for repeated extraction of data into a HANA database on top of which Experience UI technology is now used for visualization with sophisticated analyses.

In 2012, a mobile application to support the race committees in their functions has been developed using largely the same architecture. Although the server for this app currently runs in a separate process, it uses largely the same code base, versioning repository and build process. We plan to integrate it with the SAP Sailing Analytics soon. A first loose coupling will allow users of the mobile app to send wind data entered on a mobile device into the SAP Sailing Analytics back-end where it augments the wind-based calculations. Later, we plan to integrate the mobile app even closer so that it supports race officials in laying and moving marks, changing the course layout as well as detecting and announcing disqualifications.

The remainder of this document explains the key architectural principles on which the SAP Sailing Analytics have been developed. It is to be considered a snapshot of the status quo, as documented by the time stamp in the document's header.

# Runtime Environment

## Linux, Java, OSGi/Equinox

By and large, the SAP Sailing Analytics are a web application implemented using Java technology. The application's components are OSGi bundles running in an Equinox OSGi container. Some bundles offer static web content or dynamic content in the form of servlets. Those bundles are implemented as OSGi Web Bundles which we consider a simple and elegant way to meet web standards using an OSGi-based implementation. A Web Bundle's main extension compared to a regular OSGi bundle is the presence of a web.xml descriptor in the WEB-INF top-level folder where servlets and static content can be declared and mapped to URLs.

Our current server deployment uses a 64bit Java7 Hotspot virtual machine and runs on a 64bit Linux CentOS distribution. We have a single host (sapsailing.com) which runs a number of Java VMs, some to offer the application in different development stages (dev, test, prod, ...), some to perform specific tasks such as replicating UDP wind data to the various server processes, or a process to store data received from the SwissTiming connector durably while forwarding that data to a server VM requesting it.

The various processes run in "screen" sessions to which, once connected to sapsailing.com with an ssh client, users can gain access using the "screen -rd" command. We consider replacing "screen" by "tmux" which is much more flexible and powerful and reported to be less buggy. This will allow us to launch the processes required in tmux sessions automatically after an operating system reboot.

For the OSGi containers by convention we have one directory under */home/trac/servers/* per deployable branch (*dev*, *test*, *prod1*, *prod2*). In those directories we have copies of the "install" script from the git's *java/target* folder. Running it after a successful product build on the branch corresponding to the current directory will copy the compiled product to the server directory. Running the *start* script will then launch the respective server instance. A safety check in the *install* script avoids accidentally overwriting a server directory with a non-matching product version by comparing the directory name with the branch name checked out under */home/trac/git*.

## Database

By and large, we use a database to recover from a server restart. Once started, most data managed by the application is kept in main memory. We currently use MongoDB as our database. Different DB instances belong to different server instances. This allows us to cleanly separate development and test data from production data.

The GPS tracking data is currently usually fetched from the tracking provider in case the provider stores it persistently. While this avoids redundancies and ensures up-to-date versions of the tracking data are used, it also creates a strong dependence upon the provider's system availability and may cause performance issues when many GPS tracks need to be reloaded after a server restart.

We therefore consider using our database also for replicated versions of at least the "archived" tracks where further changes on behalf of the tracking provider are unlikely.

## Google Web Toolkit (GWT)

The web UI is built using the Google Web Toolkit (GWT). This allows us to share code between UI and back-end and gives us the power of the regular Eclipse Java tools for code understanding, debugging and agile manipulation.

The GWT application communicates with the server using GWT RPC which, in the back-end, is implemented as a so-called RemoteServiceServlet which again is exposed by means of an OSGi web bundle. This servlet accesses the core application through an OSGi service (RacingEventService) which is hooked up in the OSGi service registry.

We try to keep important styling information separate in CSS resources which can be manipulated by web designers more conveniently than the Java source code. We balance this with the benefits of the Java sources' traceability which does not exist really for CSS resources where everything is just a string.

## Tracking and Wind Sensor Connectors

To receive GPS and wind data in near real time, some network programming becomes necessary. Depending on the technology and provider used, a combination of HTTP, TCP and UDP connections is required to obtain live data. Particularly the UDP connectivity was the reason why deploying our solution to SAP NetWeaver Cloud was and still is difficult.

We try to isolate connectors to a particular technology or tracking provider so that the core application doesn't depend on a particular provider. Among other things, this leads to an architecture in which separate bundles encapsulate the connectivity components for each provider. There are still a few minor pieces of code in the UI area where this separation hasn't been completed yet and where the UI component knows about the concrete GPS tracking providers currently supported. We have plans to change this such that simply by deploying a tracking provider's connectivity bundle the back-end picks it up and makes it known all the way into the front-end.

### TracTrac Connector

TracTrac offers a Java client to ease the connection to their back-end systems. This client is provided as a JAR file and is referred to as the "TracTrac Client Module" (TTCM). The client offers convenient access to both, historic ("stored") data and live data which is pushed to the client.

The TracTrac system serves JSON documents, one per event, which provides an overview of the races tracked by the system. This list is visualized in the TracTrac tab of the AdminConsole when the "List Races" button is pressed after having entered a correct JSON URL. The document also contains details about the connectivity parameters which we read and use by default.

TTCM requires access to specific TCP ports (usually germanmaster.traclive.dk:4400/4401). This is to be considered when configuring a firewall. It is generally possible to tunnel these connections through an SSH tunnel. TTCM is fairly resilient to network disruptions and keeps trying to re-connect. Once connected, the push service works pretty reliably during live events.

It is worth noting that the TracTrac architecture can lead to out-of-order delivery of messages. For example, if a tracker loses network connectivity for some time, it will send the GPS fixes recorded during the outage once it re-connects. Those fixes can affect past analyses such as the wind estimation. Also, mark rounding times can change over time. Whenever the TracTrac server computes an improved mark rounding time, it will push the update to all registered TTCM clients, possibly updating previous mark rounding time estimations. Since such updates have a major impact on many calculations, it was one of the key reasons we originally decided to store only the facts and calculate all derived figures from those facts on the fly.

We map the TracTrac domain concepts to our domain concepts in an adapter we call the *DomainFactory*. It keeps track of the mappings performed so as to not create duplicate domain objects in our application for the same TracTrac competitor, buoy, waypoint or race. These canonicalizing mappings are–together with the use of immutable master data objects–at the same time currently one of the annoyances in the architecture. When master data changes on TracTrac's side, our domain objects currently aren't properly updated because they are immutable, and replacing them would not be an easy task. See also <http://bugzilla.sapsailing.com/bugzilla/show_bug.cgi?id=596> for a more detailed discussion of this problem.

TTCM has a notion of "events" which can differ from what our domain model calls an "event." With TracTrac it is possible to track multiple sailing events and regattas within a single TracTrac event. However, in our domain model, a sailing event such as "Kieler Woche 2012" is a single event.

The connector runs a number of threads for each race tracked: one per type of message received. Those types are the race course definition together with the list of competitors, the raw competitor GPS fixes, the mark positions, start/finish times and the mark rounding times. In retrospect, this design is not ideal for a number of reasons. While it keeps each receiver for each type of information fairly clean, affording at least five threads per race is quite a lot and would not be needed if we handled the receiving of each message synchronously in the callback provided by TTCM.

A particular aspect in the connector's design to re-consider is the life cycle of the *RaceDefinition* objects. They are currently only created *after* the race course definition has been received. All callers required to access the *RaceDefinition* object are currently suspended until the course layout has been successfully received. If for some reasons this process times out

### SwissTiming Connector

Other than in the case of TracTrac, the SwissTiming system broadcasts packets containing position and mark rounding information to a pre-determined set of hosts. There is no API to obtain old, stored data. Packets missed during live transmission are lost, except for a tricky, unconfirmed and yet untested process of receiving database dumps from SwissTiming at a later point.

Therefore, we have decided to implement a database buffer for the SwissTiming connector in such a way that a very simple, hence robust Java process is solely responsible for receiving, forwarding and durably storing the information packets broadcast by SwissTiming. The actual connector running in our back-end then connects to this process for the forwarded live packets while loading the packets already received so far from the persistent store. Based on packet numbers, the original sequence can be restored while live packets keep coming in.

### Expedition Connector

We like to receive wind data live from the race course(s). For this, we can install wind measurement devices on vessels such as the start vessel or RIBs following the field or dedicated solely to the task of wind measurement. Currently, we use devices that can be hooked up to a Panasonic Toughbook on which we run a software package called *Expedition* (see <http://www.tasmanbaynav.co.nz/>). This package is capable of receiving sensor data from a variety of different devices, including a Nexus on-board controller and various sensor devices connected directly to the laptop using, e.g., USB.

If sufficient information is available for Expedition to determine the sensor speed (either by a water log or by availability of GPS data), it can infer the true wind speed and bearing from the apparent wind speed/bearing measured.

Expedition can be configured to transmit one or more of the values it received or inferred across a network connection. The data is prefixed with a so-called "boat ID" which can be configured in the Expedition software. We use Expedition's capability to send the sensor data through UDP to port 2012 on the sapsailing.com host. We use a simple UDP mirroring process implemented in Java (see class *com.sap.sailing.expeditionconnector.UDPMirror*) to forward the messages received to the various server instances, each listening on a different UDP port.

Those UDP messages are received and analyzed by an active instance of class *UDPExpeditionReceiver*. Those that can be parsed successfully are used to record wind fixes in a tracked race with which the receiver is associated.

## Result Importers

For the operations of many regattas, software solutions are already in place. Those are used to manage competitor lists, fleet assignments, boat class to race course area assignments and of course scoring and ranking. Usually, they are the single source of truth also for the race committee and the sailors.

The SAP Sailing Analytics primarily base their leader boards on the tracking results. However, the tracking not always reflects the actual scoring as decided by the race committees. We therefore are interested in the ability to import the official results into our solution so that in addition to the GPS tracking data we have a copy of the truth when it comes to the scoring process. This is particularly exciting during the last race of a regatta when we can augment the official scores with the live tracking of the race currently ongoing.

We have provided an interface to import official results into our leader boards. Result importers implementing the *ScoreCorrectionProvider* interface can register with the OSGi service registry and are dynamically discovered. Such a provider can tell for which events and boat classes and dates it has "score corrections" which is a more technical term for "official results."

We currently have *ScoreCorrectionProvider* implementations for the 2011 and 2012 Kieler Woche result system (see bundle com.sap.sailing.kiworesultimport), for the french "FREG" system (see bundle com.sap.sailing.freg.resultimport) and for the Extreme Sailing Series (see bundle com.sap.sailing.ess40.resultimport). In their activators, these bundles register an instance of their score correction provider implementation with the OSGi service registry. This way, more importers can easily be added, potentially even at runtime, simply by deploying and starting another result importer bundle.

### Kieler Woche Result Importer

There is no online access to the Kieler Woche regatta system. However, we were able to agree an FTP result export with the system provider, b+m. The export format is a ZIP file containing numerous XML and PDF files. The XML files are then analyzed and provide the contents for the score corrections. We created a dedicated account for the FTP export on sapsailing.com ("kiwo"). The FTP export ends up in /home/kiwo, and all server instance directories under /home/trac/servers/(dev|test|prod1|prod2) contain a link "kiworesults" pointing to /home/kiwo.

The score correction provider implementation scans the "./kiworesults" directory for the ZIP files and offers their contents through its API.

### FREG Result Importer

At the 505 Worlds in La Rochelle we were faced with an HTML export format. Unfortunately, there was no stable URL scheme from which to obtain the HTML documents exported from the regatta management system. Therefore, we decided to leave the URL configuration to the administrator of our solution and added a tab "FREG URLs" to the AdminConsole. The documents reachable through the URLs added to this page will be scanned by the FREG score correction provider.

### ESS40 Result Importer

The Extreme Sailing Series currently manages their results through sailracer.org. The series has their own iPad app to capture the finish line passings. This app produces a CSV file managed on the series' web server before it is converted and uploaded to the sailracer.org server. We get access to the CSV files and a document listing the CSV files available for the series. Those then feed into the score correction provider.

# Basic Architectural Principles

## In-Memory Architecture and the Database

The application generally deals with two sorts of data. One is the sensor data originally created by a set of physical sensors such as GPS trackers, wind measurement devices or the sensors included in smart phones and other mobile devices. The other is master data and meta-data captured and maintained by administrators and users, such as the leaderboard configuration data, connectivity data for the tracking providers, or official scoring results imported from external sources.

For the sensor data, the time at which the data is received is never the same as the time at which the sensor data was valid. Sensors don't predict the future but measure some present value. The transmission from the sensor to the server adds a rather unpredictable latency. In the worst case, the sensor's transmission unit fails, and the data can only be imported into the server once the sensor is back on shore. With this in mind, the server's view of reality is partial and lagging, and history may be re-written at any point in time if a sensor decides to deliver its data later than most other sensors. There is no precise synchronization across the set of sensors used at an event. At best, there is a pre-configured maximum delay at which trackers make an effort to deliver their data. However, this may also fail, for example, if trackers lack network connectivity when they would actually be due to send their data. Tracking providers may also decide to re-compute some derived data which our server receives. For example, some tracking providers send data about when they think which boat passed which mark. The provider may change this at any time, sending an updated list of mark passing times. This can, e.g., happen if the course layout was changed on short notice, and the course update didn't make it into the server in time. Once the course layout change is then updated to the system, the mark passing times will be re-evaluated, and updates to the previous mark passing times will result.

These circumstances suggest an architecture which basically records the sensor facts and dynamically aggregates all derived information on the fly. This is how we started. The more complex the rules for deriving interesting figures from the sensor data grew, the more computational resources the on-the-fly aggregation required. In particular, three algorithms turned out to be quite expensive to carry out: maneuver analysis based on the recursive Douglas-Peucker algorithm; wind estimation based on the boat tracks, assuming that boats on different tacks use roughly the same beat angle to the wind; and the average cross-track error which computes a projection of each boat's position to the wind direction.

## Caching where Necessary

## Implementation Pattern for Caches

TODO talk about FutureTask, Executor, waiting for latest results vs. using a SmartFutureCache and updating in the background, using a whiteboard pattern

## Issues with Caching

TODO talk about the problem of keeping the computation and cache invalidation rules in sync

## Approaches to Locking: "synchronized" vs. ReentrantReadWriteLock

## Scale-Out through Replication

### Master/Replica Distinction

### Operational Transformation

### Operations, Services, and Events

TODO explain how some operations are issued from the outside through service interfaces, and some emerge from events such as receiving sensor data. What's accidental, what's historic, how should it be?

### Open issues

# Development Environment

## Git and Our Branches

Our main Git repository lives at *ssh://<user>@sapsailing.com/home/trac/git*. For those working in the SAP corporate network and therefore unable to access the external sapsailing.com server using SSH, the repository contents are replicated on an hourly basis into *ssh://dxxxxxx@git.wdf.sap.corp:29418/SAPSail/sapsailingcapture.git* where *dxxxxxx* obviously is to be replaced by your D- or I- or C-user. You need to have an account at <https://git.wdf.sap.corp:8080/> to be able to access this Git repository.

Small, obvious and non-disruptive developments are usually carried out immediately on our *master* branch. This branch is configured such that Maven can be used to run the tests inside the SAP corporate network. The *master* branch is never deployed onto the sapsailing.com server and hence has no corresponding */home/trac/servers/* subdirectory.

If a change looks reasonably good on the *master* branch and related JUnit tests or manual UI tests have succeeded locally, it is permissible to merge the *master* branch into the *dev* branch and run a central build on sapsailing.com. The *dev* branch is configured to run the Maven tests with direct Internet access. It can therefore also be used to run the tests locally if connected to the public Internet.

Ideally, the build should be run including the test cases. If the tests succeed[[1]](#footnote-1), the branch can be installed and the corresponding server instance can be restarted. The branch can then also be promoted to the next level (*dev*-->*test*-->*prod1*/*prod2*). Note, that currently re-starting a server instance may require re-loading the races that were previously loaded, particularly for the *prod1* and *prod2* instances, because several externally-announced URLs point to them.

We typically promote the changes to the next branch by also merging the current *master* branch into the next-"higher" branch. This should lead to equivalent results compared to merging the "previous" branch (e.g., *dev*) into the "next" branch (e.g., *test*). The branches differ largely in the configurations used for the servers, particularly the port assignments for the Jetty web server, the UDP ports used for listening for Expedition wind messages, and the queue names used for the replication based on RabbitMQ (see also ).

## Eclipse Setup, Required Plug-Ins

We use Eclipse as our development environment. Using a different IDE would make it hard to re-use the project configurations (*.project* and *.classpath* files which are specific to Eclipse) as well as the GWT plug-in which assists in locally compiling and refactoring the GWT code, in particular the RPC code.

The recommended and tested Eclipse version is currently Indigo (3.7). Colleagues have reported that they succeeded with a Juno (3.8/4.x) set-up as well.

To get started, install Eclipse with at least PDE, Git, GWT (use <http://dl.google.com/eclipse/plugin/3.7> as update site) and JSP editing support enabled. Eclipse Maven support is not recommended as in many cases it has caused trouble with the local Eclipse build.

## Target Platform

After the Eclipse installation and importing all projects under *java/* from Git, it is required to set the target platform in Eclipse (*Window* --> *Preferences* --> *Plugin Development* --> *Target Platform*). The project *com.sap.sailing.targetplatform* contains "Race Analysis Target (IDE)" as target platform definition. It uses a number of p2 update sites and defines the OSGi bundles that constitute the target platform for the application. If this is not set in Eclipse, the local build environment assumes that the developer wants to implement Eclipse plug-ins and offers the entire set of Eclipse plug-ins and only those as the target platform which doesn't make any sense for our application.

Major parts of our target platform are hosted on sapsailing.com as a p2 repository which makes it possible to have only one central target platform configuration used by everyone. The target platform can be re-built, e.g., after adding another bundle to it, using the script in *com.sap.sailing.targetplatform/scripts*. It then needs to be installed again to the */home/trac/p2-repositories* directory from where it is exposed as <http://www.sapsailing.com/p2> by the Apache web server. After such a change, all developers need to reload the target platform into their Eclipse environment.

## Maven Build and Tests

We use Maven to build our software and run our JUnit tests. The global *setting.xml* file to install in everyone's *~/.m2* directory is checked into the top-level Git folder. The checked-in copy assumes the developer is using Maven inside the SAP corporate network. If not, uncomment the *<proxy>* tag in the *settings.xml* file. See also section for details on which branch is configured to work in which network setup.

We have a top-level Maven *pom.xml* configuration file in the root folder of our Git workspace. It delegates to the *pom.xml* file in the *java/* folder where all the bundle projects are defined. We rely on the Tycho Maven plug-in to build our OSGi bundles, also known as the "manifest-first approach." The key idea is to mainly develop using Eclipse means, including its OSGi manifest editing capabilities, and keep the Maven infrastructure as simple as possible, deriving component dependencies from the OSGi manifests. See the various *pom.xml* files in the projects to see the project-specific settings. By and large, a *pom.xml* file for a bundle needs to have the bundle name and version defined (we currently have most bundles at version 1.0.0.qualifier in the manifest or 1.0.0.SNAPSHOT in Maven), and whether the bundle is a test or non-test bundle, expressed as the *packaging* type which here can be one of *eclipse-plugin* or *ecplise-test-plugin*.

Test plugins automatically have their tests executed during a Maven build unless the command-line option *-Dmaven.test.skip=true* argument is specified. It is generally a good idea to launch the Maven command using the *-fae* option which asks Maven to continue until the end, even if errors or failures occurred on the way, failing at the end if any failures occurred. This can save numerous round trips and is useful in case of known and temporarily acceptable test failures.

The Maven plug-in for the GWT compilation doesn't reliably perform a dependency check. It is therefore recommended to remove all contents of the *java/com.sap.sailing.gwt.ui/com.sap.sailing.\** folders (basically, all GWT compiler output) before launching the Maven build. A good command line for the Maven build from the *java/* subdirectory is this:

*rm -rf com.sap.sailing.gwt.ui/com.sap.sailing.\*; mvn -fae clean install 2>&1 | tee log*

It also creates a *log* file with all error messages, just in case the screen buffer is not sufficient to hold all scrolling error messages.

# Other Information Sources

1. We currently see intermittent failures in the replication and swisstimingadapter test suites. It's always worth a look, but if those are the only tests failing, it is still acceptable to promote the branch to the next level. We're working on stabilizing these two test suites to ensure they always succeed if the software is correct. [↑](#footnote-ref-1)