

Service oriented architecture for scientific analysis.

An example of a W7-X field line tracer.

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Introduction

Both fusion experiments and analysis tools become increasingly complex. Many problems require multiple measurements and models. A universal method of combining heterogeneous analysis software is, therefore, desirable. In addition, because of collaborations, the analysis tools must be accessible remotely. Service oriented architecture with web-services addresses the stated problems. Here this concept is demonstrated with a W7-X service for field line tracing. The tracer solves many problems: Poincaré maps, connection lengths, magnetic coordinates, field line diffusion, error fields, etc. The problems are solved with a realistic machine geometry. The service is illustrated with calculations of W7-X divertor loads with a 1/1 error field. Service oriented approach [1] provides a uniform access to analysis codes for building complex models. Such models can be parallelized in a private W7-X Cloud. The advantages of web-services are: extensive standards; platform/language independence; off the shelf software; reusability of existing codes; loose coupling; service development by field experts; convenience.

Service oriented architecture

Service oriented architecture is a way of building complex software by combining independent components - services. Services are invoked by language neutral, structured messages. If messages are sent via HTTP the services are called web-services. Functions provided by a service are described in a language neutral interface document; and, hence, can be automatically discovered and used in many programming languages and workflow systems. Services may reside on different machines, which provides parallelization.

For W7-X web-services SOAP/ WSDL standards are considered [2, 3]. Both are XML based with readily available tools. SOAP describes request/response message for a service operation. WSDL standardizes service interface description. It is a WSDL document that is exchanged between service developer and user. Thanks to WSDL no knowledge of the standards is required.

Listing 1: Using web-services in Python. Poincaré map example.

```

1 from osa import Client # free Python SOAP library https://bitbucket.org/sboz/osa
2 tracer = Client("http://.../FieldLine?wsdl") #create service wrappers
3 points = tracer.types.Points3D() #start points
4 config = tracer.types.MagneticConfig() #magnetic configuration
5 ...
6 poicare = tracer.service.trace(points, config, task) #tracing at the server
7 for surface in poicare.surfs: #iterate over returned results
8     x,y,z = surface.points.x1, surface.points.x2, surface.points.x3
9     plot(sqrt(x**2+y**2), z, 'k') #plot a flux surface

```

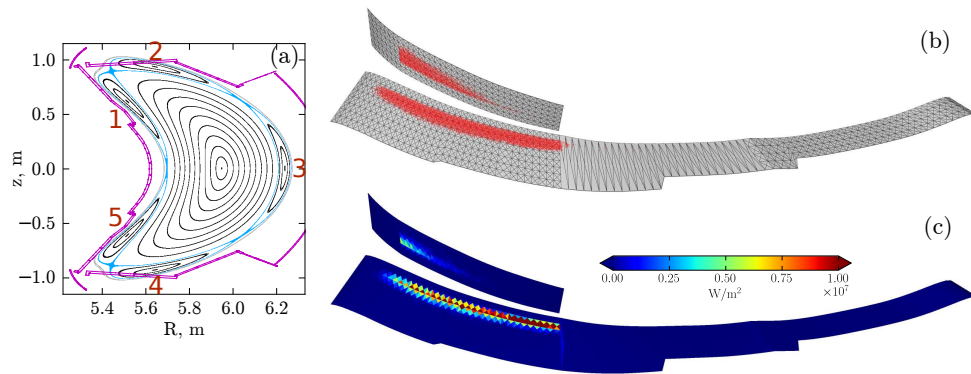


Figure 1: W7-X divertor loads, standard configuration. (a)-Poincaré map and the first wall in $\varphi = 0$, 5/5 islands are marked. (b) - hit points, in red, on the target. (c) - divertor power loads.

Web-services can be used either from a programming language via libraries or from a workflow management system. In both cases a user supplies a WSDL document to generate call wrappers. At the run-time the wrappers compose suitable SOAP messages, send and receive them. For the user calling the service is equivalent to calling a local wrapping function. This use pattern is illustrated in listing 1 with field line tracing in a Matlab like environment. In line 1 a SOAP library is imported. The library creates call wrappers from a WSDL location in line 2. Afterwards required input is constructed, further details are omitted here. In line 6 the web-service is called, and later the Poincaré map is plotted.

Developing a web-service is also straightforward. A developer defines the interface in his programming language. From these definitions the developer's SOAP tools generate boilerplate code for the service and its WSDL document. Afterwards, the developer has to fill the generated code with the logic and to install the service. The SOAP library takes care of calling a requested function and of serializing/deserializing the messages.

Field line tracing service

The new W7-X tracing web-service contains the functionality similar to expert codes like GOURDON. Starting from the WSDL, this functionality is accessible from multiple platforms. The service implementation will be detailed elsewhere. All results shown here were obtained by using the service.

The tracing service has a very flexible structure. The magnetic field can either be calculated by Biot-Savart on every step or interpolated, e.g. from an equilibrium solution. The following problems can be solved: field line polygon; Poincaré map in a φ -plane; Poincaré map in a free plane; flux surface values like effective radius r_{eff} and rotational transform ι ; connection length; heat fluxes to the wall; magnetic coordinates; finding magnetic axis, LCFS, etc. The problems can be solved with a realistic machine geometry represented by polygon meshes. At every step a field line can be tested for an intersection with the wall. To accelerate the testing a space partitioning into a regular grid is used, which gives a negligible slow down ($< 10\%$)

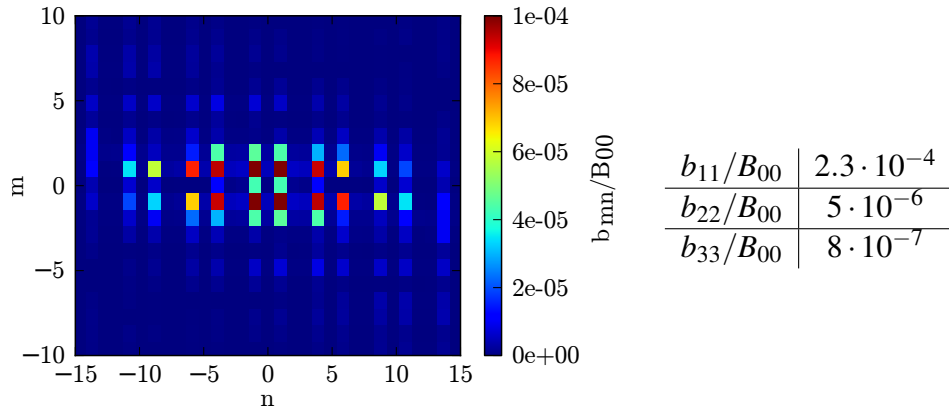


Figure 2: Spectrum of error fields produced by the trim coils. m - poloidal mode number, n - toroidal mode number. In the table the modes resonant to $\iota = 1$ are listed.

even for meshes with millions of triangles. There are also convenience methods to calculate a flux surface, normal field B_n , and B_n spectrum, given magnetic coordinates.

To estimate heat fluxes to the plasma facing components a Monte-Carlo field line diffusion model [4] was realized. Field lines from random points inside the separatrix are followed and once in a while random steps are performed to simulate the perpendicular transport. This process is continued until a field line terminates on the wall. The hit points represent strike zones and from the number of events per polygon the power loads can be estimated, figure 1. Figure 1a presents a Poincaré map and the wall in plane $\varphi = 0$ for W7-X. A 5/5 island chain is used for the divertor [4]. The target plates are in contact with two islands at the top and two islands at the bottom. Ideally the bottom and top units in all 5 modules are loaded symmetrically. Hit points in one bottom module are shown in red in figure 1b, both on the horizontal and vertical targets. These hit points correspond to the power loads in figure 1c, with lost power of 10 MW and no radiation. The highest power of about 10 MW/m² is on the horizontal target. These results are for a diffusion coefficient D_{\perp} of 1 m²/s, and a free length and velocity of 10 eV electrons.

Magnetic coordinates can be used for calculating error field spectra, visualization, field line penetration studies, etc. They are curvilinear coordinates (ρ, θ, φ) with straight field lines [5]:

$$\vec{B} = \psi' \cdot \vec{\nabla} \rho \times \vec{\nabla} \theta + \iota \psi' \cdot \vec{\nabla} \varphi \times \vec{\nabla} \rho, \quad (1)$$

where ι is rotational transform and ψ' is the radial derivative of the normalized toroidal flux. The service constructs three common systems: PEST, Hamada and Boozer. This is achieved by a Fourier decomposition of cylindrical coordinates R and z along a field line

$\sum_{mn} \{ \varphi_{mn}, R_{mn}, z_{mn} \} e^{i(m\iota + sn)\varphi}$, where s is device symmetry, 5 for W7-X. The mode amplitudes are determined during the field line tracing by FFT with Gaussian windowing.

Application example: divertor overloading by 1/1 error field

The W7-X divertor exploits an intrinsic island chain with fivefold symmetry [4]. In most cases, the rotational transform at the edge is close to 1, which makes the divertor sensitive to

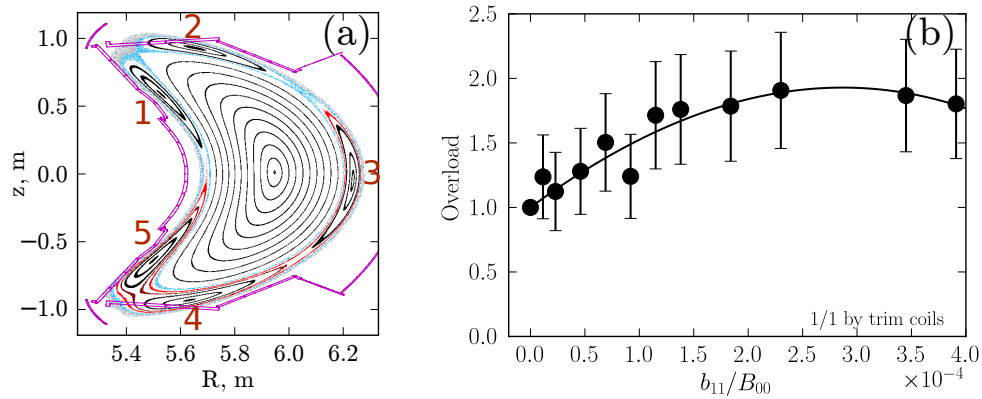


Figure 3: W7-X divertor loads with a 1/1 error field. (a) - Poincaré map in $\phi = 0$ plane, note a red 1/1 structure the edge. (b) - overloading - ratio of the maximal flux with/without the mode.

symmetry breaking perturbations. Here we consider an influence of a 1/1 perturbation produced by five W7-X trim, error compensation, coils [6]. In a real experiment perturbations are due to manufacturing imperfections. Figure 2 presents an error field spectrum by a dedicated trim coil configuration. This spectrum was calculated by the service in Boozer coordinates for the normal field component B_n . The modes cover a wide range, but the relevant ones are those resonant to $\iota = 1$ (table 2). The 1/1 mode is dominant and dictates the edge modification, red in figure 3a. The induced 1/1 structure makes the divertor loads asymmetric; some targets receive a lower load, while the others are overloaded. Figure 3b shows results of the field line diffusion simulations with a different amplitude of the perturbation. Shown is the ratio of the maximum heat flux with the 1/1 error field to that without. 1/1 field of about $2 \cdot 10^{-4}$ results in a two times overloading of the target. This demonstrates the importance of minimizing the resonant errors and also that the trim coils are a valuable tool.

Summary

Service oriented architecture is a universal way of combining software. Given WSDL documents, any user can combine independent services in many programming languages and workflow systems. Such models are parallelized in a Grid or a Cloud by commercial software. Convenience of web-services was proven by a new W7-X service for field line tracing. The tracer has a flexible structure, uses a realistic machine geometry, and solves many problems: Poincaré maps; surface characteristics; connection length; heat fluxes to the wall; magnetic coordinates; error field spectra, etc. The tracer was applied to calculate the W7-X divertor overloading for different amplitudes of a 1/1 error field; the mode of $\sim 2 \cdot 10^{-4}$ overloaded the divertor ~ 2 times. Besides, other services are becoming available: databases for coil and wall geometries, 3d equilibrium solver VMEC, etc. They will be essential for the analysis of W7-X experiments.

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