

# BPL\_TEST2\_Perfusion script with PyFMI

The key library PyFMI is installed.

After the installation a small application BPL\_TEST2\_Perfusion is loaded and run. You can continue with this example if you like.

```
In [1]: !lsb_release -a # Actual VM Ubuntu version used by Google
```

```
No LSB modules are available.  
Distributor ID: Ubuntu  
Description:    Ubuntu 22.04.4 LTS  
Release:        22.04  
Codename:       jammy
```

```
In [2]: %env PYTHONPATH=
```

```
env: PYTHONPATH=
```

```
In [3]: !python --version
```

```
Python 3.11.11
```

```
In [4]: !wget https://repo.anaconda.com/miniconda/Miniconda3-py311_24.11.1-0-Linux-x86_64.s  
!chmod +x Miniconda3-py311_24.11.1-0-Linux-x86_64.sh  
!bash ./Miniconda3-py311_24.11.1-0-Linux-x86_64.sh -b -f -p /usr/local  
import sys  
sys.path.append('/usr/local/lib/python3.11/site-packages/')
```

```
--2025-03-26 09:45:30-- https://repo.anaconda.com/miniconda/Miniconda3-py311_24.11.1-0-Linux-x86_64.sh
Resolving repo.anaconda.com (repo.anaconda.com)... 104.16.32.241, 104.16.191.158, 26
06:4700::6810:bf9e, ...
Connecting to repo.anaconda.com (repo.anaconda.com)|104.16.32.241|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 145900576 (139M) [application/octet-stream]
Saving to: 'Miniconda3-py311_24.11.1-0-Linux-x86_64.sh'
```

```
Miniconda3-py311_24 100%[=====>] 139.14M  87.4MB/s   in 1.6s
```

```
2025-03-26 09:45:32 (87.4 MB/s) - 'Miniconda3-py311_24.11.1-0-Linux-x86_64.sh' saved
[145900576/145900576]
```

```
PREFIX=/usr/local
```

```
Unpacking payload ...
```

```
Installing base environment...
```

```
Preparing transaction: ...working... done
```

```
Executing transaction: ...working... done
```

```
installation finished.
```

```
In [5]: !conda update -n base -c defaults conda --yes
```

Channels:  
- defaults  
Platform: linux-64  
Collecting package metadata (repodata.json): - 00\ 00| 00/ 00- 00\ 00| 00/ 00- 00\  
00| 00/ 00- 00\ 00| 00/ 00done  
Solving environment: \ 00| 00done

## Package Plan ##

environment location: /usr/local

added / updated specs:  
- conda

The following packages will be downloaded:

package	build	
-----	-----	
ca-certificates-2025.2.25	h06a4308_0	129 KB
certifi-2025.1.31	py311h06a4308_0	163 KB
openssl-3.0.16	h5eee18b_0	5.2 MB
-----	-----	
Total:		5.5 MB

The following packages will be UPDATED:

ca-certificates	2024.11.26-h06a4308_0 --> 2025.2.25-h06a4308_0
certifi	2024.8.30-py311h06a4308_0 --> 2025.1.31-py311h06a4308_0
openssl	3.0.15-h5eee18b_0 --> 3.0.16-h5eee18b_0

Downloading and Extracting Packages:

openssl-3.0.16	5.2 MB	: 0% 0/1 [00:00<?, ?it/s]
certifi-2025.1.31	163 KB	: 0% 0/1 [00:00<?, ?it/s]
ca-certificates-2025	129 KB	: 0% 0/1 [00:00<?, ?it/s]
ca-certificates-2025	129 KB	: 100% 1.0/1 [00:00<00:00, 14.20it/s]
openssl-3.0.16	5.2 MB	: 9% 0.08649522455469985/1 [00:00<00:01, 1.21s/it]
ca-certificates-2025	129 KB	: 100% 1.0/1 [00:00<00:00, 8.91it/s]
ca-certificates-2025	129 KB	: 100% 1.0/1 [00:00<00:00, 8.91it/s]
certifi-2025.1.31	163 KB	: 100% 1.0/1 [00:00<00:00, 6.32it/s]

Preparing transaction: - 00done  
Verifying transaction: | 00/ 00- 00\ 00done  
Executing transaction: / 00done

```
In [6]: !conda --version  
        !python --version
```

```
conda 24.11.1  
Python 3.11.11
```

```
In [7]: !conda config --set channel_priority strict
```

```
In [8]: !conda install -c conda-forge pyfmi --yes # Install the key package
```

```
Channels:
- conda-forge
- defaults
Platform: linux-64
Collecting package metadata (repodata.json): - 22\ 22| 22/ 22- 22\ 22| 22/ 22- 22\
22| 22/ 22- 22\ 22| 22/ 22- 22\ 22| 22/ 22- 22\ 22| 22/ 22- 22\ 22| 22/ 22- 22\ 22|
22/ 22- 22\ 22| 22done
Solving environment: - 22\ 22| 22/ 22done
```

## Package Plan ##

environment location: /usr/local

added / updated specs:
- pyfmi

The following packages will be downloaded:

package	build		
-----	-----		
_x86_64-microarch-level-3	2_broadwell	8 KB	conda-forge
assimulo-3.6.0	py311h083bc19_0	1.1 MB	conda-forge
certifi-2025.1.31	pyhd8ed1ab_0	159 KB	conda-forge
conda-25.1.1	py311h38be061_1	1.1 MB	conda-forge
fmilib-2.4.1	hac33072_1	383 KB	conda-forge
gmp-6.3.0	hac33072_2	449 KB	conda-forge
libamd-3.3.3	haaf9dc3_7100102	49 KB	conda-forge
libblas-3.9.0	31_h59b9bed_openblas	16 KB	conda-forge
libbtf-2.3.2	h32481e8_7100102	27 KB	conda-forge
libcamd-3.3.3	h32481e8_7100102	46 KB	conda-forge
libcbblas-3.9.0	31_he106b2a_openblas	16 KB	conda-forge
libccolamd-3.3.4	h32481e8_7100102	42 KB	conda-forge
libcholmod-5.3.1	h59ddab4_7100102	1.1 MB	conda-forge
libcolamd-3.3.4	h32481e8_7100102	33 KB	conda-forge
libcxsparse-4.4.1	h32481e8_7100102	118 KB	conda-forge
libgcc-14.2.0	h767d61c_2	828 KB	conda-forge
libgcc-ng-14.2.0	h69a702a_2	52 KB	conda-forge
libgfortran-14.2.0	h69a702a_2	52 KB	conda-forge
libgfortran-ng-14.2.0	h69a702a_2	53 KB	conda-forge
libgfortran5-14.2.0	hf1ad2bd_2	1.4 MB	conda-forge
libgomp-14.2.0	h767d61c_2	449 KB	conda-forge
libklu-2.3.5	hf24d653_7100102	142 KB	conda-forge
liblapack-3.9.0	31_h7ac8fdf_openblas	16 KB	conda-forge
libldl-3.3.2	h32481e8_7100102	24 KB	conda-forge
libopenblas-0.3.29	pthreads_h94d23a6_0	5.6 MB	conda-forge
libparu-1.0.0	h17147ab_7100102	91 KB	conda-forge
librbio-4.3.4	h32481e8_7100102	47 KB	conda-forge
libspex-3.2.3	had10066_7100102	79 KB	conda-forge
libspqr-4.3.4	h852d39f_7100102	213 KB	conda-forge
libstdcxx-14.2.0	h8f9b012_2	3.7 MB	conda-forge
libstdcxx-ng-14.2.0	h4852527_2	53 KB	conda-forge
libsuitesparseconfig-7.10.1	h92d6892_7100102	42 KB	conda-forge
libumfpack-6.3.5	heb53515_7100102	424 KB	conda-forge
metis-5.1.0	hd0bcaf9_1007	3.7 MB	conda-forge
mpfr-4.2.1	h90cbb55_3	620 KB	conda-forge

numpy-2.2.4	py311h5d046bc_0	8.6 MB	conda-forge
openssl-3.4.1	h7b32b05_0	2.8 MB	conda-forge
pyfmi-2.16.3	py311h9f3472d_0	5.2 MB	conda-forge
python_abi-3.11	2_cp311	5 KB	conda-forge
scipy-1.15.2	py311h8f841c2_0	16.4 MB	conda-forge
suitesparse-7.10.1	ha0f6916_7100102	12 KB	conda-forge
sundials-7.1.1	ha52427a_0	907 KB	conda-forge
-----			
Total:		56.1 MB	

The following NEW packages will be INSTALLED:

_x86_64-microarch~	conda-forge/noarch::_x86_64-microarch-level-3-2_broadwell
assimulo	conda-forge/linux-64::assimulo-3.6.0-py311h083bc19_0
fmilib	conda-forge/linux-64::fmilib-2.4.1-hac33072_1
gmp	conda-forge/linux-64::gmp-6.3.0-hac33072_2
libamd	conda-forge/linux-64::libamd-3.3.3-haaf9dc3_7100102
libblas	conda-forge/linux-64::libblas-3.9.0-31_h59b9bed_openblas
libbtf	conda-forge/linux-64::libbtf-2.3.2-h32481e8_7100102
libcamd	conda-forge/linux-64::libcamd-3.3.3-h32481e8_7100102
libcbblas	conda-forge/linux-64::libcbblas-3.9.0-31_he106b2a_openblas
libccolamd	conda-forge/linux-64::libccolamd-3.3.4-h32481e8_7100102
libcholmod	conda-forge/linux-64::libcholmod-5.3.1-h59ddab4_7100102
libcolamd	conda-forge/linux-64::libcolamd-3.3.4-h32481e8_7100102
libcxsparse	conda-forge/linux-64::libcxsparse-4.4.1-h32481e8_7100102
libgcc	conda-forge/linux-64::libgcc-14.2.0-h767d61c_2
libgfortran	conda-forge/linux-64::libgfortran-14.2.0-h69a702a_2
libgfortran-ng	conda-forge/linux-64::libgfortran-ng-14.2.0-h69a702a_2
libgfortran5	conda-forge/linux-64::libgfortran5-14.2.0-hf1ad2bd_2
libklu	conda-forge/linux-64::libklu-2.3.5-hf24d653_7100102
liblapack	conda-forge/linux-64::liblapack-3.9.0-31_h7ac8fdf_openblas
libldl	conda-forge/linux-64::libldl-3.3.2-h32481e8_7100102
libopenblas	conda-forge/linux-64::libopenblas-0.3.29-pthreads_h94d23a6_0
libparu	conda-forge/linux-64::libparu-1.0.0-h17147ab_7100102
librbio	conda-forge/linux-64::librbio-4.3.4-h32481e8_7100102
libspex	conda-forge/linux-64::libspex-3.2.3-had10066_7100102
libspqr	conda-forge/linux-64::libspqr-4.3.4-h852d39f_7100102
libstdcxx	conda-forge/linux-64::libstdcxx-14.2.0-h8f9b012_2
libsuitesparsecon~	conda-forge/linux-64::libsuitesparseconfig-7.10.1-h92d6892_7100102
libumfpack	conda-forge/linux-64::libumfpack-6.3.5-heb53515_7100102
metis	conda-forge/linux-64::metis-5.1.0-hd0bc9f9_1007
mpfr	conda-forge/linux-64::mpfr-4.2.1-h90cbb55_3
numpy	conda-forge/linux-64::numpy-2.2.4-py311h5d046bc_0
pyfmi	conda-forge/linux-64::pyfmi-2.16.3-py311h9f3472d_0
python_abi	conda-forge/linux-64::python_abi-3.11-2_cp311
scipy	conda-forge/linux-64::scipy-1.15.2-py311h8f841c2_0
suitesparse	conda-forge/linux-64::suitesparse-7.10.1-ha0f6916_7100102
sundials	conda-forge/linux-64::sundials-7.1.1-ha52427a_0

The following packages will be UPDATED:

conda	pkgs/main::conda-24.11.1-py311h06a430~ --> conda-forge::conda-25.1.1-py311h38be061_1
libgcc-ng	pkgs/main::libgcc-ng-11.2.0-h1234567_1 --> conda-forge::libgcc-ng-14.2.0-h69a702a_2

```
libgomp                pkgs/main::libgomp-11.2.0-h1234567_1 --> conda-forge::libgomp
-14.2.0-h767d61c_2
libstdcxx-ng           pkgs/main::libstdcxx-ng-11.2.0-h12345~ --> conda-forge::libstdc
xx-ng-14.2.0-h4852527_2
openssl                pkgs/main::openssl-3.0.16-h5eee18b_0 --> conda-forge::openssl
-3.4.1-h7b32b05_0
```

The following packages will be SUPERSEDED by a higher-priority channel:

```
certifi                pkgs/main/linux-64::certifi-2025.1.31~ --> conda-forge/noarch::
certifi-2025.1.31-pyhd8ed1ab_0
```

Downloading and Extracting Packages:

```
scipy-1.15.2           | 16.4 MB | : 0% 0/1 [00:00<?, ?it/s]
numpy-2.2.4            | 8.6 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
libopenblas-0.3.29    | 5.6 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
pyfmi-2.16.3          | 5.2 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
metis-5.1.0           | 3.7 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
libstdcxx-14.2.0      | 3.7 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
openssl-3.4.1         | 2.8 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
libgfortran5-14.2.0   | 1.4 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

```
conda-25.1.1          | 1.1 MB  | : 0% 0/1 [00:00<?, ?it/s]
```

assimulo-3.6.0 | 1.1 MB | : 0% 0/1 [00:00<?, ?it/s]

libcholmod-5.3.1 | 1.1 MB | : 0% 0/1 [00:00<?, ?it/s]

sundials-7.1.1 | 907 KB | : 0% 0/1 [00:00<?, ?it/s]

libgcc-14.2.0 | 828 KB | : 0% 0/1 [00:00<?, ?it/s]

mpfr-4.2.1 | 620 KB | : 0% 0/1 [00:00<?, ?it/s]



gmp-6.3.0 | 449 KB | : 0% 0/1 [00:00<?, ?it/s]

libgomp-14.2.0 | 449 KB | : 0% 0/1 [00:00<?, ?it/s]

libumfpack-6.3.5 | 424 KB | : 0% 0/1 [00:00<?, ?it/s]

fmilib-2.4.1	383 KB	:	0% 0/1 [00:00<?, ?it/s]
--------------	--------	---	-------------------------

libspqr-4.3.4	213 KB	:	0% 0/1 [00:00<?, ?it/s]
---------------	--------	---	-------------------------

... (more hidden) ...			
scipy-1.15.2	16.4 MB	:	1% 0.007623511861659131/1 [00:00<00:13, 13.74 s/it]

pyfmi-2.16.3	5.2 MB	:	1% 0.01491976528324333/1 [00:00<00:06, 6.71 s/it]
--------------	--------	---	---

libopenblas-0.3.29	5.6 MB	:	1% 0.011071601854817674/1 [00:00<00:09, 9.30 s/it]
--------------------	--------	---	--

metis-5.1.0	3.7 MB	:	3% 0.02923059670299422/1 [00:00<00:03, 3.46 s/it]
-------------	--------	---	---

scipy-1.15.2	16.4 MB	:	15% 0.15247023723318262/1 [00:00<00:00, 1.16 s/it]
--------------	---------	---	--

pyfmi-2.16.3 t/s]	5.2 MB	: 46% 0.45654481766724586/1 [00:00<00:00, 2.65i
libopenblas-0.3.29 t/s]	5.6 MB	: 64% 0.6449208080431295/1 [00:00<00:00, 3.72i
metis-5.1.0 t/s]	3.7 MB	: 94% 0.9437306935538133/1 [00:00<00:00, 5.46i
metis-5.1.0 scipy-1.15.2 t/s]	3.7 MB   16.4 MB	: 100% 1.0/1 [00:00<00:00, 5.46it/s]   : 38% 0.3811755930829565/1 [00:00<00:00, 1.50i
libstdcxx-14.2.0 4s/it]	3.7 MB	: 0% 0.0042177278432850495/1 [00:00<01:16, 76.8
pyfmi-2.16.3	5.2 MB	: 100% 1.0/1 [00:00<00:00, 2.77it/s]
scipy-1.15.2 t/s]	16.4 MB	: 58% 0.5755751455552643/1 [00:00<00:00, 1.63i
libopenblas-0.3.29	5.6 MB	: 100% 1.0/1 [00:00<00:00, 3.72it/s]
libstdcxx-14.2.0 t/s]	3.7 MB	: 89% 0.8857228470898605/1 [00:00<00:00, 2.71i
openssl-3.4.1 8s/it]	2.8 MB	: 1% 0.0055741049077571376/1 [00:00<01:17, 77.4
scipy-1.15.2 t/s]	16.4 MB	: 74% 0.7394806505809357/1 [00:00<00:00, 1.60i

openssl-3.4.1	2.8 MB	: 94% 0.9420237294109562/1 [00:00<00:00, 2.33it/s]
---------------	--------	--

libgfortran5-14.2.0	1.4 MB	: 100% 1.0/1 [00:00<00:00, 2.38it/s]
---------------------	--------	--------------------------------------

libgfortran5-14.2.0	1.4 MB	: 100% 1.0/1 [00:00<00:00, 2.38it/s]
---------------------	--------	--------------------------------------

libstdcxx-14.2.0	3.7 MB	: 100% 1.0/1 [00:00<00:00, 2.71it/s]
numpy-2.2.4	8.6 MB	: 100% 1.0/1 [00:00<00:00, 1.59it/s]
numpy-2.2.4	8.6 MB	: 100% 1.0/1 [00:00<00:00, 1.59it/s]

scipy-1.15.2	16.4 MB	: 97% 0.9748565793096613/1 [00:00<00:00, 1.84it/s]
--------------	---------	--

assimulo-3.6.0	1.1 MB	: 1% 0.014703493605362324/1 [00:00<00:41, 41.73s/it]
----------------	--------	--

openssl-3.4.1	2.8 MB	: 100% 1.0/1 [00:00<00:00, 2.33it/s]
---------------	--------	--------------------------------------

libcholmod-5.3.1 | 1.1 MB | : 1% 0.014870549794649543/1 [00:00<00:42, 42.69  
s/it]

conda-25.1.1 | 1.1 MB | : 100% 1.0/1 [00:00<00:00, 44.13s/it]

sundials-7.1.1 | 907 KB | : 2% 0.01763373830085844/1 [00:00<00:37, 37.92  
s/it]

assimulo-3.6.0 | 1.1 MB | : 100% 1.0/1 [00:00<00:00, 41.73s/it]

libgcc-14.2.0 | 828 KB | : 2% 0.01932337522187561/1 [00:00<00:35, 36.39  
s/it]

libcholmod-5.3.1 | 1.1 MB | : 100% 1.0/1 [00:00<00:00, 42.69s/it]

mpfr-4.2.1 | 620 KB | : 3% 0.025811696239942908/1 [00:00<00:27, 28.52  
s/it]

libgcc-14.2.0 | 828 KB | : 100% 1.0/1 [00:00<00:00, 36.39s/it]

mpfr-4.2.1 | 620 KB | : 100% 1.0/1 [00:00<00:00, 28.52s/it]

gmp-6.3.0 | 449 KB | : 4% 0.03561313321233331/1 [00:00<00:21, 21.81  
s/it]

sundials-7.1.1 | 907 KB | : 100% 1.0/1 [00:00<00:00, 1.71it/s]

sundials-7.1.1 | 907 KB | : 100% 1.0/1 [00:00<00:00, 1.71it/s]

libgomp-14.2.0 | 449 KB | : 4% 0.03562807972826631/1 [00:00<00:21, 22.26  
s/it]

gmp-6.3.0 | 449 KB | : 100% 1.0/1 [00:00<00:00, 21.81s/it]

libumfpack-6.3.5 | 424 KB | : 4% 0.037731330084655984/1 [00:00<00:20, 21.52  
s/it]

libumfpack-6.3.5 | 424 KB | : 100% 1.0/1 [00:00<00:00, 21.52s/it]

libgomp-14.2.0 | 449 KB | : 100% 1.0/1 [00:00<00:00, 22.26s/it]



fmilib-2.4.1 | 383 KB | : 4% 0.04180391656566945/1 [00:00<00:19, 19.90  
s/it]

libspqr-4.3.4 | 213 KB | : 8% 0.07503068271326775/1 [00:00<00:10, 11.29  
s/it]

fmilib-2.4.1 | 383 KB | : 100% 1.0/1 [00:00<00:00, 19.90s/it]

libspqr-4.3.4 | 213 KB | : 100% 1.0/1 [00:00<00:00, 11.29s/it]

... (more hidden) ...

... (more hidden) ...

scipy-1.15.2 | 16.4 MB | : 100% 1.0/1 [00:01<00:00, 1.84it/s]

pyfmi-2.16.3 | 5.2 MB | : 100% 1.0/1 [00:01<00:00, 2.77it/s]

libgfortran5-14.2.0 | 1.4 MB | : 100% 1.0/1 [00:01<00:00, 2.38it/s]

libstdcxx-14.2.0	3.7 MB	: 100% 1.0/1 [00:01<00:00, 2.71it/s]
------------------	--------	--------------------------------------

libopenblas-0.3.29	5.6 MB	: 100% 1.0/1 [00:01<00:00, 3.72it/s]
--------------------	--------	--------------------------------------

openssl-3.4.1	2.8 MB	: 100% 1.0/1 [00:01<00:00, 2.33it/s]
---------------	--------	--------------------------------------

conda-25.1.1	1.1 MB	: 100% 1.0/1 [00:02<00:00, 2.10s/it]
--------------	--------	--------------------------------------

conda-25.1.1	1.1 MB	: 100% 1.0/1 [00:02<00:00, 2.10s/it]
--------------	--------	--------------------------------------

assimulo-3.6.0	1.1 MB	: 100% 1.0/1 [00:02<00:00, 2.25s/it]
----------------	--------	--------------------------------------

assimulo-3.6.0	1.1 MB	: 100% 1.0/1 [00:02<00:00, 2.25s/it]
----------------	--------	--------------------------------------

libcholmod-5.3.1	1.1 MB	: 100% 1.0/1 [00:02<00:00, 2.29s/it]
------------------	--------	--------------------------------------

libcholmod-5.3.1 | 1.1 MB | : 100% 1.0/1 [00:02<00:00, 2.29s/it]

libgcc-14.2.0 | 828 KB | : 100% 1.0/1 [00:02<00:00, 2.38s/it]

libgcc-14.2.0 | 828 KB | : 100% 1.0/1 [00:02<00:00, 2.38s/it]

mpfr-4.2.1 | 620 KB | : 100% 1.0/1 [00:02<00:00, 2.44s/it]

mpfr-4.2.1 | 620 KB | : 100% 1.0/1 [00:02<00:00, 2.44s/it]

sundials-7.1.1 | 907 KB | : 100% 1.0/1 [00:02<00:00, 1.71it/s]

gmp-6.3.0 | 449 KB | : 100% 1.0/1 [00:02<00:00, 2.67s/it]

gmp-6.3.0 | 449 KB | : 100% 1.0/1 [00:02<00:00, 2.67s/it]

libumfpack-6.3.5 | 424 KB | : 100% 1.0/1 [00:02<00:00, 2.69s/it]

libumfpack-6.3.5 | 424 KB | : 100% 1.0/1 [00:02<00:00, 2.69s/it]

libgomp-14.2.0 | 449 KB | : 100% 1.0/1 [00:02<00:00, 2.77s/it]

libgomp-14.2.0 | 449 KB | : 100% 1.0/1 [00:02<00:00, 2.77s/it]

fmilib-2.4.1 | 383 KB | : 100% 1.0/1 [00:03<00:00, 2.83s/it]

fmilib-2.4.1 | 383 KB | : 100% 1.0/1 [00:03<00:00, 2.83s/it]

libspqr-4.3.4 | 213 KB | : 100% 1.0/1 [00:03<00:00, 2.88s/it]

libspqr-4.3.4 | 213 KB | : 100% 1.0/1 [00:03<00:00, 2.88s/it]

... (more hidden) ...

... (more hidden) ...  
scipy-1.15.2 | 16.4 MB | : 100% 1.0/1 [00:04<00:00, 1.84it/s]















```

Preparing transaction: - 00\ 00done
Verifying transaction: / 00- 00\ 00| 00/ 00done
Executing transaction: \ 00| 00/ 00- 00\ 00| 00/ 00- 00\ 00| 00/ 00- 00\ 00| 00/ 00-
00\ 00| 00/ 00- 00\ 00| 00/ 00- 00done

```

## Notes of BPL\_TEST2\_Perfusion

This notebook explore perfusion cultivation in comparison with ordinary continuous cultivation (chemostat) and use comparable settings to earlier notebook. Further you see here examples of interaction with the simplified commands `par()`, `init()`, `simu()` etc as well as direct interaction with the FMU which is called "model" here. The last simulation is always available in the workspace and called "sim\_res". Note that `describe()` brings mainly up from descriptive information from the Modelica code from the FMU but is complemented by some information given in the Python setup file.

Now specific installation run a simulation and notebook for that Start with connecting to Github. Then upload the two files:

- FMU - BPL\_TEST2\_Perfusion\_linux\_om\_me.fmu
- Setup-file - BPL\_TEST2\_Perfusion\_explore.py

```

In [9]: %%bash
git clone https://github.com/janpeter19/BPL_TEST2_Perfusion

```

Cloning into 'BPL\_TEST2\_Perfusion'...

```

In [10]: %cd BPL_TEST2_Perfusion

/content/BPL_TEST2_Perfusion

```

```

In [11]: run -i BPL_TEST2_Perfusion_explore.py

```

Linux - run FMU pre-compiled OpenModelica

Model for the process has been setup. Key commands:

- par() - change of parameters and initial values
- init() - change initial values only
- simu() - simulate and plot
- newplot() - make a new plot
- show() - show plot from previous simulation
- disp() - display parameters and initial values from the last simulation
- describe() - describe culture, broth, parameters, variables with values/units

Note that both disp() and describe() takes values from the last simulation and the command process\_diagram() brings up the main configuration

Brief information about a command by help(), eg help(simu)

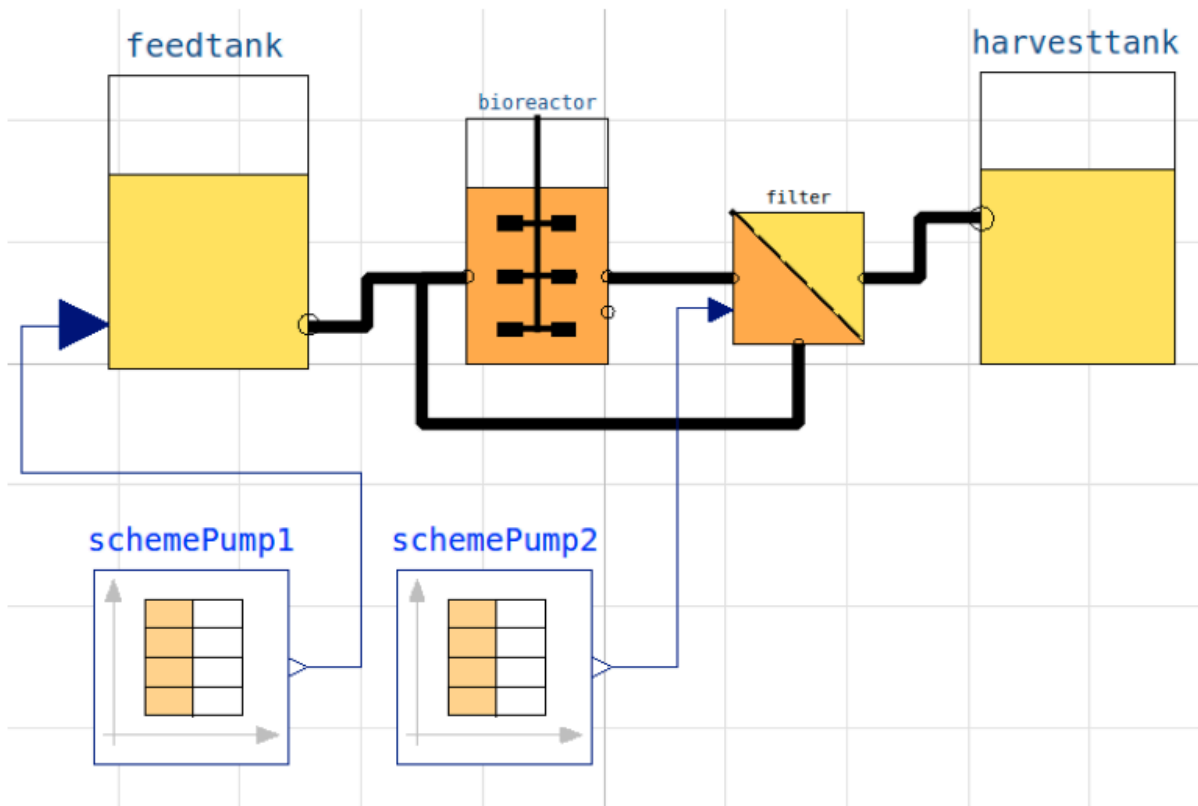
Key system information is listed with the command system\_info()

```
In [12]: # Filter out DeprecationWarnings for 'np.float as alias' is needed - wish
import warnings
warnings.filterwarnings("ignore")
```

```
In [13]: %matplotlib inline
plt.rcParams['figure.figsize'] = [25/2.54, 20/2.54]
```

```
In [14]: process_diagram()
```

No processDiagram.png file in the FMU, but try the file on disk.



```
In [15]: # Process parameters used throughout
par(Y=0.5, qSmax=0.75, Ks=0.1)                                     # Culture
par(filter_eps=0.10, filter_alpha_X=0.02, filter_alpha_S=0.10)    # Filter
```



```

par(S_in=30.0) # Inlet substrate
init(V_start=1.0, VX_start=1.0) # Process initial
eps = parDict['filter_eps'] # Pump schedule

```

In [16]: # Simulation of process with flow rate close to wash-out for chemostat

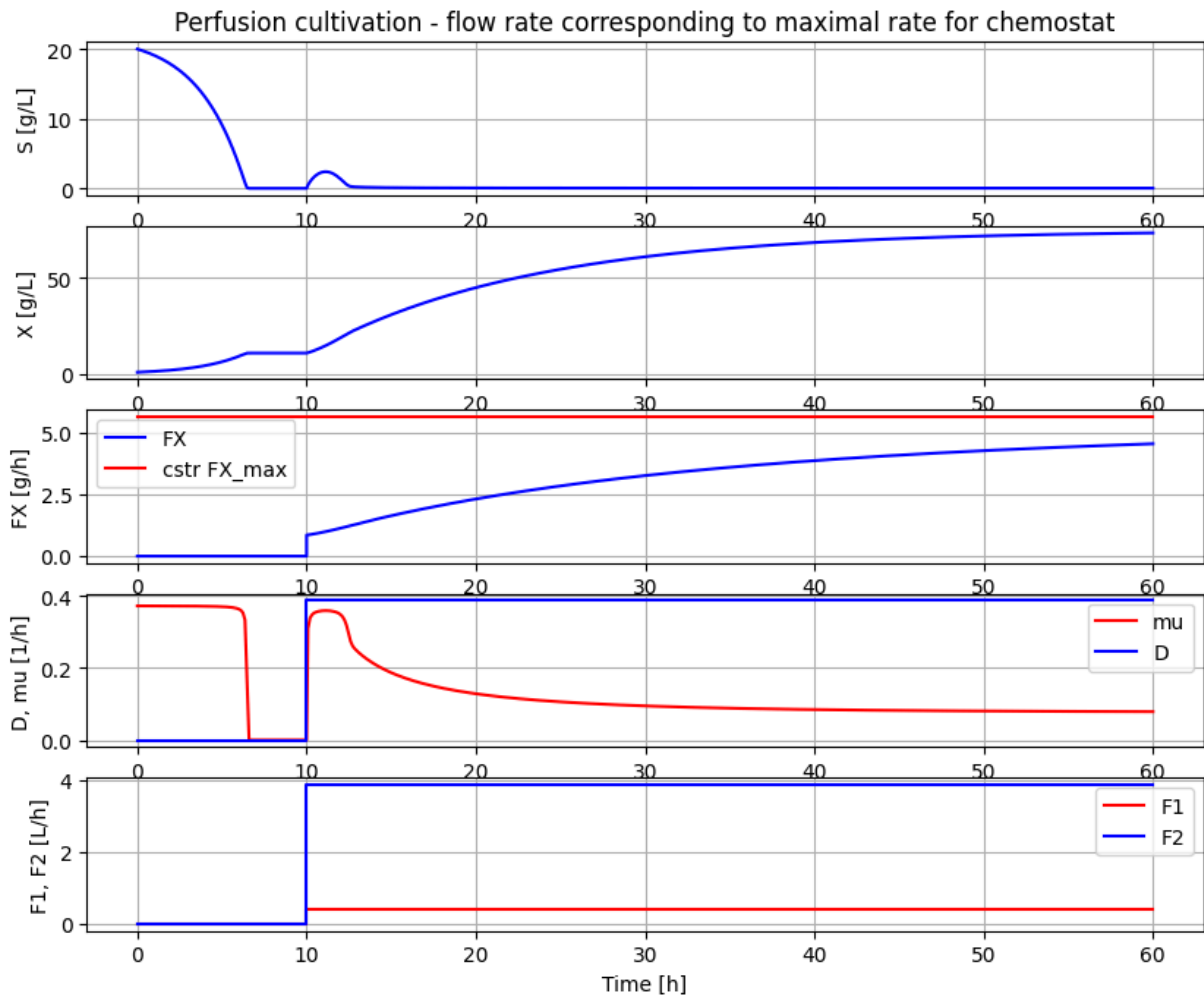
```

init(VS_start=20) # Process initial
par(pump1_t1=10, pump2_t1=10) # Pump schedule - recycle
par(pump1_F1=2.5*0.155, pump2_F1=2.5*0.155/eps)
par(pump1_t2=940, pump2_t2=940, pump1_t3=950, pump2_t3=950, pump1_t4=960, pump2_t4=960)

newplot(title='Perfusion cultivation - flow rate corresponding to maximal rate for
simu(60)

```

Could not find cannot import name 'dopri5' from 'assimulo.lib' (/usr/local/lib/python3.11/site-packages/assimulo/lib/\_\_init\_\_.py)  
 Could not find cannot import name 'rodas' from 'assimulo.lib' (/usr/local/lib/python3.11/site-packages/assimulo/lib/\_\_init\_\_.py)  
 Could not find cannot import name 'odassl' from 'assimulo.lib' (/usr/local/lib/python3.11/site-packages/assimulo/lib/\_\_init\_\_.py)  
 Could not find ODEPACK functions.  
 Could not find RADAR5  
 Could not find GLIMDA.



In [17]: # Simulation of process with flow rate close to wash-out for chemostat

Figure 10 displays five stacked plots showing the time evolution of various variables over 60 hours. The variables are:

- $S$  [g/L]: Substrate concentration, decreasing from 20 to 0.
- $X$  [g/L]: Biomass concentration, increasing from 0 to approximately 60.
- $FX$  [g/h]: Flow rate, increasing from 0 to approximately 5.
- $D, \mu$  [1/h]: Dilution rate and specific growth rate, both increasing from 0 to approximately 0.4.
- $F1, F2$  [L/h]: Feed flow rates, both increasing from 0 to approximately 4.

The plots show the response of the system to a step change in the setpoint for  $FX$  at  $t = 10$  h. Solid lines represent the actual values, and dashed lines represent the setpoints.

```
In [18]: # Concentration factor of the filter
c=model.get('filter.retentate.c[1]')[0]/model.get('filter.inlet.c[1]')[0]
print('Conc factor of perfusion filter =', np.round(c,3))
```

```
In [19]: c_data=sim_res['filter.retentate.c[1]']/sim_res['filter.inlet.c[1]']
print('Conc factor variation', np.round(min(c_data[151:]), 3), np.round(max(c_data[
```

```
In [20]: # Simulation of process with step-wise increase of perfusion rate until wash-out.
# This means that re-circulation rate change at the same time as the perfusion rate

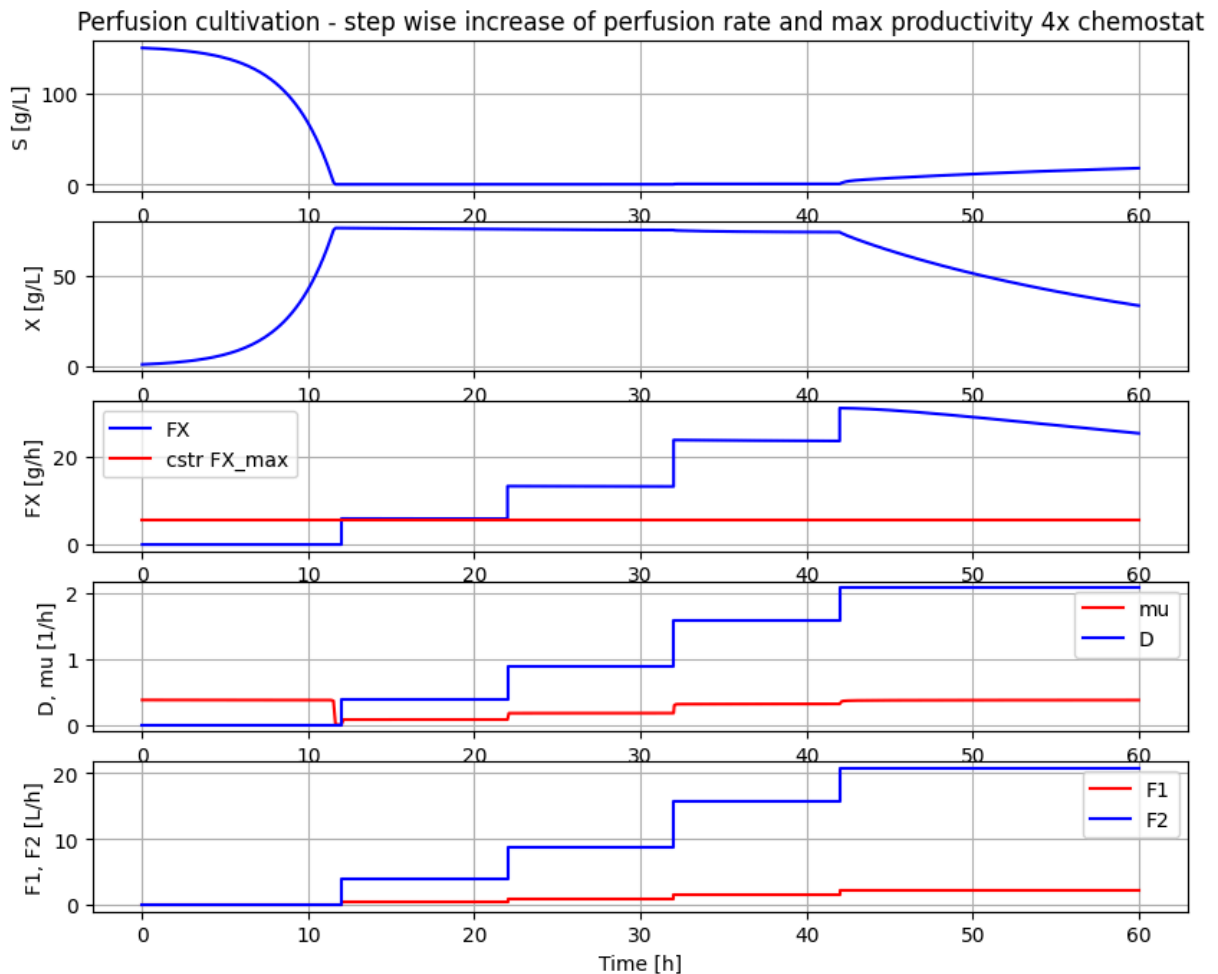
init(VS start=150) # Process initial varied
```

```

par(pump1_t1=12, pump2_t1=12) # Pump schedule - recycle
par(pump1_F1=2.5*0.155, pump2_F1=2.5*0.155/eps)
par(pump1_t2=22, pump2_t2=22)
par(pump1_F2=2.5*0.35, pump2_F2=2.5*0.35/eps)
par(pump1_t3=32, pump2_t3=32)
par(pump1_F3=2.5*0.63, pump2_F3=2.5*0.63/eps)
par(pump1_t4=42, pump2_t4=42)
par(pump1_F4=2.5*0.83, pump2_F4=2.5*0.83/eps)

newplot(title='Perfusion cultivation - step wise increase of perfusion rate and max
simu(60)

```



```

In [21]: # Simulation without a plot and just to check typical values at high production rat
simu(40)
c_data=sim_res['filter.retentate.c[1]']/sim_res['filter.inlet.c[1]']
print('Conc factor variation', np.round(min(c_data[190:]), 3), 'to', np.round(max(c

```

Conc factor variation 1.162 to 1.179

```

In [22]: #describe('cstrProdMax')

```

```

In [23]: # The maximal biomass productivity before washout is obtained aroundn 40 hours
np.round(model.get('harvesttank.inlet.F')[0]*model.get('harvesttank.inlet.c[1]')[0]

```

```
Out[23]: np.float64(23.5)
```

```
In [24]: # Thus perfusion (with this filter) brings a productivity improvement of about  
np.round(23.5/5.6,1)
```

```
Out[24]: np.float64(4.2)
```

```
In [25]: # Finally we check the filter flow rates at time 40 hour - note the negative sign f  
model.get('filter.inlet.F')[0]
```

```
Out[25]: np.float64(15.749999999999998)
```

```
In [26]: model.get('filter.filtrate.F')[0]
```

```
Out[26]: np.float64(-1.575)
```

```
In [27]: model.get('filter.retentate.F')[0]
```

```
Out[27]: np.float64(-14.174999999999999)
```

## Summary

- The perfusion filter had a concentration factor of cells around 1.08 and re-cycling flow was set to a factor 10 higher than the perfusion rate and changed when perfusion rate was change to keep the ratio factor 10.
- The first simulation showed that by cell retention using perfusion filter the process could be run at a perfusion flow rate at the maximal flow rate possible for corresponding chemostat culture and cell concentration increased steadily.
- The second simulation showed that with a proper startup cell concentration, the cell concentration remained constant when perfusion rate increased in a similar way as what we see in a chemostat.
- The second simulation also showed that biomass productivity in this case was increased by a factor 4.2 compared to chemostat.
- If the perfusion rate increased to higher levels washout started but the decrease of cell concentration was slow.

Some of you who read this may have your perfusion experience with CHO-cultures. For such cultures the cell concentration do increase with increase of perfusion rate and there are understood reasons for that. But for this simplified process as well as microbial processes they typically keep cell concentration constant when flow rate is chaged, and that under quite wide conditions. I will try come back to this phenomena in a later notebook.

```
In [28]: # List of components in the process setup and also a couple of other things like Li  
describe('parts')
```

```
['bioreactor', 'bioreactor.culture', 'D', 'feedtank', 'filter', 'harvesttank', 'schemePump1', 'schemePump2']
```

In [29]: `describe('MSL')`

MSL: 3.2.3 - used components: RealInput, RealOutput, CombiTimeTable, Types

In [30]: `system_info()`

System information

-OS: Linux

-Python: 3.11.11

-Scipy: not installed in the notebook

-PyFMI: 2.16.3

-FMU by: OpenModelica Compiler OpenModelica 1.25.0~dev-133-ga5470be

-FMI: 2.0

-Type: FMUModelME2

-Name: BPL.Examples\_TEST2.Perfusion

-Generated: 2024-11-06T21:37:58Z

-MSL: 3.2.3

-Description: Bioprocess Library version 2.3.0

-Interaction: FMU-explore version 1.0.0

In [30]: