
easi Documentation

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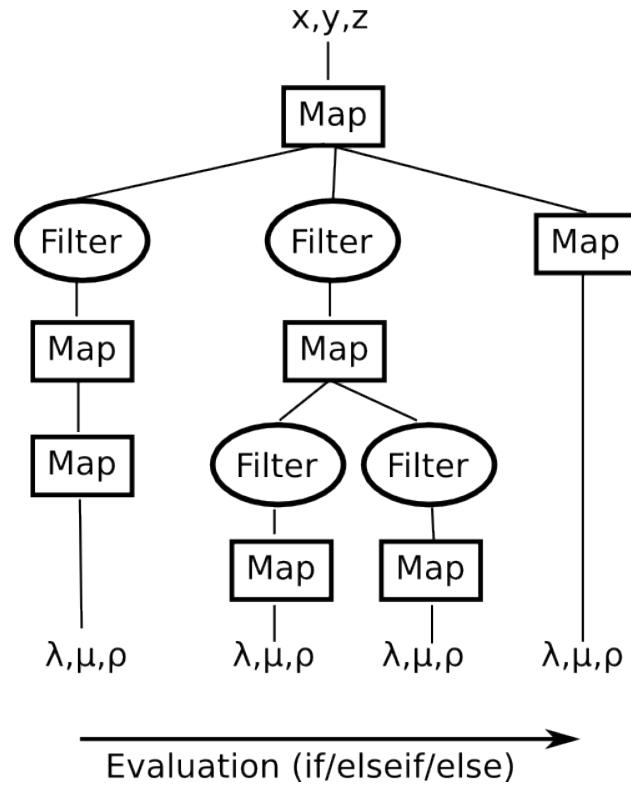
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easi is a library for the **E**asy **I**nitialization of models in three (or less or more) dimensional domains. The purpose of easi is to evaluate functions $f : \mathbb{R}^m \rightarrow \mathbb{R}^n$, which are described in a [YAML](#) configuration file. In grid-based simulation software, such as [SeisSol](#), easi may be used to define models. In SeisSol, the function f maps every point in space (say x,y,z) to a vector of parameters (e.g. λ, μ, ρ), which define a rheological model. Here, over 5000 lines of model-specific Fortran code could be replaced with YAML files.

An easi model consists of only two components: Map and Filter. These components may be wired as a tree, e.g. as in the following figure:



The procedure is as follows: A point x,y,z enters the tree at the root. The first Map takes a 3-dimensional vector as input and returns a n -dimensional vector. The following Filters decide if they accept this n -dimensional vector or reject it (e.g. accept if it lies in a hypercube and reject otherwise). Then, the branch which accepts a vector is taken (a Map accepts everything by default). The final parameter vector is, in this example, always 3-dimensional as it contains the density and the Lamé parameters.

GETTING STARTED WITH EASI

easi is a library written in C++14. It needs to be compiled with Cmake.

1.1 Dependencies

Easi depends on the following three projects:

- [yaml-cpp](#)
- [ASAGI](#)
- [ImpalaJIT](#)
- [Lua](#)

Only [yaml-cpp](#) (version 0.6.x) is a required dependency. The compilation of dependencies is detailed in [Compiling dependencies](#).

1.2 Compilation

Before installing [easi](#), you first need to install all dependencies. Next, clone the [easi repository](#) and create a separate build directory. The directory can be outside of the repository. This makes the compilation cleaner. Finally, execute the following lines:

```
# $EASI_SRC is the directory into which you've cloned the easi source
cmake -DCMAKE_PREFIX_PATH=$HOME -DCMAKE_INSTALL_PREFIX=$HOME -DASAGI=ON -DIMPALAJIT=ON -
↳DLUA=ON $EASI_SRC
make -j4 install
```

This installs [easi](#) into your home directory.

1.3 Usage example

easi is configured via [YAML](#) configuration files. For example, such a configuration file could look like the following:

```
!Any
components:
  - !AxisAlignedCuboidalDomainFilter
    limits:
      x: [-100000, 100000]
      y: [-5000, 5000]
      z: [-100000, 10000]
    components:
      - !ConstantMap
        map:
          lambda: 1e10
          mu: 2e10
          rho: 5000
      - !LayeredModel
        map: !AffineMap
        matrix:
          z: [0, 0, 1]
        translation:
          z: 0
        interpolation: linear
        parameters: [rho, mu, lambda]
        nodes:
          -100.0: [2300.0, 0.1766e10, 0.4999e10]
          -300.0: [2300.0, 0.6936e10, 1.3872e10]
          -1000.0: [2600.0, 1.3717e10, 1.8962e10]
          -3000.0: [2700.0, 2.1168e10, 2.7891e10]
          -6000.0: [2870.0, 3.1041e10, 3.8591e10]
          -31000.0: [3500.0, 3.9847e10, 4.3525e10]
          -50000.0: [3200.0, 6.4800e10, 6.5088e10]
```

Here, all points with y-coordinate inbetween -5 km and +5 km would be assigned constant model parameters. For all other points, a linear interpolation, depending on the z-coordinate is used.

1.4 Application example

The first step is always to create a model. Here, we may use the `YAMLParse` class which creates models from YAML configuration files.

```
1 easi::YAMLParse parser(3);
2 easi::Component* model = parser.parse("test.yaml");
```

The argument in `YAMLParse`'s constructor is the dimension of the input vectors. Here, we take 3 as we want to query our model in a 3-dimensional space.

As a next step, we need to define a query, which defines the input vectors for which we want to evaluate our model. In the following example we add the points (1,2,3) and (2,3,4). Each point may have an additional group parameter, which may be used to distinguish points in an easi file.


```
easi::Query query(2,3);
query.x(0,0) = 1.0;
query.x(0,1) = 2.0;
query.x(0,2) = 3.0;
query.group(0) = 1;
query.x(1,0) = 2.0;
query.x(1,1) = 3.0;
query.x(1,2) = -4.0;
query.group(1) = 1;
```

We need to store the output vectors somewhere. For this purpose, we always need to supply an adapter, which connects the output vector with locations in memory. In our sample application, the output vector shall be stored as array of structs, and hence we use an ArrayOfStructsAdapter. (Note that additional adapters can be implemented by overriding the class ResultAdapter.)

```
struct ElasticMaterial {
    double lambda, mu, rho;
};

ElasticMaterial material[2];
easi::ArrayOfStructsAdapter<ElasticMaterial> adapter(material);
adapter.addBindingPoint("lambda", &ElasticMaterial::lambda);
adapter.addBindingPoint("mu", &ElasticMaterial::mu);
adapter.addBindingPoint("rho", &ElasticMaterial::rho);
```

Finally, a simple call to evaluate is sufficient, and the model should be deleted if is not required anymore.

```
model->evaluate(query, adapter);
delete model;
```

The whole sample code is listed in the following:

```
#include <iostream>
#include "easi/YAMLParse.h"
#include "easi/ResultAdapter.h"

struct ElasticMaterial {
    double lambda, mu, rho;
};

int main(int argc, char** argv)
{
    easi::Query query(2,3);
    query.x(0,0) = 1.0;
    query.x(0,1) = 2.0;
    query.x(0,2) = 3.0;
    query.group(0) = 1;
    query.x(1,0) = 2.0;
    query.x(1,1) = 3.0;
    query.x(1,2) = -4.0;
    query.group(1) = 1;

    easi::YAMLParse parser(3);
```

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```
easi::Component* model = parser.parse("test.yaml");

ElasticMaterial material[2];
easi::ArrayOfStructsAdapter<ElasticMaterial> adapter(material);
adapter.addBindingPoint("lambda", &ElasticMaterial::lambda);
adapter.addBindingPoint("mu",      &ElasticMaterial::mu);
adapter.addBindingPoint("rho",      &ElasticMaterial::rho);

model->evaluate(query, adapter);

delete model;

for (unsigned j = 0; j < 2; ++j) {
    std::cout << material[j].lambda << " " << material[j].mu << " " << material[j].rho <
↪< std::endl;
}

return 0;
}
```

COMPILING DEPENDENCIES

1. Setting up compilers

E.g. on SupermucNG:

```
module load intel mpi-intel
export FC=mpif90
export CXX=mpiCC
export CC=mpicc
```

Alternatively for gcc compilers on SupermucNG:

```
export FC=mpifc
export CXX=mpigxx
export CC=mpigcc
```

2. Asagi

See <https://seissol.readthedocs.io/en/latest/asagi.html>.

3. yaml-cpp

On SupermucNG and with intel compilers:

```
module load yaml-cpp/0.7.0-intel21
```

Alternatively you can build from source:

```
git clone git@github.com:jbeder/yaml-cpp
# git clone https://github.com/jbeder/yaml-cpp.git
cd yaml-cpp
git checkout yaml-cpp-0.6.3
mkdir build && cd build
cmake .. -DCMAKE_INSTALL_PREFIX=$HOME
make -j 4
make install
cd ../..
```

4. ImpalaJIT

```
git clone git@github.com:uphoffc/ImpalaJIT
# git clone https://github.com/uphoffc/ImpalaJIT.git
cd ImpalaJIT
mkdir build && cd build
```

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```
cmake .. -DCMAKE_INSTALL_PREFIX=$HOME
make -j 4
make install
cd ../../
```

5. Lua

```
# cmake module on SupermucNG (cmake/3.16.5) does not support lua 5.4
wget https://www.lua.org/ftp/lua-5.3.6.tar.gz
tar -xzf lua-5.3.6.tar.gz
cd lua-5.3.6/
make linux CC=mpicc
make local
cp -r install/* ~
cd ..
```

COMPONENTS

In the following is a list of all components currently available in easi.

Every component has a domain m and a codomain n which can be thought of as a function $f : \mathbb{R}^m \rightarrow \mathbb{R}^n$. That is, a component accepts vectors in \mathbb{R}^m and passes vectors in \mathbb{R}^n to its child components (or as a result). The dimensions are labeled and a child's input dimensions must match its parent's output dimensions.

3.1 Composite components

Each composite may have a sequence of child components. Composite itself is abstract and may not be instantiated. Maps and Filters are always composite, builders are not.

!ABSTRACT
components:

- <Component>
- <Component>
- ...

example

Alternative for composites with a single child:

!ABSTRACT
components: <Component>

Remark: Composites must of at least one child component.

A map allows to map vectors from \mathbb{R}^m to \mathbb{R}^n .

4.1 ConstantMap

Assigns a constant value, independent of position.

```
!ConstantMap  
map:  
  <dimension>: <double>  
  <dimension>: <double>  
  ...
```

Domain *inherited*

Codomain keys in map

Example `0_constant`

4.2 IdentityMap

Does nothing in particular (same as !Any).

```
!IdentityMap
```

Domain *inherited*

Codomain *domain*

4.3 AffineMap

Implements the affine mapping $y = Ax + t$.

```
!AffineMap  
matrix:  
  <dimension>: [<double>, <double>, ...]  
  <dimension>: [<double>, <double>, ...]  
  ...
```

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```
translation:
  <dimension>: <double>
  <dimension>: <double>
  ...
```

Domain *inherited***Codomain** keys of matrix / translation

Example Say we have a row in matrix which reads “p: [a,b,c]”, and a corresponding row in translation “p: d”. Furthermore, assume rho, mu, and lambda are the input dimensions. Then $p = a \cdot \lambda + b \cdot \mu + c \cdot \rho + d$.

[3_layered_linear](#)

By convention, the input dimensions are ordered lexicographically (according to the ASCII code, i.e. first 0-9, then A-Z, and then a-z), hence the first entry in a matrix row corresponds to the the first input dimension in lexicographical order.

4.4 PolynomialMap

Assigns a value using a polynomial for every parameter.

```
!PolynomialMap
map:
  #          x^n,      ...,      x,      1
  <dimension>: [<double>, ..., <double>, <double>]
  <dimension>: [<double>, ..., <double>, <double>]
  ...
```

Domain *inherited* but may only be a one dimension**Codomain** keys in map**Example** [62_landers](#)

4.5 FunctionMap

Implements a mapping described by an ImpalaJIT function.

```
!FunctionMap
map:
  <dimension>: <function_body>
  <dimension>: |
    <long_function_body>
  ...
```

Domain *inherited***Codomain** keys in map

Example Input dimensions are x,y,z. Then “p: return x * y * z;” yields $p = x \cdot y \cdot z$. (Note: Don’t forget the return statement.)

[5_function](#)

The <function_body> must be an ImpalaJIT function (without surrounding curly braces). The function gets passed all input dimensions automatically.

Known limitations:

- No comments (`//` or `/* */`).
- No exponential notation (use `pow(10.,3.)` instead of `1e3`).
- No 'else if' (use `else { if () {} }`).

4.6 ASAGI

Looks up values using ASAGI (with trilinear interpolation).

```
!ASAGI
file: <string>
parameters: [<parameter>,<parameter>,...]
var: <string>
interpolation: (nearest|linear)
```

Domain *inherited*

Codomain keys in parameters

Example `101_asagi`

file Path to a NetCDF file that is compatible with ASAGI

parameters Parameters supplied by ASAGI in order of appearance in the NetCDF file

var The NetCDF variable which holds the data (default: data)

interpolation Choose between nearest neighbour and linear interpolation (default: linear)

4.7 SCECFile

Looks up fault parameters in SCEC stress file (as in http://scecddata.usc.edu/cvws/download/tpv16/TPV16_17_Description_v03.pdf).

```
!SCECFile
file: <string>
interpolation: (nearest|linear)
```

Domain *inherited*, must be 2D

Codomain cohesion, d_c, forced_rupture_time, mu_d, mu_s, s_dip, s_normal, s_strike

Example `example`

file Path to a SCEC stress file

interpolation Choose between nearest neighbour and linear interpolation (default: linear)

4.8 EvalModel

Provides values by evaluating another easi tree.

```
!EvalModel
parameters: [<parameter>,<parameter>,...]
model: <component>
... # specify easi tree
components: <component>
... # components receive output of model as input
```

Domain *inherited*

Codomain keys of parameters

Example `120_initial_stress`: [b_xx, b_yy, b_zz, b_xy, b_yz, b_xz] are defined through the component “!STRESS_STR_DIP_SLIP_AM”, which depends itself on several parameters (mu_d, mu_s, etc). One of these parameter “strike” is set to vary spatially through an “!AffineMap”. “!EvalModel” allows to evaluate this intermediate variable before executing the “!STRESS_STR_DIP_SLIP_AM” component.

4.9 OptimalStress

This function allows computing the stress which would result in faulting in the rake direction on the optimally oriented plane defined by strike and dip angles (this can be only a virtual plane if such optimal orientation does not correspond to any segment of the fault system). The principal stress magnitudes are prescribed by the relative prestress ratio R (where $R = 1/(1 + S)$), the effective confining stress ($\text{effectiveConfiningStress} = \text{Tr}(s_{ii})/3$) and the stress shape ratio $s2ratio = (s_2 - s_3)/(s_1 - s_3)$, where $s_1 > s_2 > s_3$ are the principal stress magnitudes, following the procedure described in Ulrich et al. (2019), methods section ‘Initial Stress’. To prescribe R , static and dynamic friction (mu_s and mu_d) as well as cohesion are required.

```
components: !OptimalStress
constants:
  mu_d:      <double>
  mu_s:      <double>
  strike:    <double>
  dip:       <double>
  rake:      <double>
  cohesion: <double>
  s2ratio:   <double>
  R:         <double>
  effectiveConfiningStress: <double>
```

Domain *inherited*

Codomain stress components (s_xx, s_yy, s_zz, s_xy, s_yz, and s_xz)

4.10 AndersonianStress

This function allows computing Andersonian stresses (for which one principal axis of the stress tensor is vertical).

The principal stress orientations are defined by SH_max (measured from North, positive eastwards), the direction of maximum horizontal compressive stress.

S_v defines which of the principal stresses s_i is vertical where $s_1 > s_2 > s_3$. S_v = 1, 2 or 3 should be used if the vertical principal stress is the maximum, intermediate or minimum compressive stress. Assuming mu_d=0.6, S_v = 1 favours normal faulting on a 60° dipping fault plane striking SH_max, S_v = 2 favours strike-slip faulting on a vertical fault plane making an angle of 30° with SH_max and S_v = 3 favours reverse faulting on a 30° dipping fault plane striking SH_max.

The principal stress magnitudes are prescribed by the relative fault strength S (related to the relative prestress ratio R by $R = 1/(1 + S)$), the vertical stress sig_zz and the stress shape ratio $s2ratio = (s_2 - s_3)/(s_1 - s_3)$, where $s_1 > s_2 > s_3$ are the principal stress magnitudes, following the procedure described in Ulrich et al. (2019), methods section ‘Initial Stress’. To prescribe S, static and dynamic friction (mu_s and mu_d) as well as cohesion are required.

components: !AndersonianStress

constants:

mu_d: <double>
mu_s: <double>
SH_max: <double>
S_v: <int (1,2 or 3)>
cohesion: <double>
s2ratio: <double>
S: <double>
sig_zz: <double>

Domain *inherited*

Codomain stress components (s_xx, s_yy, s_zz, s_xy, s_yz, and s_xz)

4.11 STRESS_STR_DIP_SLIP_AM (deprecated)

This routine is now replaced by the more complete and exact ‘OptimalStress’ routine. It is nevertheless preserved in the code for being able to run the exact setup we use for the Sumatra SC paper (Uphoff et al., 2017). It is mostly similar with the ‘OptimalStress’ routine, but instead of a rake parameter, the direction of slip can only be pure strike-slip and pure dip-slip faulting (depending on the parameter DipSlipFaulting). In this routine the s_zz component of the stress tensor is prescribed (and not the confining stress $\text{tr}(\text{sii})/3$) as in ‘OptimalStress’.

components: !STRESS_STR_DIP_SLIP_AM

constants:

mu_d: <double>
mu_s: <double>
strike: <double>
dip: <double>
DipSlipFaulting: <double> (0 or 1)
cohesion: <double>
s2ratio: <double>

Domain *inherited*

Codomain stress components (s_xx, s_yy, s_zz, s_xy, s_yz, and s_xz)

Example 120_initial_stress

4.12 SpecialMap

Evaluates application-defined functions.

```
!<registered-name>
constants:
  <parameter>: <double>
  <parameter>: <double>
  ...
```

Domain *inherited* without constant parameters

Codomain user-defined

Example We want to create a function which takes three input parameters and supplies two output parameters:

```
#include "easi/util/MagicStruct.h"

struct Special {
  struct in {
    double i1, i2, i3;
  };
  in i;

  struct out {
    double o1, o2;
  };
  out o;

  inline void evaluate() {
    o.o1 = exp(i.i1) + i.i2;
    o.o2 = i.i3 * o.o1;
  }
};

SELF_AWARE_STRUCT(Special::in, i1, i2, i3)
SELF_AWARE_STRUCT(Special::out, o1, o2)
```

Register this file with the parser:

```
easi::YAMLParse parser(3);
parser.registerSpecial<Special>("!Special");
```

And use it in the following way, e.g.:

```
!Special
constants:
  i2: 3.0
```

The domain of !Special is now i1, i3 and the codomain is o1, o2. i2 is constant and has the value 3.

FILTERS

Filters accept only a subsets of points and allows for the spatial partitioning of models.

5.1 Any

Any mostly serves as a root node and accepts every point and every group.

```
!Any
```

Domain *inherited*

Codomain *domain*

Example `1_groups`

5.2 AxisAlignedCuboidalDomainFilter

Accepts only points inside an axis-aligned bounding box, i.e. when $l_x \leq x \leq u_x$ and $l_y \leq y \leq u_y$ and ...

```
!AxisAlignedCuboidalDomainFilter
limits:
  <dimension>: [<double>, <double>] # [l_x, u_x]
  <dimension>: [<double>, <double>] # [l_y, u_y]
  ...
```

Domain *codomain*

Codomain keys of limits

Example `f_103_scec`

5.3 SphericalDomainFilter

Accepts only points inside a sphere, i.e. when $\|x - c\| \leq r$.

```
!SphericalDomainFilter
radius: <double>
centre:
  <dimension>: <double>
  <dimension>: <double>
  ...
```

Domain *codomain*

Codomain keys of centre

5.4 GroupFilter

Accepts only points belonging to a set of groups.

```
!GroupFilter
groups: [<int>, <int>, ...]
```

Domain *inherited*

Codomain *domain*

Example `120_sumatra`

5.5 Switch

Can be used to use select a component based on the requested parameters.

```
!Switch
[<parameter>, <parameter>, ...]: <component>
[<parameter>, <parameter>, ...]: <component>
...
```

Domain *inherited*

Codomain *domain*

Example `120_sumatra`: `[mu_d, mu_s, d_c]` are defined with a `!ConstantMap` and `[cohesion, forced_rupture_time]` are defined with a `!FunctionMap`.

The component on the right-hand side of the colon specifies a sub-model for the parameters on the left-hand side of the colon. The parameter lists must not intersect, as otherwise the sub-model, which shall be evaluated for a parameter, would not be uniquely defined.

BUILDERS

Builders are not components by itself, but build a subtree using available components.

6.1 LayeredModel

Defines parameters at nodes, which are interpolated inbetween nodes.

```
!LayeredModel
map: <map> # Mapping to 1D (root component)
interpolation: (lower|upper|linear)
parameters: [<dimension>, <dimension>, ...] # order of dimension
nodes:
  <double>: [<double>, <double>, ...] # key: node position, value: dimension values
  <double>: [<double>, <double>, ...]
  ...
```

Domain *inherited*, must be 1D

Codomain length of coefficients sequence

Interpolation methods

lower Take the value of the lower (smaller) node

upper Take the value of the upper (larger) node

linear Linear interpolation

Example `3_layered_linear`

6.2 Include

Includes another configuration file.

```
!Include <filename>
```

Example `f_120_sumatra`

GLOSSARY

Domain and codomain The set of all permitted inputs to a given function is called the domain of the function, while the set of permissible outputs is called the codomain.

Map A map transforms a m-dimensional input vector into an n-dimensional output vector.

Filter A filter is a boolean function which either accepts or rejects input vectors.

Composite components A composite component is a component with attached components (that is, a composite is the root of a tree). Basically, it means that several components can be plugged to process a chain of operations. Maps and Filters are composite components, Builders are not.