No C++, please. We're users!

Case setup and quantitative evaluation using swak4Foam (and a bit of PyFoam)

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Outline

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Aim of this lecture

- Introduction to `swak4Foam`
- Give a crash-course in the use of the `pyFoam`-utilities
  - We will see some of the lesser known utilities in action
- After this lecture you should know
  - what `swak4Foam` can do
  - how to use it yourself

About this presentation

- This presentation is accompanied by a tar with the necessary case files to reproduce the steps described here
  - More about that later
- The slides with the word **Movie** in the title have an embedded movie
  - This is not directly playable with all PDF-viewers
  - ... for instance with Okular on the stick you'll have to safe it and play it separately
- If you see <brk> <cnt> in the code examples then this is just a line that was too long for the slide

Meeting Ignaz . . . again

- Ignaz is a CFD-engineer
  - A specialist for the `damBreak`-case
- We already met him in two presentations on `PyFoam`
  - Happy foaming with Python (Montreal 2009)
  - Automatisation with PyFoam (Gothenburg 2010)
- We meet during a severe crisis in his live

Ignaz problem

- For a `damBreak`-project Ignaz needed complex boundary conditions and procedures to evaluate the results
- Ignaz decided to code these in C++
- After encountering a 42-line compiler error message Ignaz suffered a nervous breakdown
- After recovering his doctor forbid him the use of C++
  - ... and to limit his use of Python
- Ignaz is devastated because he does not know how to complete his job
  - He goes on a binge of watching MacGuyver reruns
- .... and then the solution occurs to him:

What is swak4Foam

From http://openfoamwiki.net/index.php/Contrib/swak4Foam

> swak4Foam stands for SWiss Army Knife for Foam. Like that knife it rarely is the best tool for any given task, but sometimes it is more convenient to get it out of your pocket than going to the tool-shed to get the chain-saw.

It is the result of the merge of

- funkySetFields
- groovyBC

and has become something mightier and scarier. Something that even the mighty Chutulu does not dare to anger without good reason... but I digress

Outline

Setting the OpenFOAM-version

- Currently Ignaz uses OpenFOAM 1.7
  - No particular reaseon. He just likes odd numbers
- Make sure that you're using it as well
  - If you're not sure whether your shell is set to it. Just enter

```
startOF171
```

on the shell

- or just click the "OpenFOAM 1.7.1"-button on the desktop
  - You get a terminal with the a `zsh` that is pre-configured to use OpenFOAM 1.7.1

Advertisement: `zsh`

- Ignaz likes the `zsh`
- With a good configuration file (`.zshrc`) it kicks the `bash`'es ... whatever
  - It is more colorful
  - It has a nice tab-completion
  - It knows about `SVN`, `git` or `mercurial`

Preparing our environment

- Make sure you use OF 1.7
- Go to the directory you plan to work in

```
cd $HOME
```

- Get the contents of the archive with the training material

```
tar xzf /cdrom/OFW6/Training/gschaider_material.tgz
```

- Enter the directory

```
cd swakAndPyFoam
```

- The shell prompt should tell you
  - That you're in a `git`-archive
  - That you're on the `default`-branch

Going to specific points with git

- We're going to cover a lot of ground during this lecture
- If you get lost: don't despair
  - Throughout the presentations there will be commands like

```
git checkout 0000_OriginalTutorial -b original
```

- This means:
  - Got to the tag `0000_OriginalTutorial` (on the `zsh` entering `000` then pressing TAB will complete the tag name for you. Can you understand why Ignaz likes the `zsh`?)
  - Open a new branch `original` (that name you can choose for yourself)
- If you did changes that you want to keep for a later review (on the flight home) enter something like (the text of the message is yours)

```
git commit -a -m "This works. Cool. But we're moving to the next stage"
```

- and later you can recall it with

```
git checkout original
```

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What is PyFoam

- `PyFoam` is a library for
  - Manipulating `OpenFOAM`-cases
  - Controlling `OpenFOAM`-runs
- It is written in Python
- Based upon that library there is a number of utilities
  - For case manipulation
  - Running simulations
  - Looking at the results
- All utilities start with `pyFoam` (so TAB-completion gives you an overview)
  - Each utility has an online help that is shown when using the `-help`-option
  - Additional information can be found
    - on `openfoamwiki.net`
    - in the two presentations mentioned above

Outline

Case setup

- Cloning an existing case

```
pyFoamCloneCase.py $FOAM_TUTORIALS/incompressible/simpleFoam/pitzDaily test
```

- Decomposing the case

```
blockMesh -case test
pyFoamDecompose.py test 2
```

- Getting info about the case

```
pyFoamCaseReport.py test --short-bc --decomposition | rst2pdf >test.pdf
```

- Clearing non-essential data

```
pyFoamClearCase.py test --processors
```

- Pack the case into an archive (including the last time-step)

```
pyFoamPackCase.py test --last
```

- List all the OpenFOAM-cases in a directory (with additional information)

```
pyFoamListCases.py .
```

Running

- Straight running of a solver

```
pyFoamRunner.py interFoam
```

- Clear the case beforehand and only show the time

```
pyFoamRunner.py --clear --progress interFoam
```

- Show plots while simulating

```
pyFoamPlotRunner.py --clear --progress interFoam
```

- Change `controlDict` to write all time-steps (afterwards change it back)

```
pyFoamRunner.py --write-all interFoam
```

- Run a different OpenFOAM-Version than the default-one

```
pyFoamRunner.py --foam=1.9-beta interFoam
```

- Run the debug-version of the current version

```
pyFoamRunner.py --current --force-debug interFoam
```

Generated files

- Typically PyFoam generates several files during a run (the names of some of those depend on the case-name)

  case.foam Stub-file to open the case in ParaView

  PyFoamRunner.solver.logfile File with all the output that usually goes to the standard-output

  PyFoamRunner.solver..analyzed Directory with the results of the output analysis

  pickledPlots A special file that stores all the results of the analysis

  PyFoamHistory Log with all the PyFoam commands used on that case

Plotting

- Any logfile can be analyzed and plotted

```
pyFoamPlotWatcher.py --progress someOldLogfile
```

- A number of things can be plotted
  - Residuals
  - Continuity error
  - Courant number
  - Time-step
- User-defined plots can be specified
  - Specified in a file `customRegexp`
  - Data is analyzed using regular expressions
  - We will see examples for this later
- The option `-hardcopy` generates pictures of the plots

Outline

What else can PyFoam do for me?

- Write and read dictionaries from the command line
- Display the `blockMeshDict`
- Generate plots of Surfaces and sample lines
- Interact with paraView
- Control OpenFOAM-runs over the net

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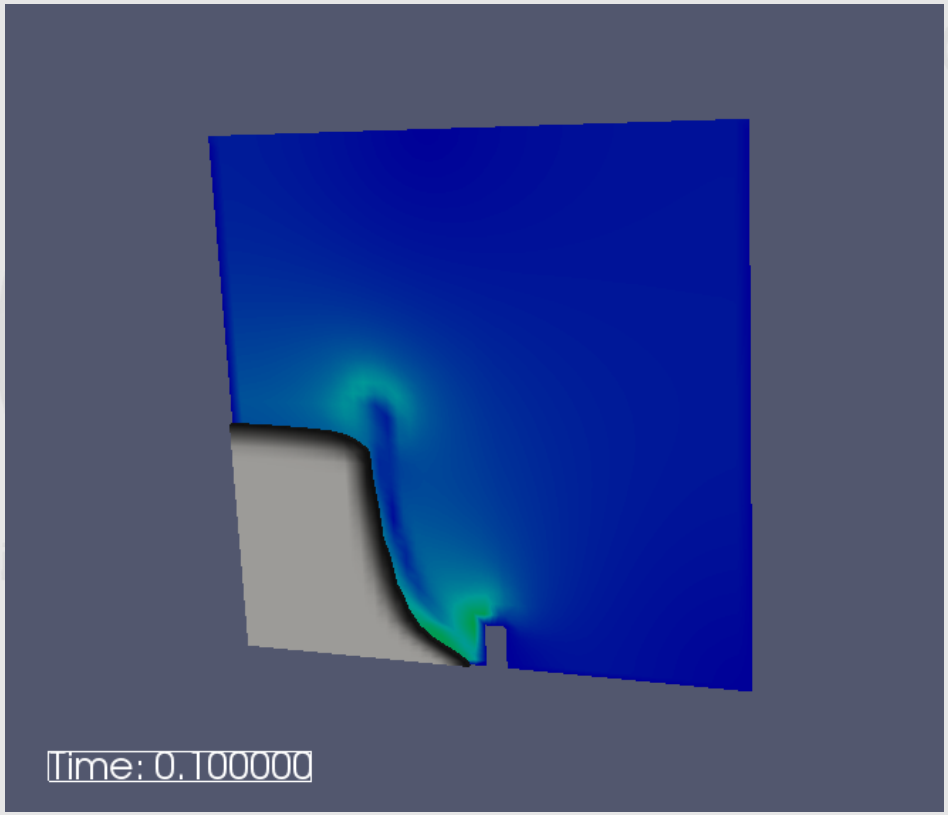
Description of the `damBreak` case

- Ignaz is a specialist on the `damBreak` case
  - We already said that
- The case can be found in the `FOAM_TUTORIALS`
- This is how the case looks like


```
git checkout 0000_OriginalTutorial -b original
```

Movie: damBreak original



Clearing out unused stuff

- Ignaz prepares the case for his purposes:
  - Remove the unneeded `setFieldsDict`
  - Make sure that all the files touched by a utility end with `.gz`

```
git checkout 0010_StartingPoint -b step1
```

Outline

Ignaz wants to play ball

- Ignaz is asked to apply his knowledge in the sports industry:
  - Investigate the possibility to use liquid spheres for games
- He reuses the `damBreak`-case but the initial conditions should be different

```
git checkout 0020_throwABall -b step2
```

Preparing the case from now on

In the following sections the case will always be prepared in this way:

- Create the mesh

```
blockMesh
```

- Run script with some additional commands

```
./prepareCase.sh
```

- Run the solver

```
pyFoamRunner.py --clear --progress interFoam
```

The preparation script

```
1 #! /bin/sh

3 pyFoamClearCase.py .

5 rm -f 0/*.gz

7 cp 0/alpha1.org 0/alpha1
  cp 0/U.org 0/U
9
  funkySetFields -time 0
```

What it does

1. Clears out old time-steps (if present)
2. Removes files touched by utilities from the initial time-step
3. Copy the template files
4. And last but not least: call `funkySetFields`

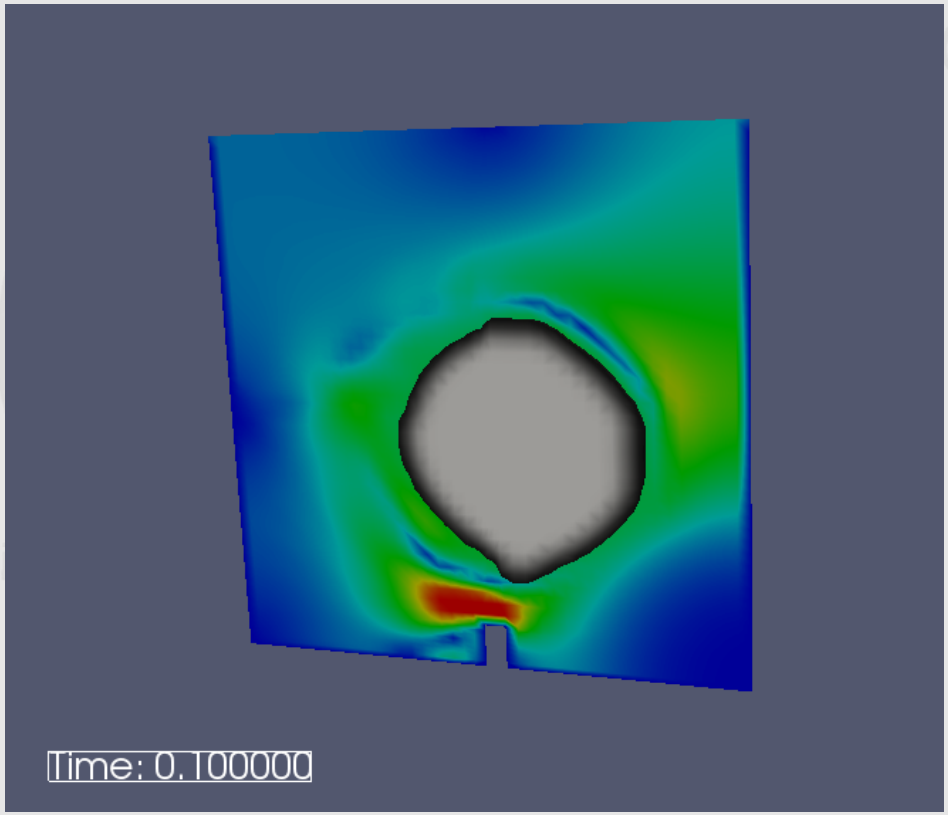
`funkySetFields` - basic usage

- `FSF` always needs the time for which it should be used to be specified on the command line
- For the further information two modes are possible:
  1. `expression` and all the other parameters are specified on the command line
     - This is nice for quickly modifying fields and trying out stuff
     - Only one expression can be entered at a time
  2. Additional parameters are specified in a dictionary file
     - One entry `expressions` with a list of dictionaries is needed
     - Basic parameters have the same names as the command line options

The funkySetFieldsDict

```
expressions
(
    initZero
    {
        field alpha1;
        create false;
        expression "0";
        keepPatches true;
    }
    setCircle
    {
        field alpha1;
        expression "1";
        keepPatches true;
        condition "mag(pos()-vector(0.15,0.3,0.007))<0.12";
    }
    setVel
    {
        field U;
        keepPatches true;
        create false;
        expression "alpha1*vector(2,0,0)";
    }
);
```

Movie: Splashing ball



Expressions in `funkySetFields` - general structure

- The basic format of the expressions is the format of C++-expressions
  - The usual operators `+-*/` (also logical operations and `&&` and `||`)
  - The `if-then-else` operators `?:`
  - `&` and `^` have the same meaning they have in OpenFOAM: inner- and cross-vector-product
- All functions which are implemented for fields in OpenFOAM (`sin`, `cos` etc) can be used
- Components of a vector can be extracted with `.x`, `.y` and `.z`
- There are additional functions. The most important ones are:

  pos the position of the cell center
  vol The volume of the cell

- Numbers create a constant field
  - Vector fields are created with the `vector` "function"
- If an unknown symbol fits an existing field then this field is used (with the correct type)

Outline

Making it more maintainable

- Ignaz is asked to investigate a number of different geometries
- But the proportion of the ball to the geometry should always be the same
- Also his intern thinks that the hardcoded center `vector(0.15,0.3,0.007)` is ugly
  - Ignaz would never argue with an intern

```
git checkout 0030_throwABallVariables -b step3
```

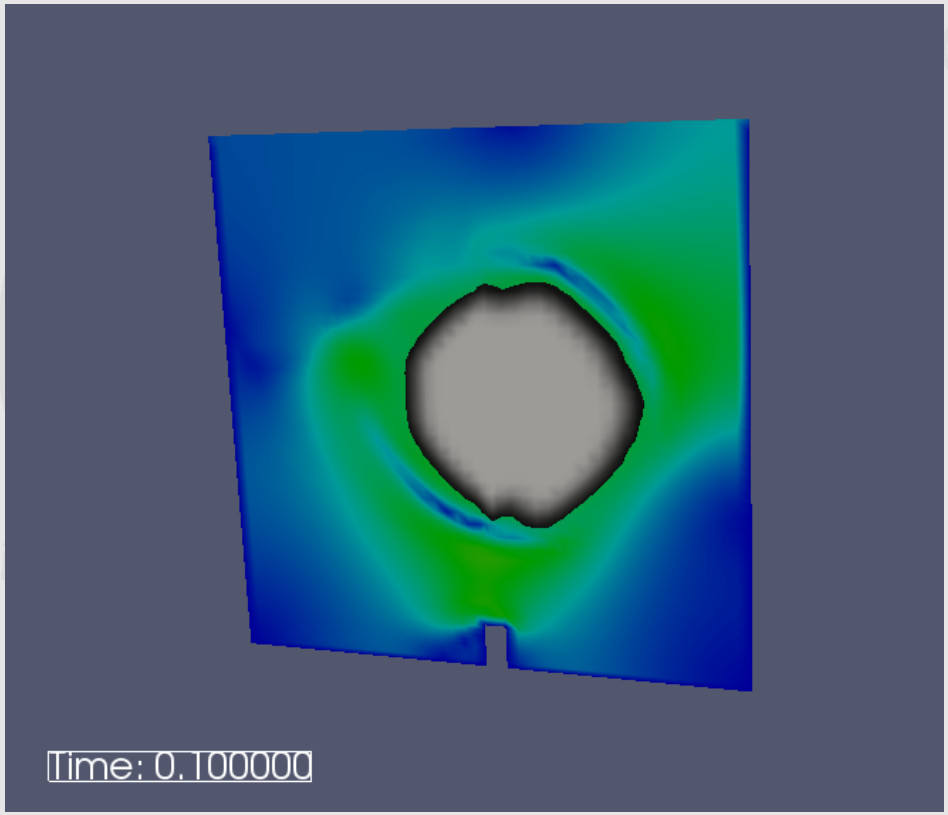
Change in the dictionary

```
setCircle
{
        field alpha1;
        keepPatches true;
        expression  "mag(pos()-center)<radius";
        variables (
           "width=max(pos().x)-min(pos().x);"
           "height=max(pos().y)-min(pos().y);"
           "middle=(max(pos().z)+min(pos().z))/2;"
           "center=vector(min(pos().x)+width/4,min(pos().y)+height<brk>
              <cont>*3/5,middle);"
           "radius=width/5;"
        );
}
```

Things you should know about variables

- Variables are defined in a surprisingly appropriately named list `variables`
  - Used to be a single unreadably long string
- Syntax is
  1. Variable name
  2. `=|`
  3. `Expression (can contain previously defined variables)`
  4. `A closing ;`
- A variable takes precedence over a field of the same name (be careful!)
- Variables are only available in FSF if being used in dictionary-mode

Movie: Slightly different splash



Outline

Alternative to the old `setFields`-expression

- Ignaz is asked to investigate a slightly more boring type of wave
  - Can reuse the existing case
- Because he doesn't want to overwrite the amazing ball-condition in `funkySetFieldsDict` he uses an alternate dictionary `funkySetFieldsDict.alternate`:

```
funkySetFields -time 0 -dictExt alternate
```

- This case can be found in

```
git checkout 0040_boringAlternative -b boring
```

The expression

```
setLower
{
        field alpha1;
        keepPatches true;
        expression  "(pos().y<height/2) ? 1 : <brk>
            <cont>((pos().y<height*3/5 && pos()<brk>
            <cont>.x>width/2) ? 1 : 0)";
        variables (
            "width=max(pos().x)-min(pos().x);"
            "height=max(pos().y)-min(pos().y);"
        );
}
```

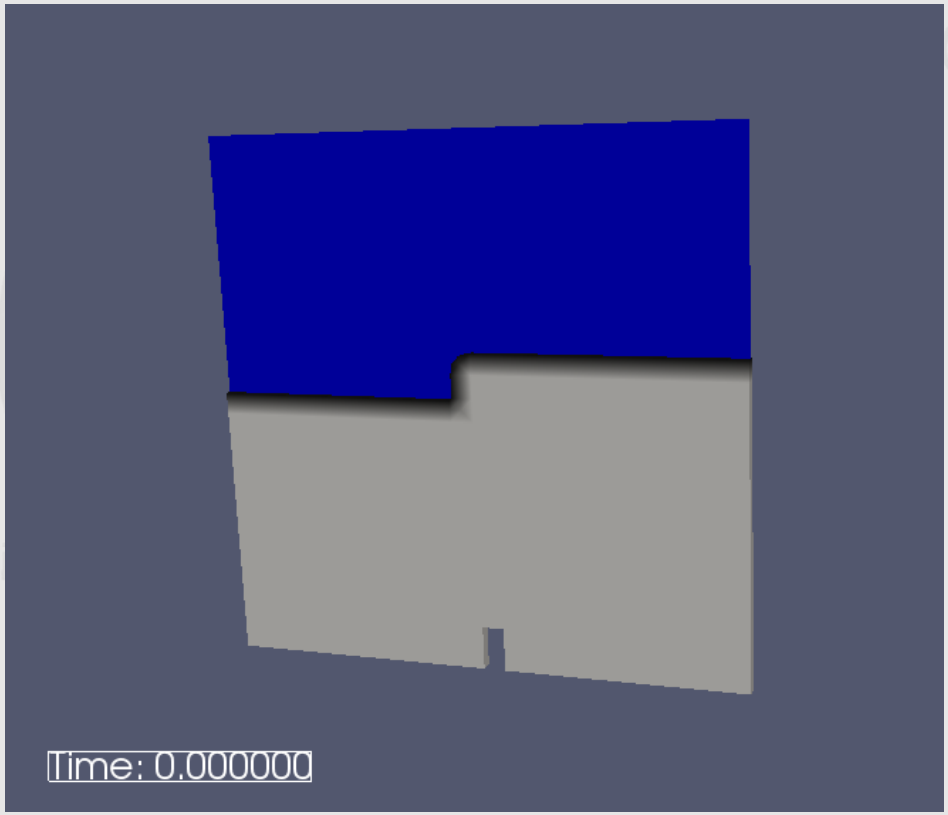
The conditional expression

- Common on the C/C++/Java-family of programming languages
- Is basically a `if-then-else` in one line
  - `a ? b : c` means if `a` is true then use `b` else use `c`
    - `a` has to be a logical expression
    - `b` and `c` have to evaluate to the same type (scalar or vector)
- **Careful**: `b` and `c` are always completely evaluated
  - So something like `x==0 ? 0 : 1/x` will fail with a division by zero
- For the non-programmers: in C++

  `&&` means logical **and**

  `||` is logical **or**

Movie: A gentler `damBreak`



Outline

Filling from below

- Ignaz would like to investigate whether there are faster ways to fill the geometry than throwing balls
  - Liquid is inserted on the right
  - Height of the insertion depends on the geometry size
- But Ignaz is too lazy to rewrite the `blockMeshDict`
  - He only changes the boundary condition on the `rightWall` to `mixed`
- This is what he did:

```
git checkout 0050_waterFromTheRight -b staticBC
```

- He sets the static boundary condition with

```
funkySetBoundaryField -time 0
```

alpha1 before

```
boundaryField
{
    leftWall
    {
        type            zeroGradient;
    }

    rightWall
    {
        type            mixed;
        value uniform 0;
        refValue uniform 0;
        refGradient uniform 0;
        valueFraction uniform 0;
    }
```

Excerpt from `funkySetBoundaryFields`

```
blowIn {
    field alpha1;
    expressions
    (
        {
            target refValue;
            patchName rightWall;
            expression "1";
        }
        {
            target valueFraction;
            patchName rightWall;
            variables (
                "maxY=max(pts().y);"
                "thres=0.2*maxY;"
            );
            expression "pos().y<thres ? 1 : 0";
        }
    );
}
```

alpha1 after

```
    rightWall
    {
        type            mixed;
        value           uniform 0;
        refValueOld     uniform 0;
        refGradient     uniform 0;
        valueFractionOld uniform 0;
        refValue        uniform 1;
        valueFraction   nonuniform List<scalar <brk>
            <cont>>
50
(
1
1
1
```

Executing the solver

- The version 1.7.1 of the `interFoam` has a strange bug when using `mixed` boundary conditions
  - This is fixed in `1.7.x`
  - But on the stick we only have `1.7.1`
- Nevertheless we can execute these examples with another solver

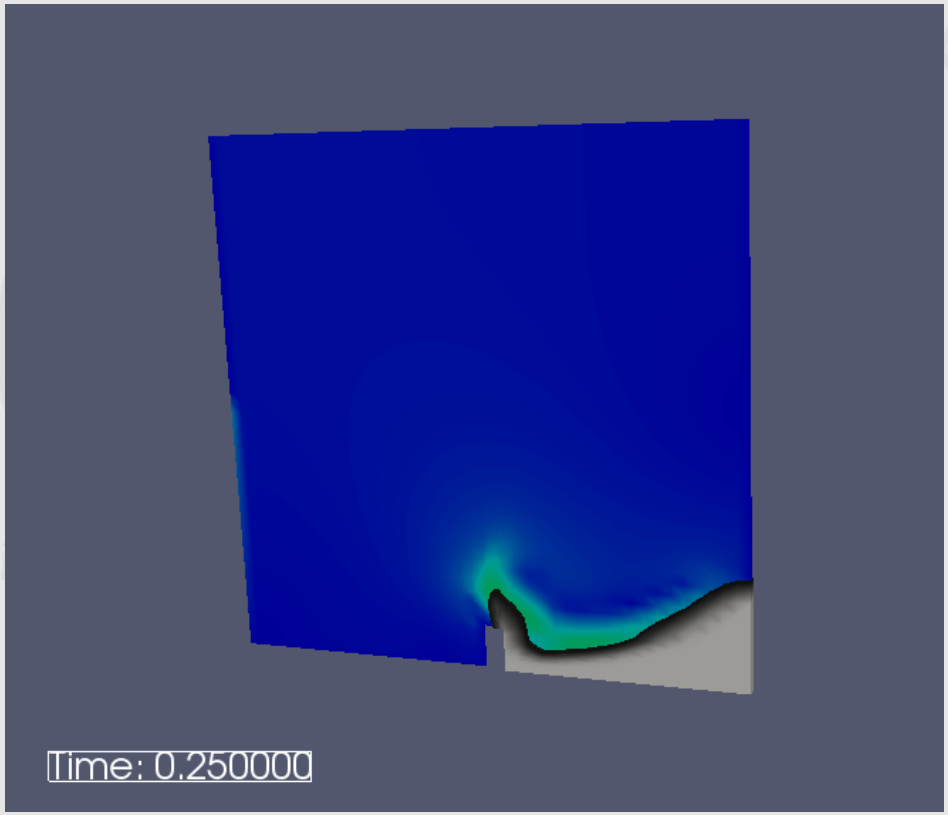
```
pyFoamRunner.py --clear --progress interFlux
```

- But what is this `interFlux`-solver?
- It is part of ...

pythonFlu

- `pythonFlu` is a Python-binding for OpenFOAM
  - by Alexey Petrov
- Makes it possible to access all the OpenFOAM-functionality from Python
  - With all the speed of C++
  - All the comfort of Python
- So `interFlux` is a solver written in Python
  - With the speed of `interFoam`
  - and the same functionality

Movie: Liquid from the right



Outline

Outline

Only the velocity that matters

- Ignaz is not interested in the velocity in the air
- He wants to have the pure liquid velocity for post-processing

```
git checkout 0060_expressionField -b exprfield
```

Function objects

- `functionObjects` are plugins that can be loaded at run-time
- They can be executed at every time-step and do various things
  - Post-process
  - Manipulate the solution
  - etc
- A number of functionObjects comes with OpenFOAM
- To use a functionObject
  - The library that defines it has to be loaded in the `libs`-list in the `controlDict`
  - It has to have an entry in the `functions`-list
    - An entry is a dictionary with various entries

      type Determines which functionObject this is
      outputControl when the function object is executed
    - All other entries depend on the `functionObject`-type

Entry in the controlDict

```
libs (
    "libswakFunctionObjects.so"
);

functions (
    liquidVel {
        type expressionField;
        outputControl outputTime;
        fieldName Uliquid;
        expression "U*alpha1";
        autowrite true;
    }
);
```

The expressionField

- Create a new field from an expression

fieldName	Name under which this field will be known
expression	What should be in the field
autowrite	Whether the field should be written to disc at the usual write times (otherwise the field is only of use for other expressions)

Two velocities - Before

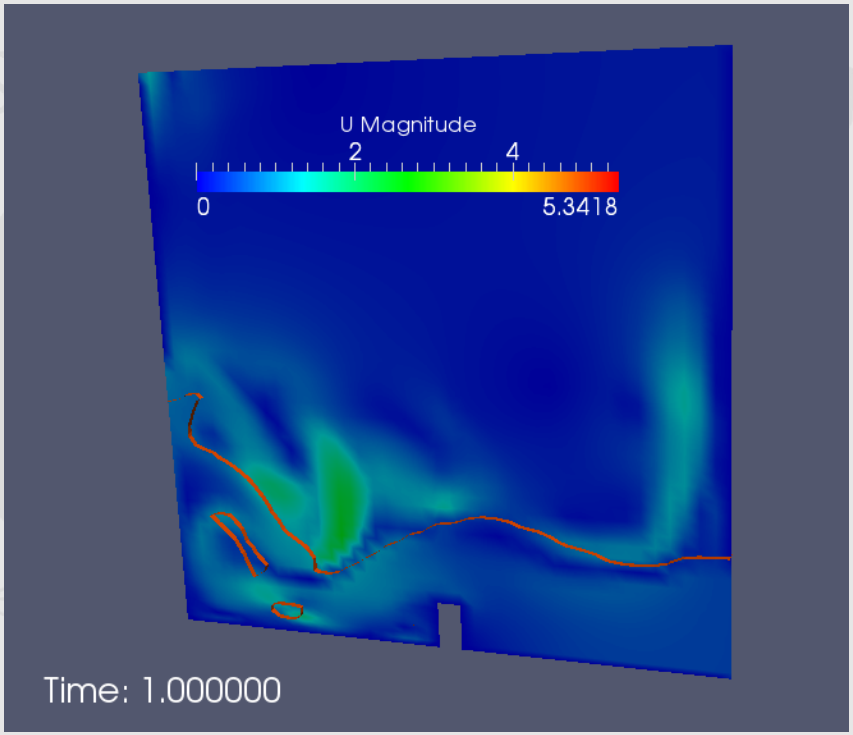


Figure: Overall velocity

Two velocities - After

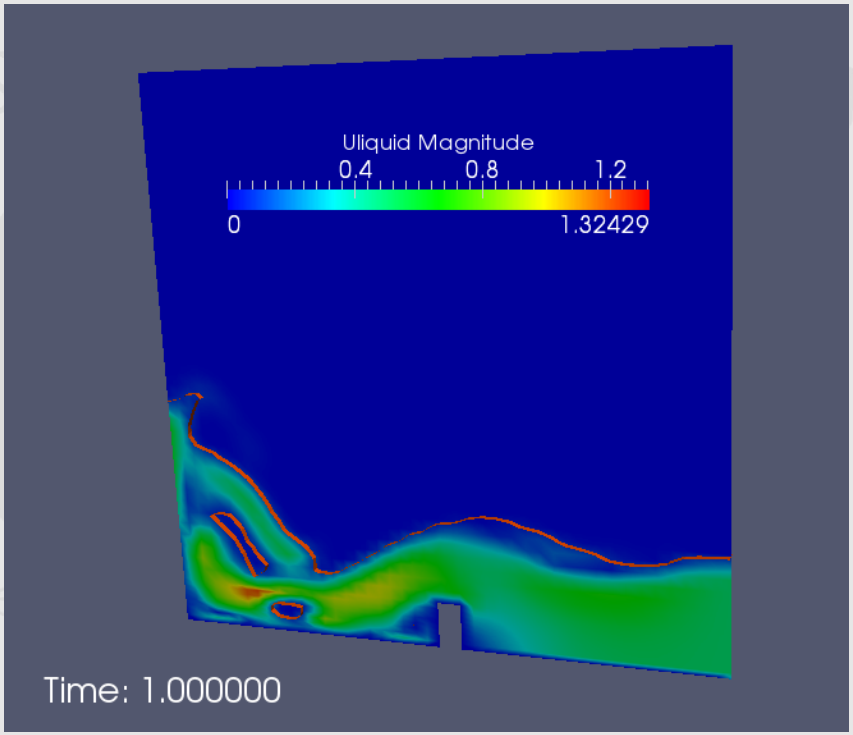


Figure: Liquid velocity

Outline

How fast is it filling

- Ignaz wants to see during the simulation how fast the geometry is filling with liquid
- This is what he does to the case

```
git checkout 0070_simpleFunctionObject -b simpleFO
```

- This is how he runs it

```
pyFoamPlotRunner.py --progress --clear interFlux
```

What is simpleFunctionObjects

- simpleFunctionObjects is a collection of functionObjects
  - Mostly for post-processing
    - Calculates and outputs extremes, averages and integrals on
    - volumes
    - patches
  - Other stuff: writing additional fields, tracking dictionaries etc
- Some of the functionality is now present in OpenFOAM
  - But it is kept in simpleFunctionObjects for backward compatibility

Addition to controlDict

```
libs (
    "libswakFunctionObjects.so"
    "libsimpleFunctionObjects.so"
);

functions (
    totalLiquid {
        type volumeIntegrate;
        fields (
            alpha1
        );
        verbose true;
    }
    liquidVel {
        type expressionField;
        outputControl outputTime;
        fieldName Uliquid;
        expression "U*alpha1";
        autowrite true;
    }
);
```

What `simpleFunctionObjects` usually do

- Data gets written into a directory that is named after the name of the function object
- Usual fields:

verbose Also write the data on the standard output (this is necessary for the next step)

fields List of fields on which the FO should work

patches If the FO works on patches these are specified in this list

The customRegexp

- Every entry in the customRegexp file is one data set

expr A regular expression that the output of the solver is scanned for

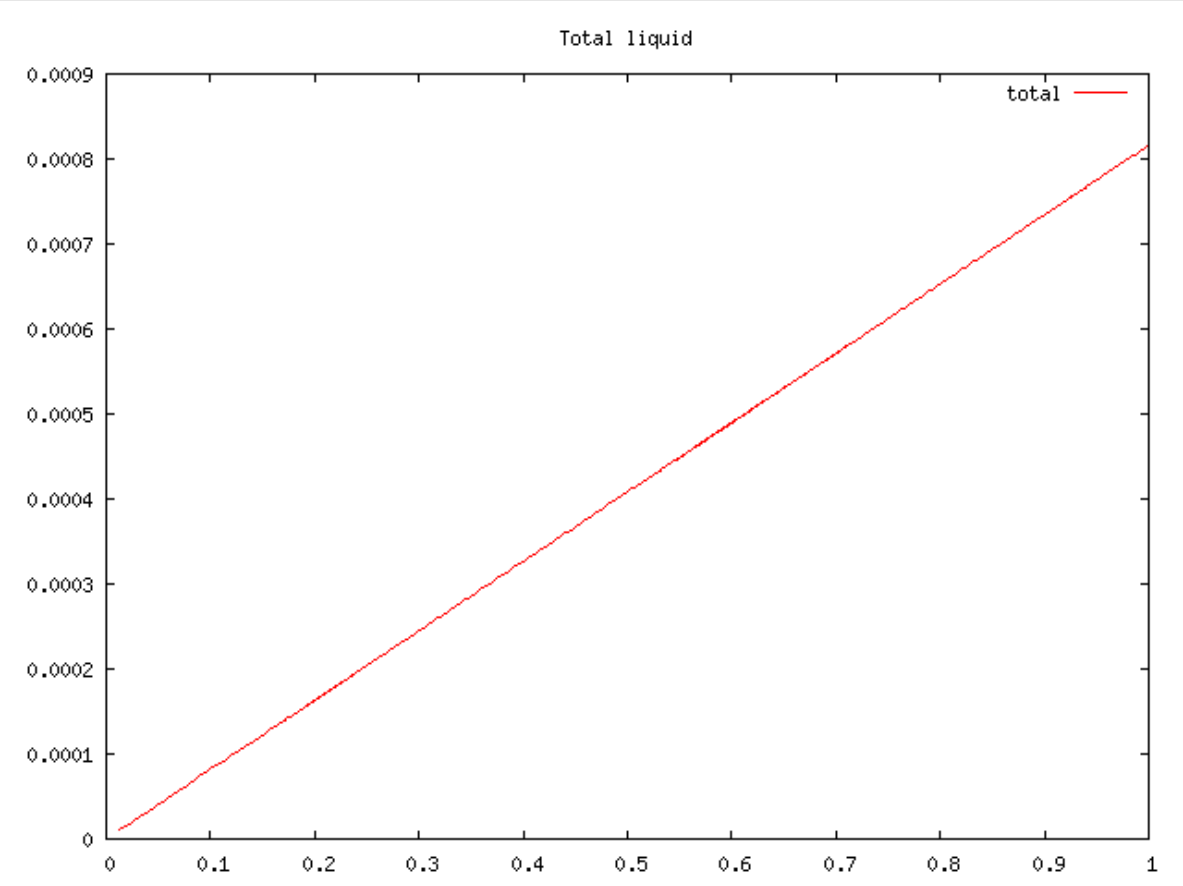
- Each group enclosed in () is one data item
- %f% is an abbreviation for the regular expression that matches a floating point number

theTitle Title of the plot

titles Names of the data sets

```
liquid {
        expr "Integral␣of␣alpha1␣=␣(%f%)";
        theTitle "Total␣liquid";
        titles ( total );
}
```

Total amount of liquid



Outline

The tide is high

- The amount of liquid is interesting, but Ignaz wants to know more:
  - What is currently the highest level of the liquid?
  - Definition of liquid is: $\alpha > 0.5$
- We go to:

```
git checkout 0080_liquidHeight -b liquidHeight
```

General expressions

- Adding

  ```
  "libsimpleSwakFunctionObjects.so"
  ```

  gives us a combination of the simpleFunctionObjects and swak-expressions:

- Calculating arbitrary expressions on any entity swak knows about

  type Always `swakExpression`
  valueType Type of the entity. Other entities than `internalField` might need additional specifications
  expression The expression to be calculated
  accumulations The calculated values have to be distilled into a single value. This is a list of specifications how this should be done. Possible values are `min`, `max`, `average` and `sum` (Finding out what they do is left to the reader as an exercise)

Maximum height of the liquid


```
maxHeight {
    type swakExpression;
    valueType internalField;
    expression "(alpha1>0.5) ? pos().y : 0";
    accumulations (
        max
    );
    verbose true;
}
```

Average height of the liquid

Note: if this gives you a floating point exception, probably the expression `sum(alpha1*vol())` is 0 in the beginning. Modification is left to the reader as an exercise

```
liquidHeight {
    type swakExpression;
    valueType internalField;
    expression "pos().y*alpha1*vol()/sum(<brk>
        <cont>alpha1*vol())";
    accumulations (
        sum
    );
    verbose true;
}
```

Calculating on patches

- For patches there is a specialized FO `patchExpression`
  - But you can also use `swakExpression` with `valueType` set to `patch`
  - But `patchExpression` makes working with more than one patch at a time possible
- The entry `patches` lets you specify a list of patches

Height on the walls

```
wallHeight {
    type patchExpression;
    expression "(alpha1>0.5) ? pos().y : 0";
    patches (
        leftWall
        rightWall
        lowerWall
    );
    accumulations (
        max
    );
    verbose true;
}
```

Joining plots into one

- An expression in `customRegexp` can only match one line of the output
  - Sometimes we want information from more than one line in a plot
- To achieve this we have two types of entries:

  master By default every plot is a master (it has its own plotting window). Noting has to be done

  slave This entry doesn't get his own window but it appends its data to another window. The following entries have to be added:

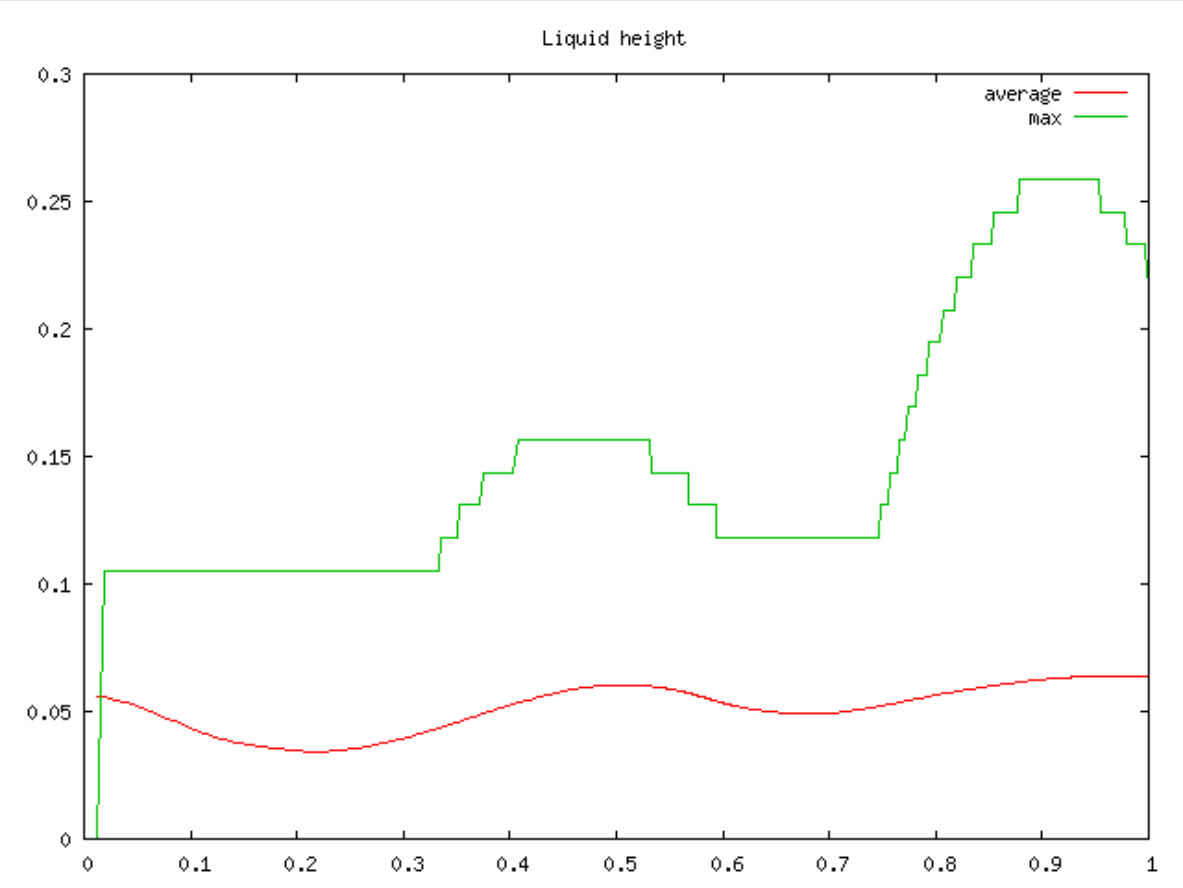
  type This is set to `slave`

  master Name of the plot that the data is added to

Master and slave in customRegexp

```
height {
        expr "Expression liquidHeight : sum=(%<brk>
            <cont>f%)";
        theTitle "Liquid height";
        titles ( average );
}
maxheight {
        expr "Expression maxHeight : max=(%f%)<brk>
            <cont>";
        titles ( max );
        type slave;
        master height;
}
```

Liquid height



Dynamic plots

- Sometimes a number of similar data-sets should be joined into a plot
  - The pattern is similar. They are only distinguished be their name
- This kind of plot can be set using these entries:

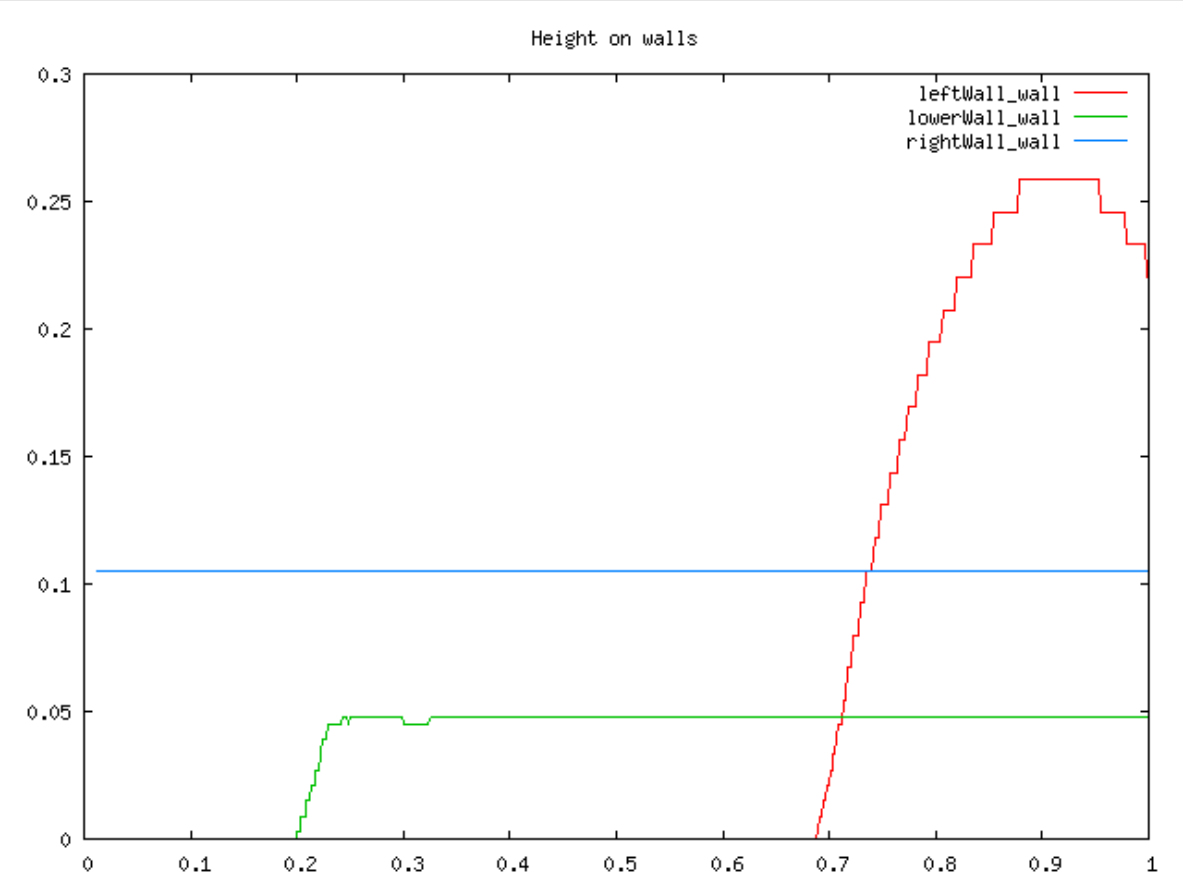
  type is set to `dynamic` (a dynamic plot can't be a `slave`)

  idNr The number of the pattern that contains the name (according to the regular expression convention this the number of the opening `(` of a `()`-group)

Don't know how many names we've got


```
wallheight {
        theTitle "Height on walls";
        expr "Expression wallHeight on (.+):  <brk>
            <cont>max=(%f%)";
        titles ( wall );
        type dynamic;
        idNr 1;
}
```

Liquid height on the walls



BTW: debugging the customRegexp

- The Plot-utilities have a number of command line options that help with debugging/working with customRegexp:

  –dump Output the data as internally stored (helps finding problems with missing ; or similar)

  –exclude-regexp-fitting Exclude all plots that fit a regular expression (used more than once. Processed in the order of occurrence)

  –include-regexp-fitting To switch on excluded plots again (by default all are included)

  –list-custom-Regexp List all the plots. Shows whether they are switched on or off by exclude/include

Outline

How much liquid is in the 'pools'

- A swimming pool manufacturer approaches Ignaz because he thinks the `damBreak`-case might help him to find optimal filling strategies for pools
- For a first calculation Ignaz defines the cavities to the left and the right of the dam as pools
  - He wants to define them as `cellSets`

```
git checkout 0090_setCalculations -b setCalc
```

Creating cellSet's

- Since old times (but known by few) it is possible to define blocks as cellSet's in blockMeshDict
  - Just insert a word in the block-specification

```
blocks
(
    hex (0 1 5 4 12 13 17 16) leftPool  (23 8 1) <brk>
        <cont>simpleGrading (1 1 1)
    hex (2 3 7 6 14 15 19 18) rightPool (19 8 1) <brk>
        <cont>simpleGrading (1 1 1)
    hex (4 5 9 8 16 17 21 20) (23 42 1) simpleGrading (1 1 <brk>
        <cont>1)
    hex (5 6 10 9 17 18 22 21) (4 42 1) simpleGrading (1 1 <brk>
        <cont>1)
    hex (6 7 11 10 18 19 23 22) (19 42 1) simpleGrading (1 <brk>
        <cont>1 1)
);
```

Defining a `cellSet` depending on a position

- The `cellSet`-utility that comes with OpenFOAM allows one to create a `cellSet`
  - By adding

```
"libswakTopoSources.so"
```

  to the `libs` entry it can be extended to use Swak
- The type of the new creator is `expressionToCell` and all cells for which the logical `expression` evaluates to `true` are added
- Ignaz uses this to create a `cellSet` at the starting position of the liquid

Starting position

```
// Name of set to operate on
name inBall;

// One of clear/new/invert/add/delete|subset/list
action new;

topoSetSources
(
    expressionToCell
    {
        expression "alpha1 > 0.5";
    }
);
```

Defining a `faceSet`

- Similarly there is a creator `expressionToFace` that creates a `cellSet`.
- swak can't return expressions defined on faces
  - To work around this the definition is: "a face belongs to a `faceSet` if the expression evaluates to `true` in one of its cells and to `false` in the other"

Border of the starting position

```
// Name of set to operate on
name aroundBall;

// One of clear/new/invert/add/delete|subset/list
action new;

topoSetSources
(
    expressionToFace
    {
        expression "alpha1 > 0.5";
    }
);
```

Amount of liquid in the starting position

```
inBall {
    type swakExpression;
    valueType cellSet;
    setName inBall;
    expression "(alpha1*vol())/sum(vol())";
    accumulations (
        sum
    );
    verbose true;
}
```

The `flip()`-function

- This gives back the `flipMap` (orientation) of a `faceZone`
  - Is needed to get the right sign of `phi`
- For a `faceSet` OpenFOAM does not define a `flipMap`
  - By default `flip()` gives back 1 for the whole set
  - If a `cellSet` exists that has the same name as the `faceSet` plus `SlaveCells` then `flip()` is calculated from this
    - This is the same convention as the `setsToZones`-utility of OpenFOAM

Flow through the starting position

```
flowBall {
    type swakExpression;
    valueType faceSet;
    setName aroundBall;
    expression "phi*flip()*alpha1";
    accumulations (
        sum
    );
    verbose true;
    autoInterpolate true;
    warnAutoInterpolate false;
}
```

Alternate expression for the flow

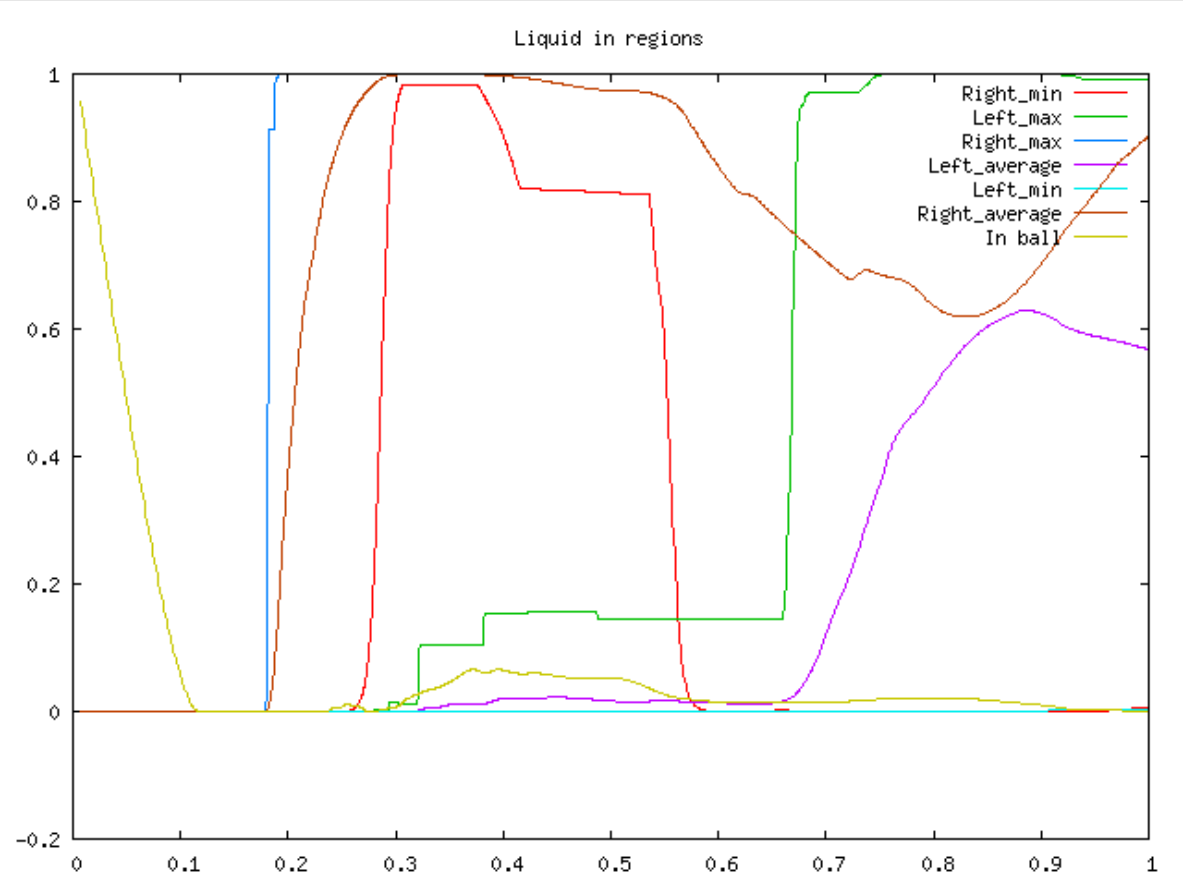
- An alternate way to calculate the flow through a `faceSet` would be to calculate `phi` by hand:

```
expression "(U & Sf())*flip()*alpha1";
```

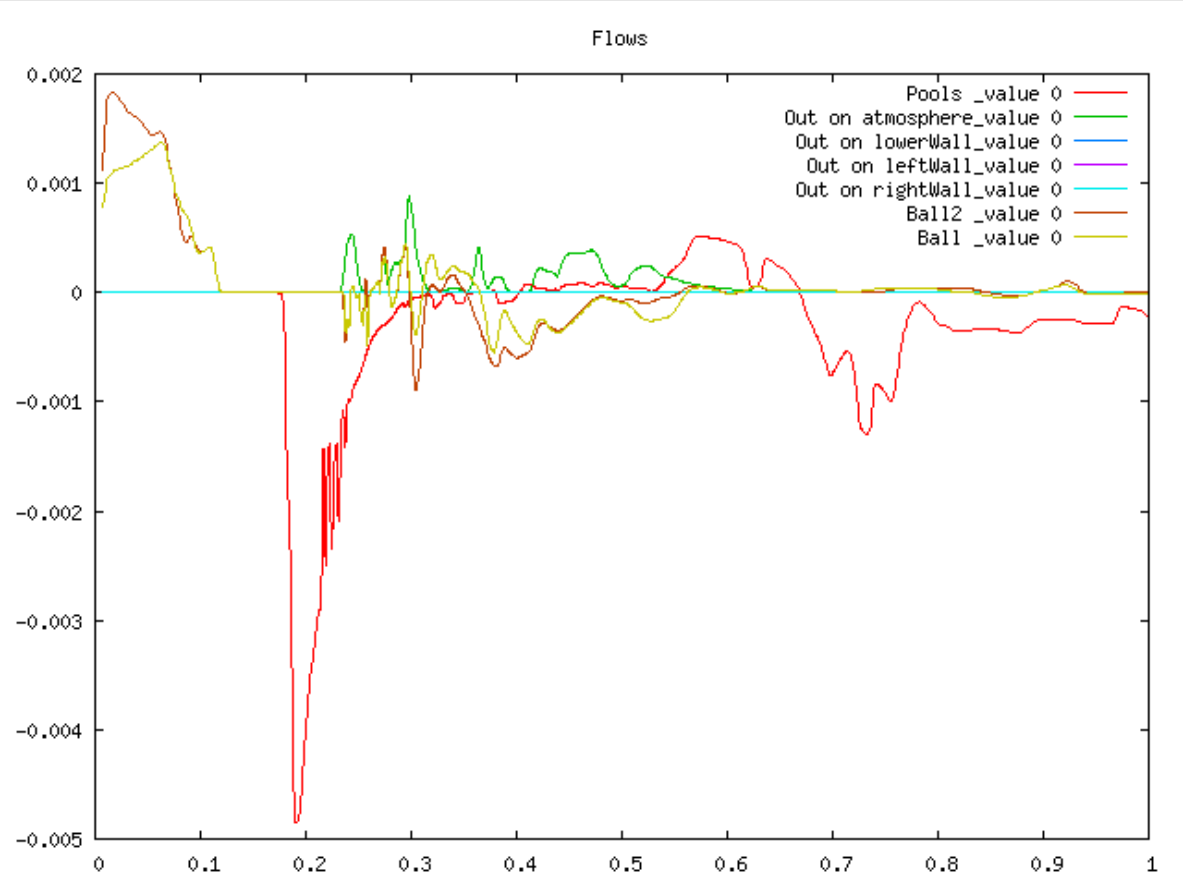
Collecting the results

```
inPools {
        theTitle "Liquid in regions";
        expr "Expression in (.+) : : average=(%f%) min=(%f%) max=(%f%) <brk>
            <cont>";
        titles ( average min max);
        type dynamic;
        idNr 1;
}
inBall {
       expr "Expression inBall : : sum=(%f%)";
       titles ( "In ball");
       type slave;
       master inPools;
}
flowBall {
         theTitle "Flows";
         expr "Expression flow(.+): : sum=(%f%)";
         type dynamic;
         idNr 1;
}
```

Normalized amount in regions



What goes where



Outline

Outline

Preparing for the sum

- Ignaz wants to have a quick overview how much liquid is in all the pools
- Alternatives would be:
  - Calculate this by hand from the available results
  - Create a new `cellSet` that contains both pools
- But instead Ignaz does this:

```
git checkout 0100_remoteVariables -b remote
```

Syntax of remote variables

- A variable is a remote variable if between the name and the = there is a string enclosed by {} that tells us where the variable is to be calculated
- The string is split into two parts by a ' and has an optional part separated by /:

  type of the entity this is one of the types known to swak (like `internalField`, `cellSet`, `patch`). If no type is given `patch` is assumed

  name of the entity speaks for itself. If the `type` is `internalField` then no name is given

  mesh region This is optional for multi-region meshes. The entity is now sought on another mesh with that name

- The weird syntax is used because these are the only characters that can not be part of a valid entity name

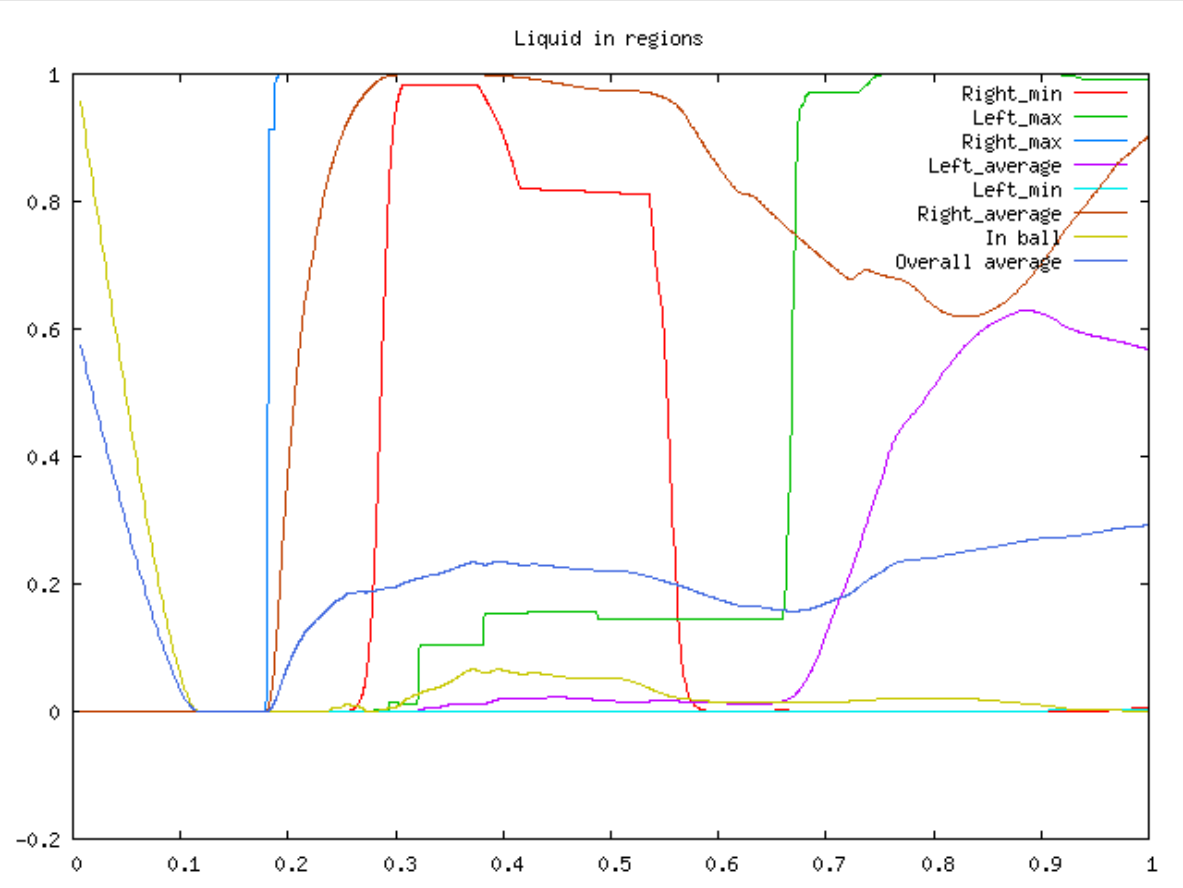
Total sum

```
inTotal {
    type swakExpression;
    valueType cellZone;
    zoneName leftPool;
    accumulations (
        average
    );
    expression "(sum(alpha1*vol())+alphaBall+alphaRight)/(sum(vol())<brk>
        <cont>+volBall+volRight)";
    variables (
        "alphaRight{cellZone'rightPool}=sum(alpha1*vol());"
        "volRight{cellZone'rightPool}=sum(vol());"
        "alphaBall{cellSet'inBall}=sum(alpha1*vol());"
        "volBall{cellSet'inBall}=sum(vol());"
    );
    verbose true;
}
```

Collecting the sum

```
inTotal {
    expr "Expression inTotal : average=(%f <brk>
        <cont>%)";
    titles ( "Overall average");
    type slave;
    master inPools;
}
```

Normalized amount in regions with average



Outline

Just give me a single number

- Ignaz would like a short "report" for the last time-step
  - With stuff that he already calculated
    - Liquid flow through the ball-region
  - Stuff that hasn't been calculated yet
    - Pressure difference between top and bottom
- He sets the case to

```
git checkout 0110_funkyDoCalc -b doCalc
```

- And starts editing a dictionary `checkSimulation`

Something we already calculated

```
flowBall {
    valueType faceSet;
    setName aroundBall;
    expression "phi*flip()*alpha1";
    accumulations (
        sum
    );
    autoInterpolate true;
    warnAutoInterpolate false;
}
```

Pressure difference

```
pressureDiff {
    valueType patch;
    patchName lowerWall;
    variables (
        "topP{patch'atmosphere}=average(p);"
    );
    expression "p-topP";
    accumulations (
        min
        max
        average
    );
}
```

Doing the calculation

```
funkyDoCalc -time 0.05: checkSimulation
```

```
Time = 1
totalLiquid :  sum=0.000525861
liquidHeight :  sum=0.0596091
maxHeight :  max=0.181999
flowBall :  sum=-5.16526e-06
inTotal :  average=0.292424
pressureDiff :  min=119.405 max=1163.75 <brk>
    <cont>average=536.356
End
```

Outline

Outline

Things at the inlet are not always the same

- The pool-builder finds the initial results quite interesting
  - "But we have a different filling procedure. The amount of water changes"
- So Ignaz has to find a way to set changing boundary conditions
- He sets the case to

```
git checkout 0120_groovyBC -b groovyBC
```

and starts to use groovyBC

What is groovyBC

- It is the built-in boundary condition `mixed` on steroids
  - All relevant fields can be set by expressions

    valueExpression the value if the BC is to be considered a Dirichlet-conditions. This always has to be set

    gradientExpression Value of the gradient if the condition is a Neuman-condition. Defaults to 0 (or equivalent for vectors and tensors)

    fractionExpression Whether this is a Dirichlet condition (1) or a Neuman (0). Defaults to 1
  - To use the groovyBC the entry

```
"libgroovyBC.so"
```

has to be added to the `libs`-list

Changing velocities

```
rightWall
{
    type            groovyBC;
    value           uniform (0 0 0);
    variables (
        "top=max(pts().y)/5;"
        "s=pos().y/top;"
    );
    valueExpression "-normal()*inVel";
    timelines (
        {
            name inVel;
            outOfBounds clamp;
            fileName "$FOAM_CASE/inVelocity.data";
        }
    );
}
```

Additional fields in a groovyBC

timelines List of timeline data. They can be used under the `name` in expression and will return the value at the current time

- They use the same mechanism for reading timelines as `timeVaryingUniform`. Therefore the format is similar and if you have a recent incarnation of 1.7.x that has the right patches you can also read CSV-files

lookuptables Like `timelines` but the `name` can be used as a function where the value is looked up

The time-line data

- A list of pairs with
  1. time (these have to be sorted)
  2. value

```
(
        (0  0)
        (0.1  1)
        (0.3  1)
        (0.5  1.5)
        (0.8  1.5)
        (0.9  1)
)
```

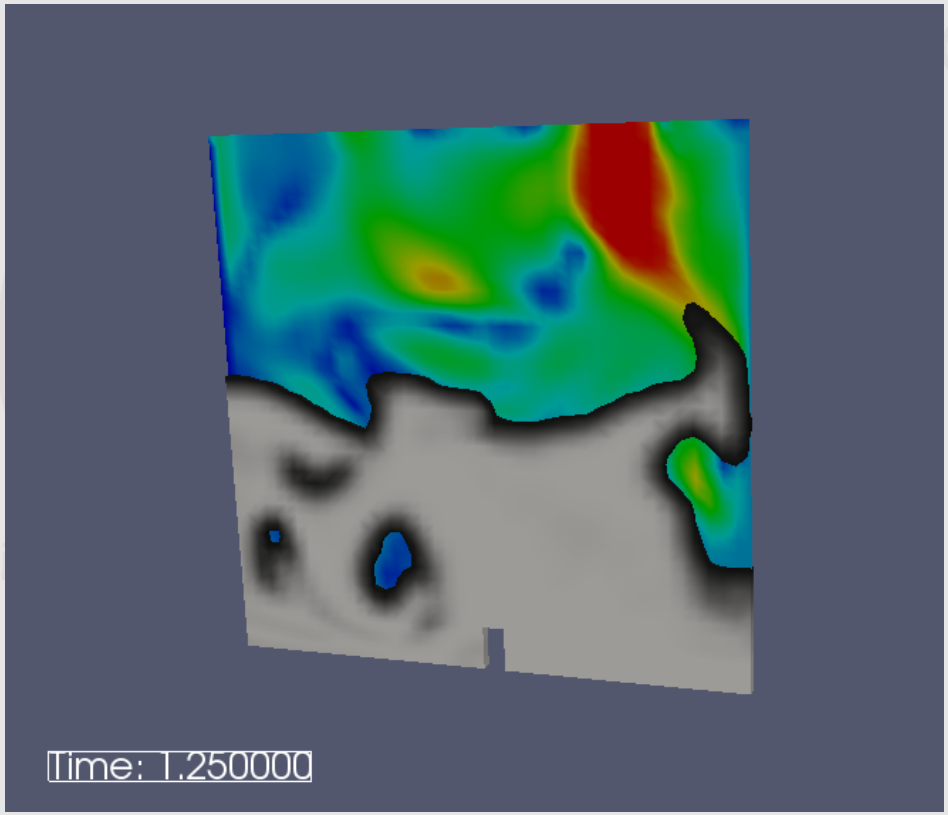
Non-homogeneous inlet

```
rightWall
{
    type            groovyBC;
    value           uniform 0;
    variables (
        "top=max(pts().y)/5;"
        "s=pos().y/top;"
        "switchOff=1.5;"
    );
    fractionExpression "s<=1 ? 1 : 0";
    valueExpression    "(time() < switchOff ? 1 : 0)*profile(s)";
    lookuptables (
        {
            name profile;
            outOfBounds clamp;
            fileName "$FOAM_CASE/inProfile.data";
        }
    );
}
```

The profile data

```
(
        (0.3  1)
        (0.7  0.8)
        (0.9  0.5)
        (1    0.1)
)
```

Movie: Switched off inlet



Outline

The one who doesn't do anything makes no mistakes

- Sometimes Ignaz has a problem with one of his =groovyBC=s
  - A switch occurs at the wrong time
  - He got the coefficients of some polynomials wrong
  - ...
- Usually this things only reveal themselves when the simulation is finished
- To check out these things there is the utility `replayTransientBC`
  - Also works with other transient boundary conditions

```
git checkout 0130_replayTransientBC -b replayBC
```

The replayTransientBCDict

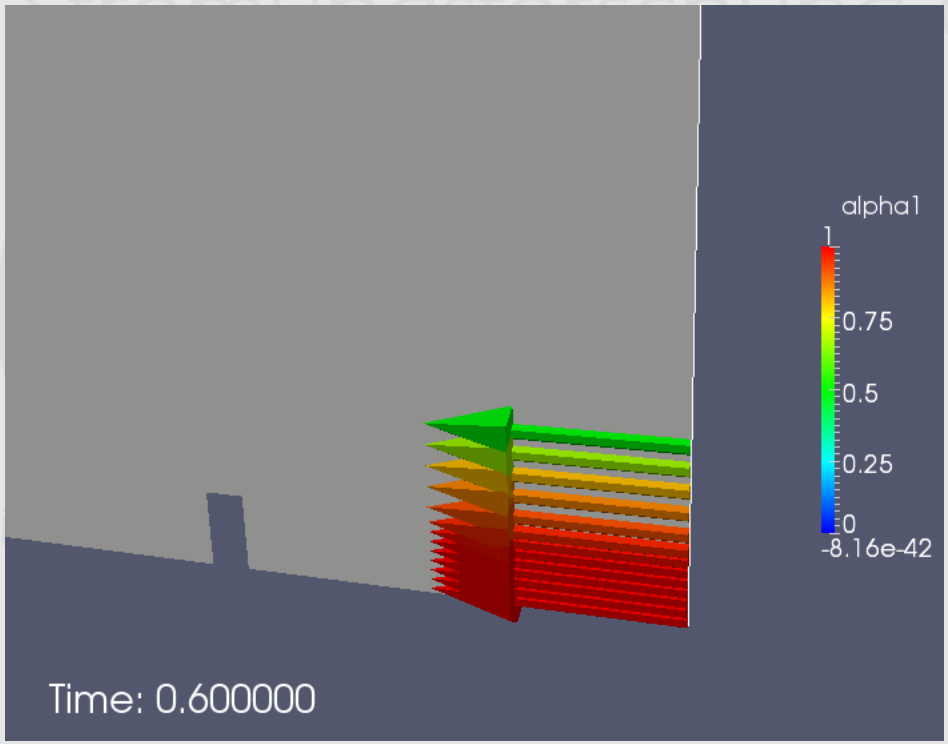
- Only one entry
  - List of all the fields which
    1. should be loaded in the beginning
    2. the boundary conditions are evaluated
    3. the fields get written

```
fields (
    U
    alpha1
);
```

Some BCs have to be modified

- Boundary conditions that depend on variables that are calculated by the simulation
  - Like `phi`
  - Affected is also the whole `inletOutlet`-family
- Of course if the BC depends on the solution provided by the solver `replayTransientBC` can't help too

Movie: Only the conditions



Outline

Outline

How much liquid entered the system?

- Ignaz wants to check the conservation in his simulation
  - To do this he wants to know the accumulated amount of liquid that entered the system
  - But all currently known function objects only know about the current state
- But the solution is there: stored variables

```
git checkout 0140_storedVariableInflow -b storedVars
```

Using stored variables

- Stored variables are declared in a list `storedVariables` where each element has two entries

name	name of the variable (surprising, isn't it?)
initialValue	value of the variable in the beginning

- The variable can be used like any other variable
- When the variable is assigned a value then this is the new value
  - For accumulations you've got to explicitly add it to the old value
  - The value from the **last** time-step is used
    - Not the last one from the current time-step (if the variable is for instance evaluated multiple times during a PISO-loop)

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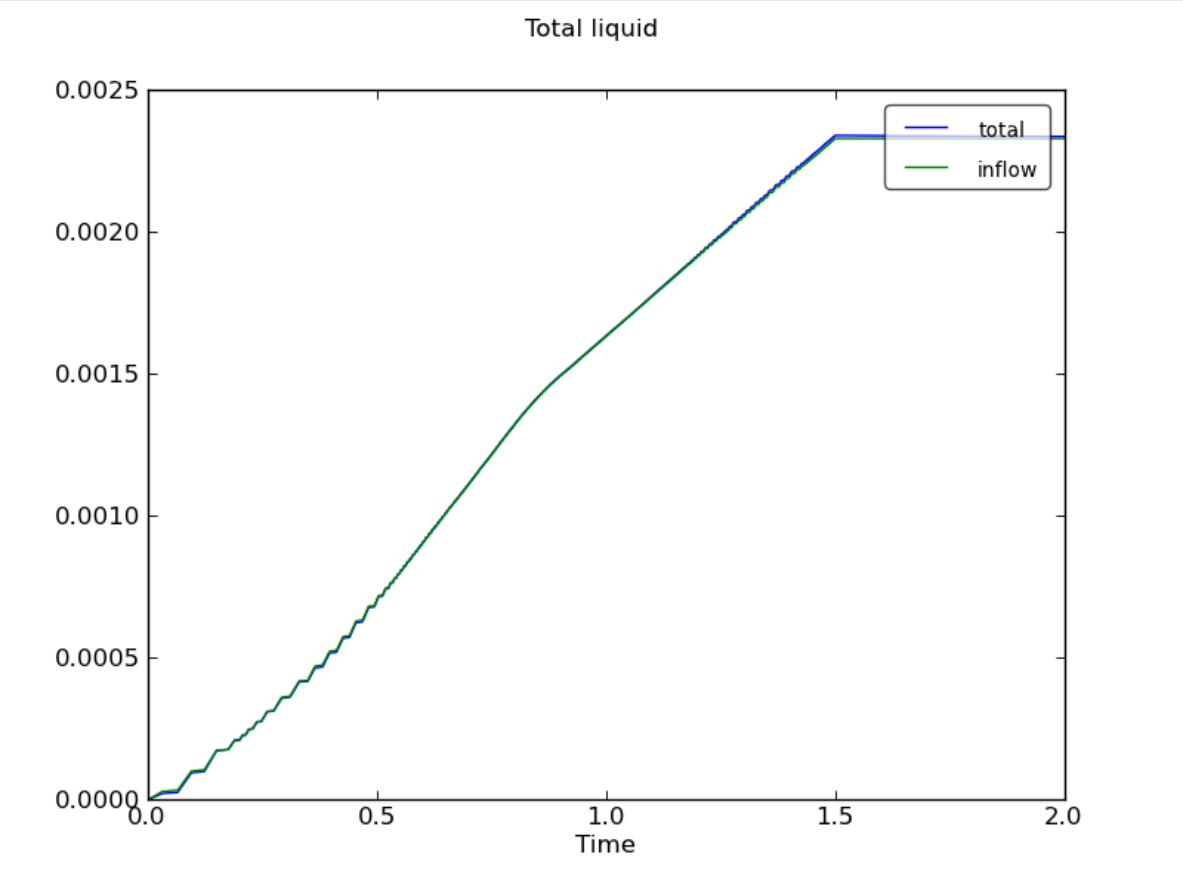
Accumulated liquid

```
    accumulatedInflow {
        type patchExpression;
        patches (
            rightWall
            atmosphere
        );
        variables (
            "patchFlow=patchFlow-deltaT()*alpha1*phi;"
        );
        storedVariables (
            {
                name patchFlow;
                initialValue "0";
            }
        );
        expression "patchFlow";
        accumulations (
            sum
        );
        verbose true;
    }
);
```

Getting the values

```
rightIn {
    expr "Expression accumulatedInflow on <brk>
        <cont>rightWall:  sum=(%f%)";
    titles ( inflow );
    type slave;
    master liquid;
}
```

Accumulated amount of liquid is the same



Outline

Getting the height at a special position

- The pool builder informs Ignaz that the simulations look nice but there is no way that he can compare the calculated height to the measurements
  - The liquid height sensor only measures the height at one location in the pool
- Ignaz asks for the location of the sensor and decides to use a `sampledSet` there

```
git checkout 0150_sampledSet -b sampledSets
```

Using sampled sets in swak4Foam

- sampledSet is a facility in OpenFOAM that allows sampling fields at specified locations
  - Usually lines but points are also possible
- Essential entries in the dictionary are:

  setName specifies the name of the sampled set (under this name it can be accessed)

  set Dictionary that specifies the sampledSet the way it is specified for the sample-utility
    - swak4Foam introduces a new type swakRegistryProxy. This reuses a previously defined sampleSet (identified by the setName)
- The usual operations can be done on the sampledSet
  - For fields the sampled values are used

Maximum height

```
fillHeight {
    type swakExpression;
    valueType set;
    verbose true;
    setName lineUp;
    set {
        type uniform;
        axis y;
        start (0.2 0 0.007);
        end (0.2 0.585 0.007);
        nPoints 200;
    }
    expression "(alpha1 > 0.5) ? pos().y : 0";
    accumulations (
        max
    );
    interpolate true;
    interpolationType cellPoint;
}
```

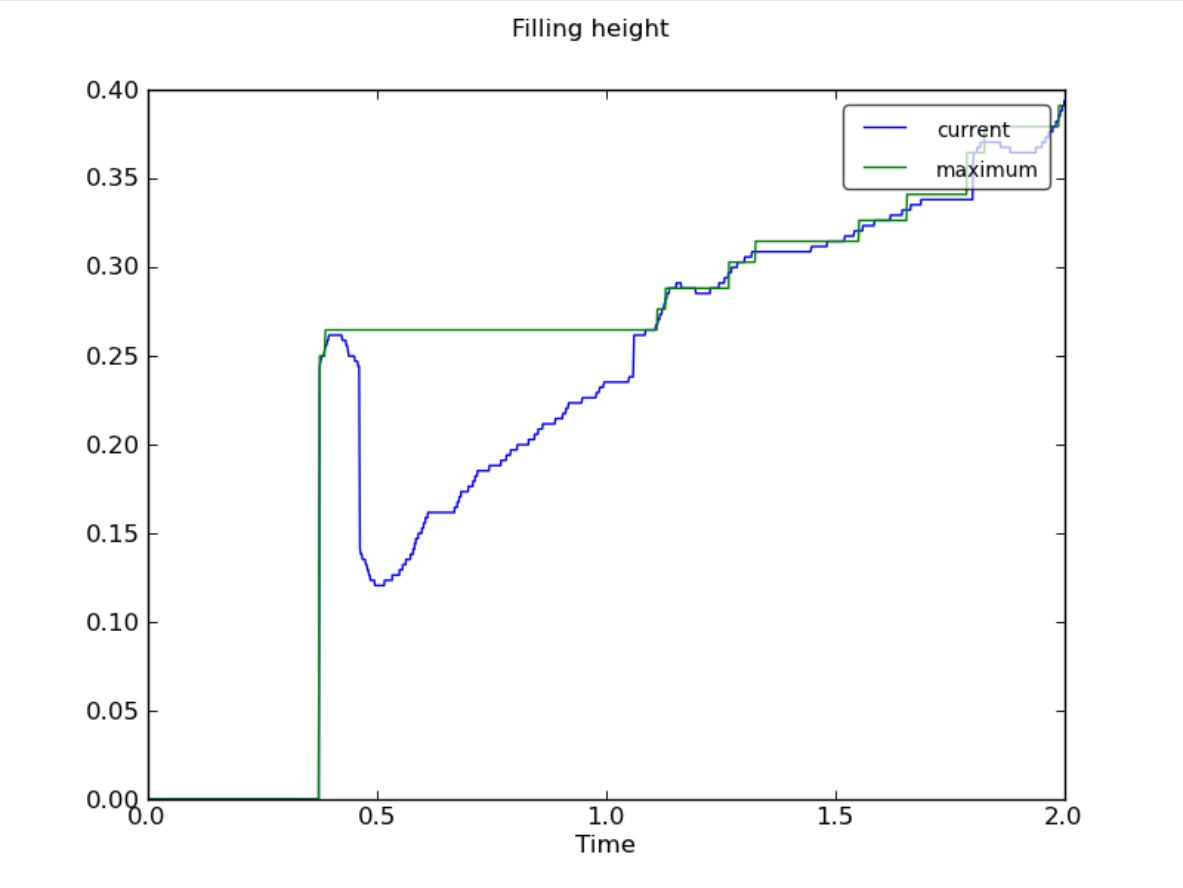
All-time high

```
maxFillHeight {
    type swakExpression;
    valueType set;
    verbose true;
    setName lineUpCopy;
    set {
        type swakRegistryProxy;
        axis y;
        setName lineUp;
    }
    expression "currentMax";
    accumulations (
        max
    );
    variables (
        "currentMax=(alpha1 > 0.5) ? pos().y : currentMax;"
    );
    storedVariables (
        {
            name currentMax;
            initialValue "0";
        }
    );
}
```

Recording the values

```
fillHeight {
        theTitle "Filling height";
        expr "Expression fillHeight : max=(%f%)";
        titles ( current );
        progress "h: $0";
}
maxFillHeight {
        expr "Expression maxFillHeight : max=(%f%)"<brk>
            <cont>;
        titles ( maximum );
        type slave;
        master fillHeight;
        progress "max: $0";
}
```

Filling height and maximum



Getting the processed data

- Ignaz re-generates the pictures from the pickled data:

```
pyFoamRedoPlot.py --pick PyFoamRunner.interFoam.analyzed/pickledPlots
```

- But the customer wants hard numbers to compare them in his spread-sheet program

```
pyFoamRedoPlot.py  --csv --file=sampledSets --pick PyFoamRunner.interFoam
```

Outline

The higher it gets, the less comes in

- The customer informs Ignaz that the data looks nice, but not realistic:
  - There are three sensors installed. If one of them gets wet then the inflow-rate is reduced by a third
- Ignaz says that can do this

```
git checkout 0160_switchingBySamples -b switchSamples
```

The grand scheme

- Ignaz needs two things to interact because the set can not be created in the BC:
  1. The sampledSet `threePoints`. This is created by a function object of the type `createSampledSet`
  2. The boundary condition. This reads the values at the sensor positions via an external variable and acts accordingly

Probes at three points

```
1  switchPoints {
       type createSampledSet;
3      outputControl timeStep;
       outputInterval 1;
5      setName threePoints;
       set {
7          type cloud;
           axis x;
9          points (
               (0.1  0.3 0.007)
11             (0.25 0.3 0.007)
               (0.4  0.3 0.007)
13         );
       }
15 }
```

The switching inlet

```
rightWall
{
    type            groovyBC;
    value           uniform 0;
    variables (
        "current{set'threePoints}=average(alpha1>0.5 ? 1 : 0);"
        "maxVal=maxVal<current ? current : maxVal;"
        "top=max(pts().y)/5;"
        "s=pos().y/top;"
    );
    storedVariables (
        {
            name maxVal;
            initialValue "0";
        }
    );
    fractionExpression "s<=1 ? 1 : 0";
    valueExpression    "(1-maxVal)*profile(s)";
    lookuptables (
        {
            name profile;
            outOfBounds clamp;
            fileName "$FOAM_CASE/inProfile.data";
        }
    );
}
```

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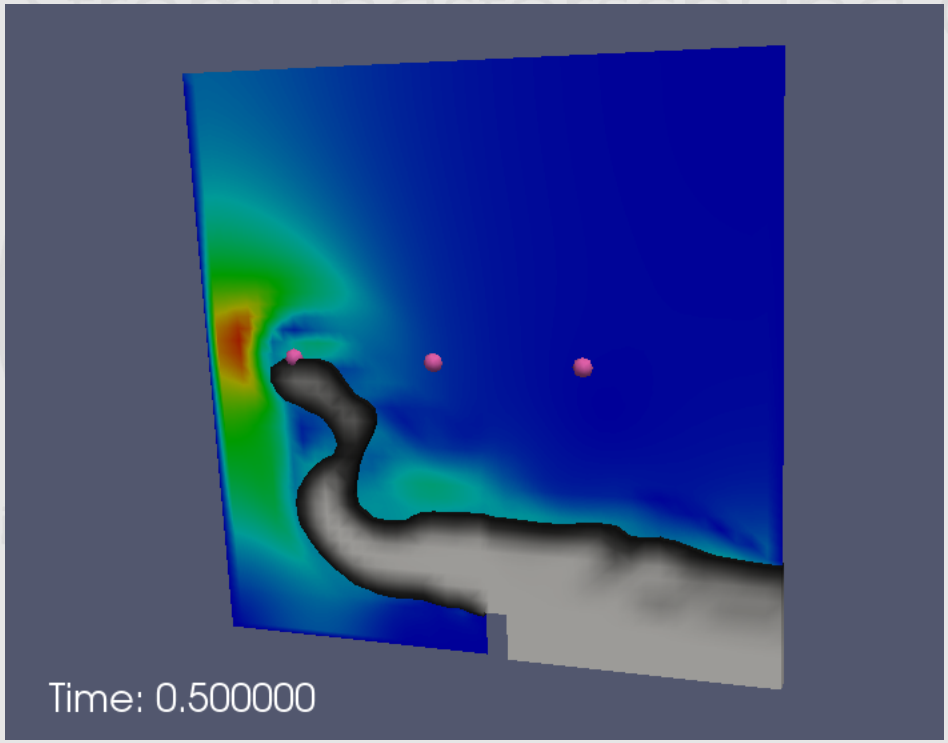
Movie: Running it



Comparing the data

- Ignaz now wants to compare the new data:

```
pyFoamRedoPlot.py --pick --csv --file=switching PyFoamRunner.interFoam.analyzed/pickledPlots
```

- He merges this data and the one from the old run into a common CSV
  - Data is re-sampled to the times in the first source CSV

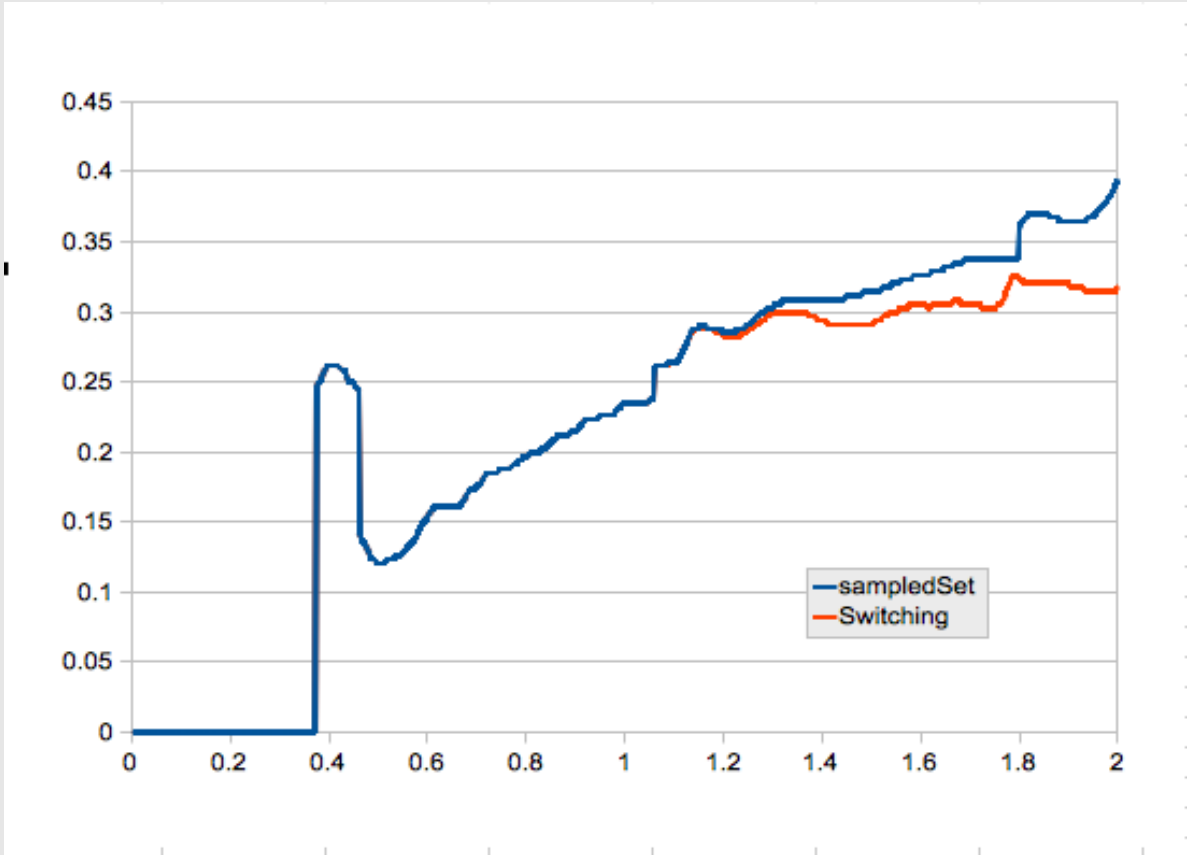
```
pyFoamJoinCSV.py sampledSetsfillHeight.csv switchingfillHeight.csv joinedFillHeight.csv
```

- Which he opens with OpenOffice:

```
kde-open joinedFillHeight.csv
```

- and produces a nice comparison:

Comparing the filling height



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Outline

Looking at the interface of the liquid

- The pool maker has one last request:
  1. he wants to know the flow through some tilted plane
     - This can not be represented with a `faceSet`
  2. He wants to know how big the liquid surface is and how fast it is moving

```
git checkout 0170_sampledSurfaces -b surfaces
```

- **Note:** Due to a problem in 1.7.1 `sampledSurfaces` won't work on the stick
  - Changing of the size of the surface is not properly handled
  - This is fixed in 1.7.x

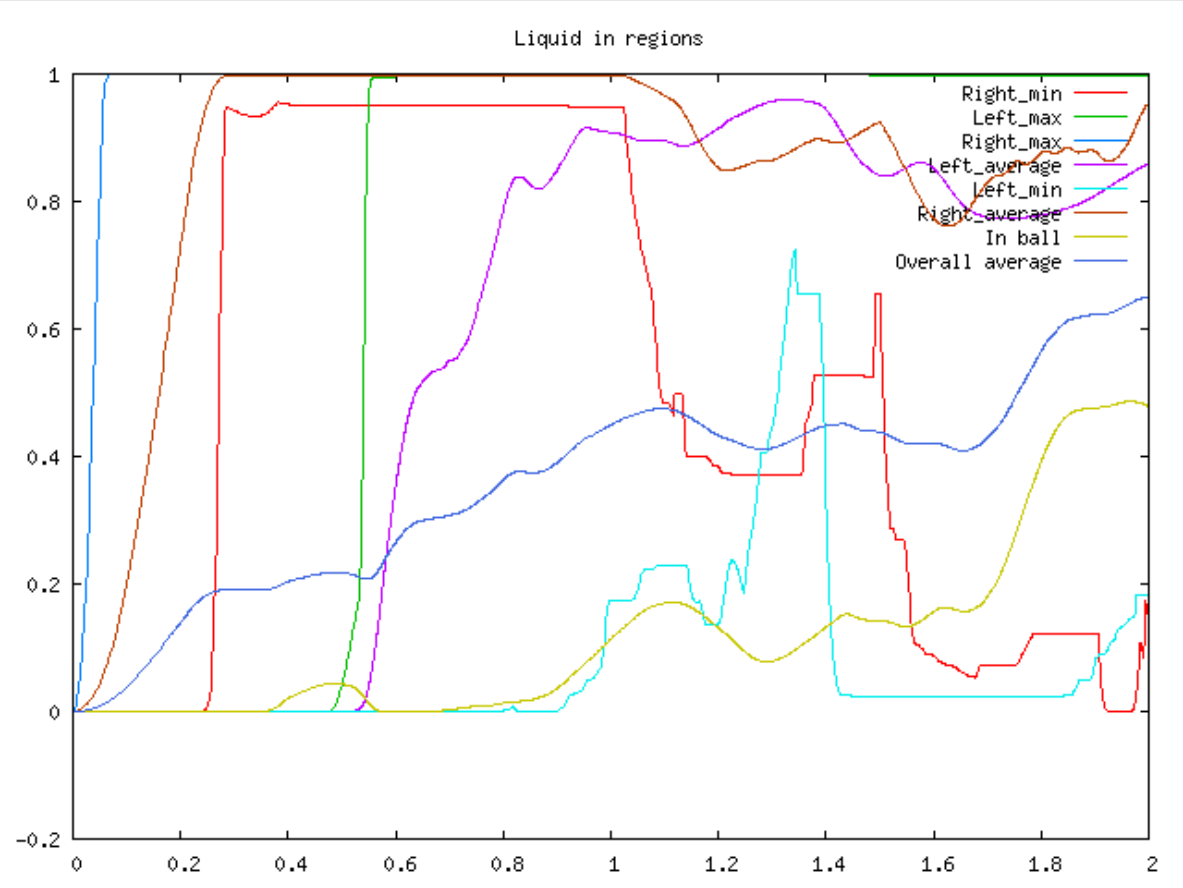
Working with sampled surfaces

Is similar to working with sampled sets.
Just replace *set* with *surface*

Control surfaces everywhere

```
flowSurface {
    type swakExpression;
    valueType surface;
    verbose true;
    surfaceName tiltedPlane;
    surface {
        type plane;
        basePoint (0.2 0.2 0);
        normalVector (1 5 0);
        interpolate true;
    }
    expression "(U & Sf())*alpha1";
    accumulations (
        sum
    );
}
```

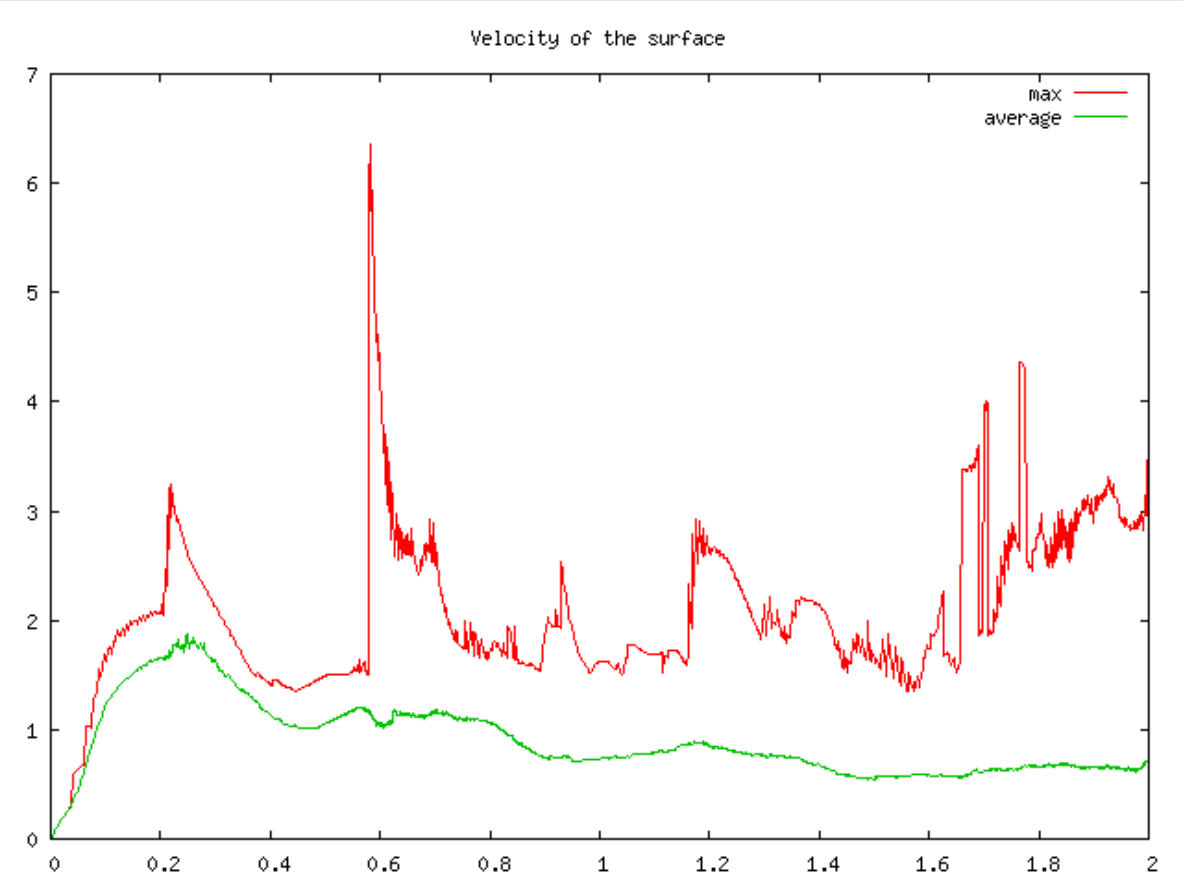
There can be too much information



Velocity of the liquid surface

```
surfaceVel {
    type swakExpression;
    valueType surface;
    verbose true;
    surfaceName liquidSurf;
    surface {
        type isoSurface;
        isoField alpha1;
        isoValue 0.5;
        interpolate true;
    }
    expression "mag(U)";
    accumulations (
        max
        average
    );
}
```

How fast is the interface



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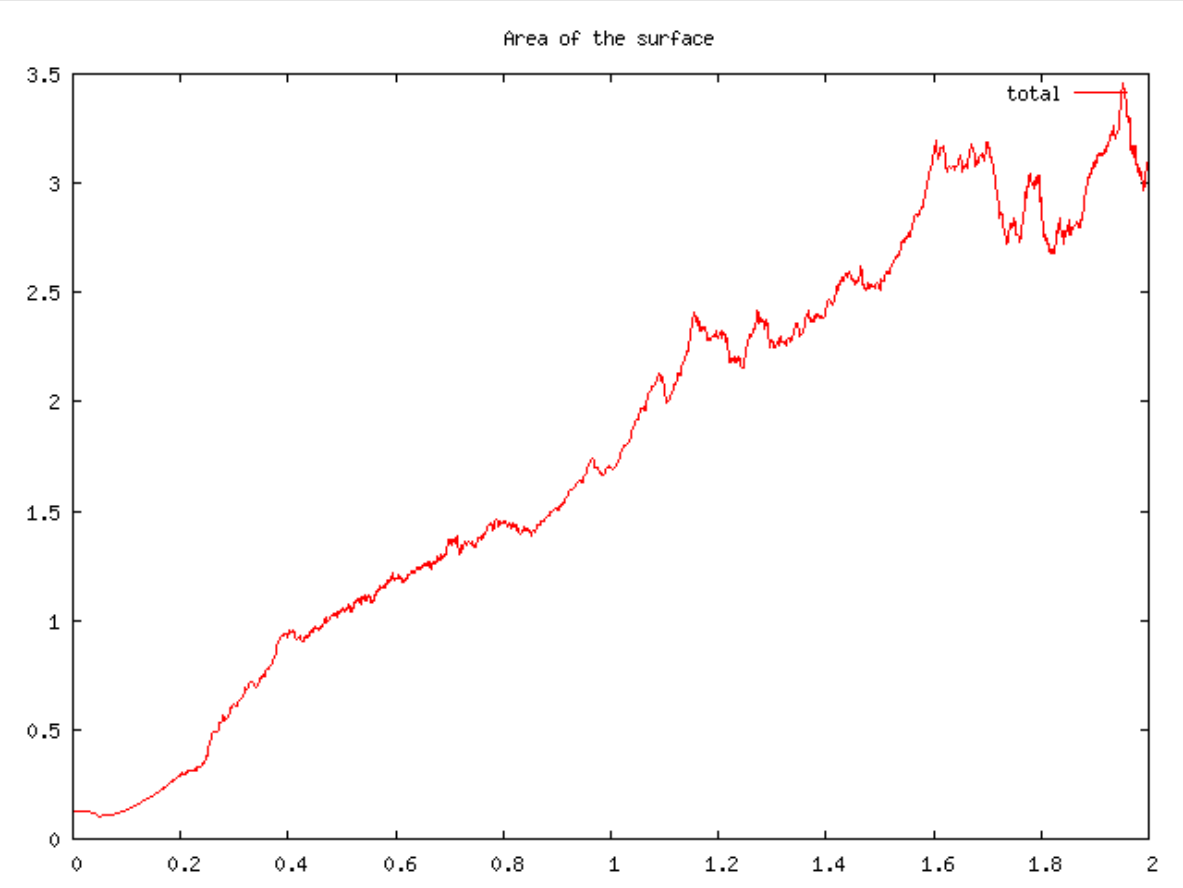
How big is the interface?

```
surfaceSize {
    type swakExpression;
    valueType surface;
    verbose true;
    surfaceName liquidSurf2;
    surface {
        type isoSurface;
        isoField alpha1;
        isoValue 0.5;
        interpolate true;
        // type swakRegistryProxy; // doesn't work due to <brk>
            <cont> bug
        //surfaceName liquidSurf;
    }
    expression "area()/0.0146";
    accumulations (
        sum
    );
}
```

How big is the interface



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Outline

Violating the solution

- Of course this was not the last request
- The last question is: "What is the effect of filling the pools from above (will the rubber ducks survive?)"
  - A preliminary study is needed in 10 minutes

```
git checkout 0180_manipulateSolution -b manipulating
```

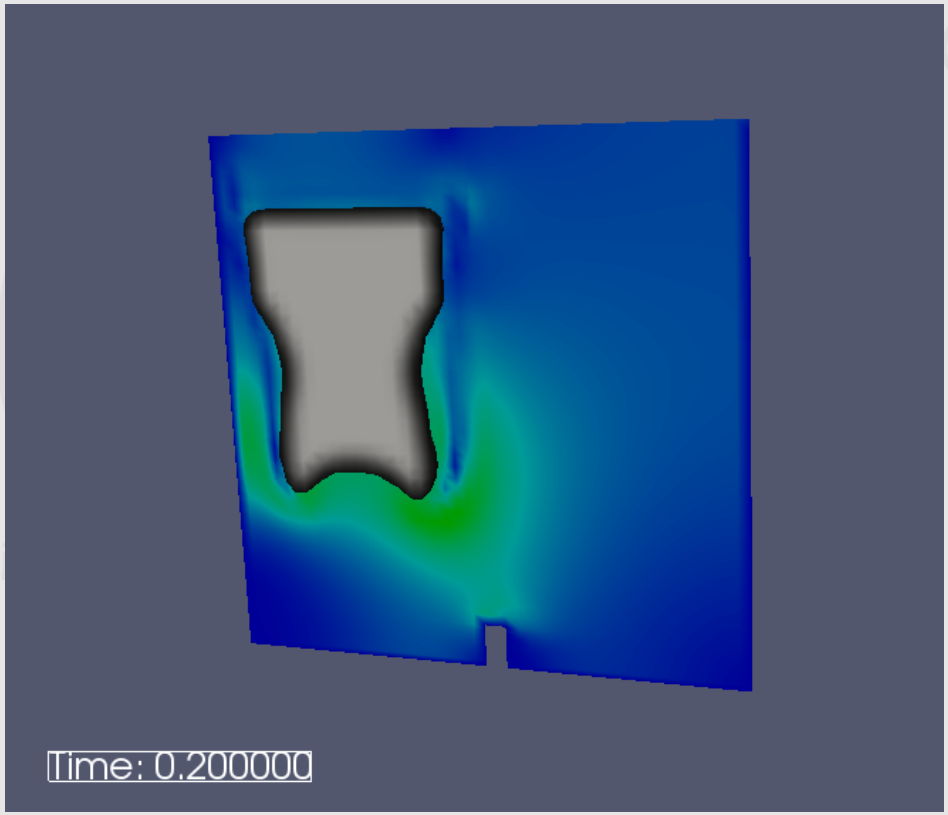
- Ignaz decides to do something ugly to the solution (although his conscience objects)

Producing liquid out of thin air

- He used a function object that manipulates the solution at the end of every time-step:

```
letItRain {
    type manipulateField;
    outputControl timeStep;
    outputInterval 1;
    fieldName alpha1;
    expression "1";
    mask "pos().x > 0.05 && pos().x < 0.25 && <brk>
        <cont>pos().y >0.4 && pos().y<0.5";
}
```

Movie: The last picture show



Outline

Outline

Topics we didn't touch

Have a look at the Wiki-page and the examples

- Differential operators on fields
- Plugging expression source terms into a solver
  - This was promised in the abstract. Sorry. Anybody wants to stay for an improvised session on that?
- Groovifying boundary conditions
  - Look it up in the dictionary. The meaning of this word is "Extending an existing boundary condition to use the swak4Foam-machinery instead of constant parameters"
- Other stuff that I've forgotten

Final remarks

As a figure of American literature (hint: it is not Huckleberry Finn) said:

With great power comes great responsibility

When using swak4Foam always consider:

Physical correctness swak4Foam allows you to do things that are not physical (some of the examples **do** that). Try not to do this

Performance Certain things swak4Foam does (especially the `sampled`-stuff) are computationally expensive. Try to avoid such operations

Outline

Trying different stuff at the same time

- Sometimes Ignaz does different things with a case at the same time
  - Improve the numerics
  - Test different physical parameters
- Merging the results of these without forgetting something can be a nerve wrecking experience
  - And there is always the issue "Where did this come from"
- For this task PyFoam supports us with its Mercurial-support
  - Other VCS-systems are possible

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Setting up two different cases

- Make sure the master is under version control

```
cd masterCase
pyFoamInitVCSCase . --commit-message="Initial commit"
```

- Create two working cases (`pyFoamCloneCase.py` knows about Mercurial)

```
cd ..
pyFoamCloneCase.py masterCase numericsTests
pyFoamCloneCase.py masterCase parameterTests
```

Working on the cases

cd numericsTests

```
hg branch numericsBranch
```

- Work on the numerics
- Review the changes (Mercurial-style)

```
hg diff
```

- Review the changes (pyFoam-style)

```
hg foamdiff .
```

- Commit the changes

```
hg commit -m "Now the numerics seem to work"
```

- Push to the master case

```
hg push --new-branch
```

- Do the same in the physics-case

Getting all the changes

- Got to the master

```
cd ../masterCase
```

- Merge in the numerics

```
hg merge numericsBranch
```

- Merge in the physics:

```
hg merge physicsBranch
```

- All the wisdom in one case

```
hg log
```

Why Mercurial?

- It can do the same things as `git` but it is simpler and more consistent
- It is written in Python
  - So interaction with PyFoam is easy
- It is easily extendable
  - Writing a plugin like `foamdiff` for `git` is no fun
- If the case is in a `git`-controlled directory, then the two do not collide
  - Which they would if PyFoam used `git` for that

Outline

We're leaving Ignaz

- For all his trouble Ignaz got a nice pool installed in his garden
- He lies in that pool thinking "Who needs C++?"
- We leave him there
  - Wondering: "Will he come back? Or will he lie in the sun forever doing studies on heat transfer by radiation?"

Bring your bugs

A program without bugs wasn't worth writing in the first place

I'm sure as you start using swak4Foam you will encounter bugs

- Bugs in swak4Foam (my ego can stand these)
- Bugs in OpenFOAM (a couple of these was already found during the development of swak4Foam)

If you find a bug please don't grumble and gossip about it, but report it on the Mantis-Bugtracker of the **openfoam-extend**-project

Bring your examples

- This is the call for a competition: **Sickest use of swak4Foam**
- The example should:
  - Demonstrate the use of swak4Foam (no C++-programming should be required)
  - Do something astonishing that nevertheless makes sense (either on a physical or on a spiritual level)
  - Be simple
    - Run on a state-of-the-art PC in under an hour
    - Have a `blockMesh`-geometry (or something else that comes with OF)
  - Should be shown to me at least after the end of the last session
- The winner
  - will be announced after the conference dinner at the bar (if there is one) by a committee (which consists of me, Fritz and Wolfgang)
  - will receive a refreshing beverage of choice (alcoholic optional)