cameo Documentation

Release 0.1.0

Nikolaus Sonnenschein, João Cardoso

July 21, 2015

Contents

1 Table of Contents **3**

1.1 Installation . . . 3
1.2 Getting started with . . . 4
1.3 Simulating models with . . . 38
1.4 Analyzing models with . . . 40
1.5 Differential flux variability analysis . . . 41
1.6 E. coli core model . . . 42
1.7 iJO1366 model . . . 45
1.8 Parallelization . . . 47
1.9 cameo vs. cobrapy . . . 47
1.10 How to 48
1.11 API . . . 48

2 Indices and tables **53**

Warning: These pages are under construction. Feel free to look around ...

Cameo is a high-level python library developed to aid the strain design process in metabolic engineering projects. The library provides a modular framework of simulation methods, strain design methods, access to models, that targets developers that want custom analysis workflows.

Computationally heavy methods have been parallelized and can be run on a clusters using the IPython parallelization framework (see example and documentation for more details). The default fallback is python's multiprocessing library.

Furthermore, it exposes a high-level API to users that just want to compute promising strain designs.

```
from cameo.api import design
design(product='L-Serine')
```

You got curious? Head over to try.cameo.bio and give it a try.

CHAPTER 1

Table of Contents

1.1 Installation

1.1.1 Setting up a virtual environment first

We highly recommended installing cameo inside a virtual environment (virtualenv). virtualenvwrapper tremendously simplifies using virtualenv and can easily be installed using virtualenv-burrito. Once you installed virtualenv and virtualenvwrapper, run

```
$ mkvirtualenv cameo  # or whatever you'd like to call your virtual environment
$ workon cameo
```

and then continue with the installation instructions described below.

1.1.2 Non-python dependencies

cameo relies on optlang to solve optimization problems. Currently, optlang supports either glpk (open source) or cplex (academic licenses available), which are not python tools. At least one of them has to be installed before one can proceed with the cameo installation.

GLPK

Using cameo with glpk also requires swig to be installed (in order to generate python bindings). On ubuntu (or other similar linux platforms) we recommend using `apt-get`:

```
$ sudo apt-get install libglpk-dev glpk-utils swig
```

On macs we recommend using homebrew.

```
$ brew install swig
$ brew install glpk
```

CPLEX

The cplex contains a python directory (similar to `IBM/ILOG/CPLEX_Studio1251/cplex/python/x86-64_osx`). Inside this directory run

```
$ python setup.py install
```

to install the python bindings.

1.1.3 Normal installation

Warning: cameo is still under heavy development. We recommend installing the development version (see below) if you would like to stay up-to-date with the latest changes.

cameo can be installed using *pip*.

```
$ pip install cameo
```

1.1.4 Development setup

pip can also be used to install cameo directly from the github repository.

```
$ pip install -e git+https://github.com/biosustain/cameo.git@devel#egg=cameo
```

Alternatively, you can clone the repository (or your fork) and then run

```
$ python setup.py install
```

From withing the cameo directory.

```
from pandas import options
options.display.max_rows = 8
```

1.2 Getting started with

computer **a**ided **m**etabolic **e**ngineering and **o**ptimization

cameo reuses and extends model data structures defined by cobrapy (**CO**nstraints-**B**ased **R**econstruction and **A**nalysis tool for **Py**thon). So, in addition to following this quick start guide and other **cameo** tutorials, we encourage you to explore cobrapy's documentation as well.

1.2.1 Step 1: Load a model

Loading a model is easy. Just import the `load_model` function.

```
from cameo import load_model
```

For example, load the most current genome-scale metabolic reconstruction of *Escherichia coli*.

```
model = load_model("iJO1366")
```

Models, reactions, metabolites, etc., provide return HTML when evaluated in Jupyter notebooks and can thus be easily inspected.

```
model
```

1.2.2 Step 2: Simulate a model

The model can be simulated by executing `model.solve()`.

```
solution = model.solve()
```

A quick overview of the solution can be obtained in form of a pandas DataFrame (all solution objects in cameo provide access to data frames through a `data_frame` attribute).

```
solution
```

The data frame is accessible through `solution.data_frame`.

```
solution.data_frame
```

Data frames make it very easy to process results. For example, let's take a look at reactions with flux != 0

```
solution.data_frame.query('fluxes != 0')
```

1.2.3 Step 3: Exploring a model

Objects—models, reactions, metabolites, genes—can easily be explored in the Jupyter notebook, taking advantage of tab completion. For example, place your cursor after the period in `model.reactions.` and press the TAB key. A dialog will appear that allows you to navigate the list of reactions encoded in the model.

```
model.reactions. # place your cursor after the period and press the TAB key.
```

For example, you can access the E4PD (*Erythrose 4-phosphate dehydrogenase*) reaction in the model.

```
model.reactions.E4PD
```

Be aware though that due variable naming restrictions in Python dot notation access to reactions (and other objects) might not work in some cases.

```
model.reactions.12DGR120tipp
```

```
  File "<ipython-input-11-fa7ea4193315>", line 1
    model.reactions.12DGR120tipp
                    ^
SyntaxError: invalid syntax
```

In these cases you need to use the `model.reactions.get_by_id`.

```
model.reactions.get_by_id('12DGR120tipp')
```

Metabolites are accessible through `model.metabolites`. For example, D-glucose in the cytosolic compartment.

```
model.metabolites.glc_dsh_D_c
```

```
<Metabolite glc_dsh_D_c at 0x112a22f98>
```

A list of the genes encoded in the model can be accessed via `model.genes`.

```
model.genes
```

```
[<Gene b1377 at 0x112b65208>,
 <Gene b2215 at 0x112b65240>,
 <Gene b0929 at 0x112b651d0>,
 <Gene b0241 at 0x112b65278>,
```

```
<Gene b4033 at 0x112b65588>,
<Gene b4034 at 0x112b65630>,
<Gene b4032 at 0x112b655c0>,
<Gene b4035 at 0x112b655f8>,
<Gene b4036 at 0x112b65518>,
<Gene b4213 at 0x112b65cc0>,
<Gene b2835 at 0x112b65f98>,
<Gene b2836 at 0x112b6ea58>,
<Gene b3553 at 0x112b78898>,
<Gene b1134 at 0x112b78c88>,
<Gene b0446 at 0x112b78cc0>,
<Gene b1009 at 0x112b78e48>,
<Gene b0954 at 0x112b7f400>,
<Gene b0180 at 0x112b7f3c8>,
<Gene b0347 at 0x112b7fe48>,
<Gene b3580 at 0x112b88240>,
<Gene b1093 at 0x112b886a0>,
<Gene b2323 at 0x112b8e240>,
<Gene b1095 at 0x112b8e278>,
<Gene b1397 at 0x112b8eba8>,
<Gene b1246 at 0x112b8ee80>,
<Gene b1247 at 0x112b8ef28>,
<Gene b1329 at 0x112b8eeb8>,
<Gene b1244 at 0x112b8ef60>,
<Gene b1245 at 0x112b8eef0>,
<Gene b1386 at 0x112b96208>,
<Gene b0004 at 0x112b96400>,
<Gene b1192 at 0x112b964e0>,
<Gene b1243 at 0x112b96748>,
<Gene b4266 at 0x112b96908>,
<Gene b4265 at 0x112b96a20>,
<Gene b0159 at 0x112b96c50>,
<Gene b3197 at 0x112b96f98>,
<Gene b2708 at 0x112b96f60>,
<Gene b1094 at 0x112b9d128>,
<Gene b4481 at 0x112b9d908>,
<Gene b1927 at 0x112b9da20>,
<Gene b3571 at 0x112b9db38>,
<Gene b2901 at 0x112b9dc88>,
<Gene b2662 at 0x112b9de10>,
<Gene b1302 at 0x112b9ddd8>,
<Gene b1444 at 0x112b9deb8>,
<Gene b2663 at 0x112b9dfd0>,
<Gene b2222 at 0x112ba5320>,
<Gene b2221 at 0x112ba52e8>,
<Gene b2224 at 0x112ba5518>,
<Gene b2342 at 0x112ba5550>,
<Gene b3845 at 0x112ba54e0>,
<Gene b2223 at 0x112ba5b70>,
<Gene b1241 at 0x112ba5e10>,
<Gene b0351 at 0x112ba5e48>,
<Gene s0001 at 0x112ba5ef0>,
<Gene b1463 at 0x112bae128>,
<Gene b1993 at 0x112bae240>,
<Gene b2316 at 0x112bae588>,
<Gene b0185 at 0x112bae518>,
<Gene b3255 at 0x112bae550>,
<Gene b3256 at 0x112bae4e0>,
```

```
<Gene b4069 at 0x112bae470>,
<Gene b1119 at 0x112baea58>,
<Gene b3784 at 0x112baeb38>,
<Gene b2416 at 0x112baef98>,
<Gene b2415 at 0x112baef28>,
<Gene b2417 at 0x112baefd0>,
<Gene b1101 at 0x112baef60>,
<Gene b0679 at 0x112baeef0>,
<Gene b3959 at 0x112bb30b8>,
<Gene b2818 at 0x112bb31d0>,
<Gene b0078 at 0x112bb3518>,
<Gene b3671 at 0x112bb34a8>,
<Gene b0077 at 0x112bb34e0>,
<Gene b3670 at 0x112bb3470>,
<Gene b2296 at 0x112bb3630>,
<Gene b1849 at 0x112bb3668>,
<Gene b3115 at 0x112bb35f8>,
<Gene b2428 at 0x112bb36d8>,
<Gene b3794 at 0x112bb38d0>,
<Gene b1817 at 0x112bb3ba8>,
<Gene b1819 at 0x112bb3b38>,
<Gene b1818 at 0x112bb3b70>,
<Gene b2429 at 0x112bb3da0>,
<Gene b3224 at 0x112bb3f60>,
<Gene b4311 at 0x112bbe0b8>,
<Gene b3225 at 0x112bbe208>,
<Gene b0221 at 0x112bbe2b0>,
<Gene b1091 at 0x112bbea58>,
<Gene b3957 at 0x112bbeb38>,
<Gene b4261 at 0x112bbee80>,
<Gene b3200 at 0x112bbee10>,
<Gene b3201 at 0x112bbeda0>,
<Gene b3199 at 0x112bbee48>,
<Gene b4262 at 0x112bbedd8>,
<Gene b1519 at 0x112bbef60>,
<Gene b1276 at 0x112bc3198>,
<Gene b0118 at 0x112bc31d0>,
<Gene b1748 at 0x112bc3390>,
<Gene b3359 at 0x112bc3358>,
<Gene b1090 at 0x112bc3438>,
<Gene b3475 at 0x112bc3a20>,
<Gene b2563 at 0x112bc39e8>,
<Gene b1533 at 0x112bc3c88>,
<Gene b2578 at 0x112bc3cc0>,
<Gene b4067 at 0x112bc3e10>,
<Gene b1623 at 0x112bca0f0>,
<Gene b1096 at 0x112bca1d0>,
<Gene b3360 at 0x112bca320>,
<Gene b1812 at 0x112bca358>,
<Gene b3665 at 0x112bca470>,
<Gene b3714 at 0x112bca588>,
<Gene b3654 at 0x112bca5c0>,
<Gene b0474 at 0x112bca7f0>,
<Gene b0120 at 0x112bcaa90>,
<Gene b3806 at 0x112bcabe0>,
<Gene b0030 at 0x112bcada0>,
<Gene b2393 at 0x112bcaf28>,
<Gene b2964 at 0x112bcaf60>,
```

```
<Gene b2406 at 0x112bcafd0>,
<Gene b0411 at 0x112bd1128>,
<Gene b1992 at 0x112bd1320>,
<Gene b0158 at 0x112bd1518>,
<Gene b1709 at 0x112bd1550>,
<Gene b1711 at 0x112bd14e0>,
<Gene b3006 at 0x112bd1780>,
<Gene b3005 at 0x112bd1710>,
<Gene b1252 at 0x112bd1748>,
<Gene b3966 at 0x112bd16d8>,
<Gene b3034 at 0x112bd1828>,
<Gene b3397 at 0x112bd1860>,
<Gene b0469 at 0x112bd1940>,
<Gene b2750 at 0x112bd19e8>,
<Gene b1131 at 0x112bd1b70>,
<Gene b4177 at 0x112bd1d68>,
<Gene b0677 at 0x112bd1e10>,
<Gene b0110 at 0x112bd1f28>,
<Gene b4169 at 0x112bd7198>,
<Gene b2435 at 0x112bd7128>,
<Gene b2817 at 0x112bd7160>,
<Gene b1107 at 0x112bd7208>,
<Gene b0433 at 0x112bd7320>,
<Gene b3619 at 0x112bd7940>,
<Gene b2937 at 0x112bd7a58>,
<Gene b3018 at 0x112bd7c88>,
<Gene b3958 at 0x112bdf2b0>,
<Gene b0574 at 0x112bdf588>,
<Gene b0575 at 0x112bdf5c0>,
<Gene b0572 at 0x112bdf550>,
<Gene b0573 at 0x112bdf5f8>,
<Gene b4006 at 0x112bdf748>,
<Gene b0522 at 0x112bdf828>,
<Gene b0523 at 0x112bdf908>,
<Gene b0727 at 0x112bdfb00>,
<Gene b0116 at 0x112bdfb38>,
<Gene b0726 at 0x112bdfb70>,
<Gene b2587 at 0x112bdfbe0>,
<Gene b1488 at 0x112bdfd30>,
<Gene b3541 at 0x112be5400>,
<Gene b1485 at 0x112be5438>,
<Gene b1484 at 0x112be5470>,
<Gene b3542 at 0x112be54a8>,
<Gene b3540 at 0x112be54e0>,
<Gene b1486 at 0x112be5518>,
<Gene b3543 at 0x112be5550>,
<Gene b1483 at 0x112be5588>,
<Gene b3544 at 0x112be53c8>,
<Gene b1487 at 0x112be55c0>,
<Gene b0092 at 0x112be52b0>,
<Gene b0381 at 0x112be52e8>,
<Gene b1325 at 0x112be5668>,
<Gene b4053 at 0x112be5828>,
<Gene b1190 at 0x112be5860>,
<Gene b2551 at 0x112be5940>,
<Gene b0870 at 0x112be5978>,
<Gene b2379 at 0x112be5b00>,
<Gene b2290 at 0x112be5ac8>,
```

```
<Gene b2697 at 0x112be5c50>,
<Gene b3457 at 0x112be5f98>,
<Gene b3454 at 0x112be5f28>,
<Gene b3460 at 0x112be5eb8>,
<Gene b3455 at 0x112be5f60>,
<Gene b3456 at 0x112be5ef0>,
<Gene b4208 at 0x112be5e80>,
<Gene b0007 at 0x112bea128>,
<Gene b0356 at 0x112bea3c8>,
<Gene b1478 at 0x112bea550>,
<Gene b1385 at 0x112bea5c0>,
<Gene b1300 at 0x112bea6d8>,
<Gene b3588 at 0x112bea7f0>,
<Gene b4084 at 0x112beaa58>,
<Gene b4090 at 0x112beab38>,
<Gene b0516 at 0x112beac88>,
<Gene b0512 at 0x112beadd8>,
<Gene b0511 at 0x112beae80>,
<Gene b4085 at 0x112bf20f0>,
<Gene b4086 at 0x112bf2320>,
<Gene b4088 at 0x112bf22b0>,
<Gene b4087 at 0x112bf22e8>,
<Gene b1677 at 0x112bf2518>,
<Gene b0657 at 0x112bf2550>,
<Gene b3012 at 0x112bf2828>,
<Gene b3001 at 0x112bf27b8>,
<Gene b0207 at 0x112bf2860>,
<Gene b1781 at 0x112bf27f0>,
<Gene b3945 at 0x112bf28d0>,
<Gene b3091 at 0x112bf2a20>,
<Gene b3416 at 0x112bf2d68>,
<Gene b3223 at 0x112bf8128>,
<Gene b3222 at 0x112bf8278>,
<Gene b0774 at 0x112bf8358>,
<Gene b3833 at 0x112bf8470>,
<Gene b3994 at 0x112bf8588>,
<Gene b1982 at 0x112bf8710>,
<Gene b4260 at 0x112bf8908>,
<Gene b0932 at 0x112bf89b0>,
<Gene b2523 at 0x112bf8940>,
<Gene b0237 at 0x112bf8978>,
<Gene b1640 at 0x112bf8d68>,
<Gene b1263 at 0x112bf8e48>,
<Gene b1264 at 0x112bf8fd0>,
<Gene b0776 at 0x112bfe1d0>,
<Gene b0049 at 0x112bfe2e8>,
<Gene b4129 at 0x112bfe400>,
<Gene b0121 at 0x112bfe5c0>,
<Gene b3059 at 0x112bfe6d8>,
<Gene b0968 at 0x112bfec18>,
<Gene b0414 at 0x114856320>,
<Gene b0062 at 0x114856470>,
<Gene b0153 at 0x114856780>,
<Gene b0151 at 0x1148567b8>,
<Gene b0152 at 0x1148567f0>,
<Gene b3722 at 0x114856b38>,
<Gene b2715 at 0x114856be0>,
<Gene b1901 at 0x114856da0>,
```

```
<Gene b1900 at 0x114856d30>,
<Gene b4460 at 0x114856d68>,
<Gene b2841 at 0x114856dd8>,
<Gene b1528 at 0x114856e80>,
<Gene b4115 at 0x11485f128>,
<Gene b4117 at 0x11485f240>,
<Gene b2938 at 0x11485f358>,
<Gene b1605 at 0x11485f438>,
<Gene b3960 at 0x11485f588>,
<Gene b3172 at 0x11485f6a0>,
<Gene b1876 at 0x11485f780>,
<Gene b2308 at 0x11485fe10>,
<Gene b0860 at 0x11485fc50>,
<Gene b0862 at 0x11485fc88>,
<Gene b0863 at 0x11485fcc0>,
<Gene b2306 at 0x11485fcf8>,
<Gene b2310 at 0x11485fd30>,
<Gene b0861 at 0x11485fd68>,
<Gene b0864 at 0x11485fda0>,
<Gene b2307 at 0x11485fdd8>,
<Gene b2923 at 0x11485fa90>,
<Gene b3433 at 0x11485fef0>,
<Gene b4192 at 0x114865080>,
<Gene b4194 at 0x114865390>,
<Gene b4195 at 0x114865320>,
<Gene b4193 at 0x1148652b0>,
<Gene b1767 at 0x114865588>,
<Gene b0828 at 0x1148655c0>,
<Gene b2957 at 0x114865668>,
<Gene b0674 at 0x114865780>,
<Gene b3744 at 0x114865898>,
<Gene b0930 at 0x114865978>,
<Gene b1453 at 0x114865a90>,
<Gene b3502 at 0x114865ba8>,
<Gene b0131 at 0x114865f28>,
<Gene b4244 at 0x11486c198>,
<Gene b4245 at 0x11486c1d0>,
<Gene b3940 at 0x11486c320>,
<Gene b4024 at 0x11486c358>,
<Gene b0002 at 0x11486c2e8>,
<Gene b2574 at 0x11486c2b0>,
<Gene b4139 at 0x11486c780>,
<Gene b0928 at 0x11486c898>,
<Gene b1866 at 0x11486c978>,
<Gene b0652 at 0x11486cc18>,
<Gene b0654 at 0x11486cba8>,
<Gene b0653 at 0x11486cc50>,
<Gene b0655 at 0x11486cbe0>,
<Gene b3528 at 0x11486cb70>,
<Gene b4138 at 0x11486cda0>,
<Gene b4123 at 0x11486cdd8>,
<Gene b4077 at 0x11486ce80>,
<Gene b1064 at 0x114870208>,
<Gene b3503 at 0x1148701d0>,
<Gene b1747 at 0x114870278>,
<Gene b1539 at 0x114870390>,
<Gene b2019 at 0x1148705f8>,
<Gene b3735 at 0x114870e10>,
```

```
<Gene b3731 at 0x114870e48>,
<Gene b3736 at 0x114870e80>,
<Gene b3734 at 0x114870eb8>,
<Gene b3738 at 0x114870ef0>,
<Gene b3739 at 0x114870f28>,
<Gene b3733 at 0x114870f60>,
<Gene b3737 at 0x114870da0>,
<Gene b3732 at 0x114870dd8>,
<Gene b0312 at 0x114870b38>,
<Gene b0827 at 0x114870cf8>,
<Gene b3856 at 0x11487a128>,
<Gene b3857 at 0x11487a160>,
<Gene b4214 at 0x11487a2b0>,
<Gene b3551 at 0x11487a390>,
<Gene b0775 at 0x11487a710>,
<Gene b0367 at 0x11487ac18>,
<Gene b0934 at 0x11487ac50>,
<Gene b0365 at 0x11487ac88>,
<Gene b0366 at 0x11487ab70>,
<Gene b0936 at 0x11487aba8>,
<Gene b0933 at 0x11487abe0>,
<Gene b1216 at 0x114882160>,
<Gene b4132 at 0x1148822b0>,
<Gene b1732 at 0x114882588>,
<Gene b3942 at 0x114882550>,
<Gene b3196 at 0x114882630>,
<Gene b1270 at 0x114882710>,
<Gene b0323 at 0x114882f98>,
<Gene b0521 at 0x114882f28>,
<Gene b2874 at 0x114882f60>,
<Gene b0032 at 0x1148880b8>,
<Gene b0033 at 0x1148880f0>,
<Gene b0444 at 0x114888128>,
<Gene b3469 at 0x114888240>,
<Gene b0752 at 0x114888400>,
<Gene b3915 at 0x1148883c8>,
<Gene b3040 at 0x1148885f8>,
<Gene b3918 at 0x1148886a0>,
<Gene b2794 at 0x114888ba8>,
<Gene b1208 at 0x114888d68>,
<Gene b1661 at 0x114888e48>,
<Gene b2128 at 0x114890588>,
<Gene b2131 at 0x1148905c0>,
<Gene b2129 at 0x114890550>,
<Gene b2130 at 0x1148905f8>,
<Gene b0314 at 0x1148906a0>,
<Gene b1801 at 0x1148906d8>,
<Gene b0311 at 0x114890898>,
<Gene b2600 at 0x114890a20>,
<Gene b2599 at 0x114890a58>,
<Gene b2329 at 0x114890b70>,
<Gene b4039 at 0x114890c50>,
<Gene b2542 at 0x1148a8128>,
<Gene b2538 at 0x1148a80b8>,
<Gene b2539 at 0x1148a8160>,
<Gene b2540 at 0x1148a80f0>,
<Gene b0617 at 0x1148a8400>,
<Gene b0614 at 0x1148a8390>,
```

```
<Gene b0615 at 0x1148a83c8>,
<Gene b0616 at 0x1148a8358>,
<Gene b0612 at 0x1148a8320>,
<Gene b1249 at 0x1148a89b0>,
<Gene b0789 at 0x1148a8978>,
<Gene b0155 at 0x1148a8eb8>,
<Gene b1592 at 0x1148a8ef0>,
<Gene b3035 at 0x1148af710>,
<Gene b2470 at 0x1148af6a0>,
<Gene b0462 at 0x1148af6d8>,
<Gene b0463 at 0x1148af668>,
<Gene b3816 at 0x1148afac8>,
<Gene b2174 at 0x1148afb70>,
<Gene b0914 at 0x1148afc88>,
<Gene b1102 at 0x1148b7470>,
<Gene b2765 at 0x1148b7438>,
<Gene b0781 at 0x1148b7710>,
<Gene b0783 at 0x1148b76d8>,
<Gene b2436 at 0x1148b77b8>,
<Gene b3867 at 0x1148b7898>,
<Gene b0038 at 0x1148b79b0>,
<Gene b0037 at 0x1148b7b00>,
<Gene b0036 at 0x1148b7be0>,
<Gene b2679 at 0x1148be080>,
<Gene b2677 at 0x1148be0b8>,
<Gene b2678 at 0x1148be0f0>,
<Gene b4111 at 0x1148be128>,
<Gene b0040 at 0x1148be4e0>,
<Gene b0720 at 0x1148be860>,
<Gene b0337 at 0x1148be9b0>,
<Gene b0336 at 0x1148bea90>,
<Gene b3846 at 0x1148beef0>,
<Gene b2780 at 0x1148c71d0>,
<Gene b0123 at 0x1148c72b0>,
<Gene b0484 at 0x1148c7390>,
<Gene b3425 at 0x1148c7a20>,
<Gene b1308 at 0x1148c7b00>,
<Gene b0340 at 0x1148c7d68>,
<Gene b0341 at 0x1148c7e48>,
<Gene b1919 at 0x1148ce0f0>,
<Gene b3008 at 0x1148ce2b0>,
<Gene b3708 at 0x1148ce278>,
<Gene b2414 at 0x1148ce588>,
<Gene b2421 at 0x1148ce550>,
<Gene b2810 at 0x1148ce630>,
<Gene b1622 at 0x1148ce7f0>,
<Gene b0526 at 0x1148ce860>,
<Gene b0887 at 0x1148ce9b0>,
<Gene b0886 at 0x1148ce978>,
<Gene b0978 at 0x1148ced30>,
<Gene b0979 at 0x1148ced68>,
<Gene b0734 at 0x1148d5048>,
<Gene b0733 at 0x1148cef60>,
<Gene b0432 at 0x1148d5198>,
<Gene b0430 at 0x1148d5128>,
<Gene b0429 at 0x1148d51d0>,
<Gene b0431 at 0x1148d5160>,
<Gene b2143 at 0x1148d5240>,
```

```
<Gene b2162 at 0x1148d5438>,
<Gene b0651 at 0x1148d53c8>,
<Gene b2066 at 0x1148d54a8>,
<Gene b0910 at 0x1148d5860>,
<Gene b3603 at 0x1148d5a90>,
<Gene b2975 at 0x1148d5a58>,
<Gene b1189 at 0x1148d5c88>,
<Gene b4042 at 0x1148de0f0>,
<Gene b2871 at 0x1148deac8>,
<Gene b2838 at 0x1148deba8>,
<Gene b3809 at 0x1148decf8>,
<Gene b0175 at 0x1148def60>,
<Gene b3041 at 0x1148e3588>,
<Gene b0778 at 0x1148e36d8>,
<Gene b1734 at 0x1148e3780>,
<Gene b2065 at 0x1148e3b70>,
<Gene b2344 at 0x1148e3e80>,
<Gene b3693 at 0x1148e3fd0>,
<Gene b3909 at 0x1148ea0f0>,
<Gene b3526 at 0x1148ea320>,
<Gene b1704 at 0x1148ea588>,
<Gene b2601 at 0x1148ea518>,
<Gene b0754 at 0x1148ea550>,
<Gene b4477 at 0x1148ea5f8>,
<Gene b3648 at 0x1148ea710>,
<Gene b1393 at 0x1148eab38>,
<Gene b3771 at 0x1148eacc0>,
<Gene b1200 at 0x1148f10b8>,
<Gene b1199 at 0x1148f1048>,
<Gene b1198 at 0x1148eafd0>,
<Gene b0596 at 0x1148f1278>,
<Gene b0594 at 0x1148f13c8>,
<Gene b2541 at 0x1148f1518>,
<Gene b0348 at 0x1148f1630>,
<Gene b0031 at 0x1148f1748>,
<Gene b2478 at 0x1148f1898>,
<Gene b1606 at 0x1148f1a90>,
<Gene b0048 at 0x1148f1a58>,
<Gene b2315 at 0x1148f1b00>,
<Gene b3930 at 0x1148f1cf8>,
<Gene b2262 at 0x1148f1e10>,
<Gene b0736 at 0x1148f1f28>,
<Gene b3058 at 0x1148f7048>,
<Gene b0945 at 0x1148f7278>,
<Gene b1062 at 0x1148f74e0>,
<Gene b3177 at 0x1148f7780>,
<Gene b0578 at 0x1148f7908>,
<Gene b2303 at 0x1148f7ac8>,
<Gene b3389 at 0x1148f7c50>,
<Gene b1693 at 0x1148f7d30>,
<Gene b0421 at 0x1148ff400>,
<Gene b0029 at 0x1148ff4e0>,
<Gene b2232 at 0x1148ff5c0>,
<Gene b1589 at 0x1148ffa20>,
<Gene b1587 at 0x1148ffa58>,
<Gene b1590 at 0x1148ffa90>,
<Gene b0895 at 0x1148ffac8>,
<Gene b0894 at 0x1148ffb00>,
```

```
<Gene b1588 at 0x1148ffb38>,
<Gene b0896 at 0x1148ff9e8>,
<Gene b1873 at 0x1148ff940>,
<Gene b1872 at 0x1148ff978>,
<Gene b1865 at 0x114906208>,
<Gene b0099 at 0x114906240>,
<Gene b3575 at 0x1149062e8>,
<Gene b0103 at 0x1149066a0>,
<Gene b3774 at 0x114906908>,
<Gene b0425 at 0x1149068d0>,
<Gene b4381 at 0x114906a20>,
<Gene b3860 at 0x114906b38>,
<Gene b1185 at 0x114906b70>,
<Gene b2893 at 0x114906cf8>,
<Gene b4136 at 0x114906f98>,
<Gene b2582 at 0x11490c048>,
<Gene b3781 at 0x114906fd0>,
<Gene b0604 at 0x114906f28>,
<Gene b4122 at 0x11490c438>,
<Gene b1098 at 0x11490c550>,
<Gene b2147 at 0x11490c9b0>,
<Gene b2146 at 0x11490c9e8>,
<Gene b1238 at 0x11490ca58>,
<Gene b4382 at 0x11490cc18>,
<Gene b4384 at 0x11490cbe0>,
<Gene b2251 at 0x11490ceb8>,
<Gene b3640 at 0x11490cef0>,
<Gene b0173 at 0x11490cf60>,
<Gene b0420 at 0x1149140b8>,
<Gene b3564 at 0x114914208>,
<Gene b1779 at 0x114914390>,
<Gene b2927 at 0x114914358>,
<Gene b1288 at 0x1149144a8>,
<Gene b3622 at 0x11491a9b0>,
<Gene b3785 at 0x11491ac88>,
<Gene b3793 at 0x11491ac50>,
<Gene b3792 at 0x11491aef0>,
<Gene b2341 at 0x1149210f0>,
<Gene b1850 at 0x1149217b8>,
<Gene b1851 at 0x1149218d0>,
<Gene b1054 at 0x1149219b0>,
<Gene b1855 at 0x114921ac8>,
<Gene b2378 at 0x114921be0>,
<Gene b2779 at 0x114928080>,
<Gene b0583 at 0x114928198>,
<Gene b0585 at 0x1149282b0>,
<Gene b2441 at 0x1149285c0>,
<Gene b2440 at 0x1149285f8>,
<Gene b3946 at 0x114928c88>,
<Gene b0825 at 0x114928c50>,
<Gene b0822 at 0x114928d30>,
<Gene b3666 at 0x114928e10>,
<Gene b0404 at 0x114928f60>,
<Gene b0452 at 0x11492f550>,
<Gene b1805 at 0x11492fcc0>,
<Gene b1701 at 0x11492fcf8>,
<Gene b3844 at 0x11493a390>,
<Gene b2763 at 0x11493a518>,
```

```
<Gene b2764 at 0x11493a4e0>,
<Gene b2097 at 0x11493ab00>,
<Gene b1773 at 0x11493aa90>,
<Gene b2925 at 0x11493aac8>,
<Gene b2930 at 0x11493ada0>,
<Gene b3925 at 0x11493ad30>,
<Gene b4232 at 0x11493ad68>,
<Gene b2802 at 0x11493add8>,
<Gene b2803 at 0x11493af28>,
<Gene b2800 at 0x1149400b8>,
<Gene b2738 at 0x1149400f0>,
<Gene b0475 at 0x114940198>,
<Gene b3893 at 0x114940630>,
<Gene b1476 at 0x114940668>,
<Gene b1475 at 0x1149406a0>,
<Gene b1474 at 0x1149406d8>,
<Gene b3892 at 0x1149405c0>,
<Gene b3894 at 0x1149405f8>,
<Gene b0935 at 0x114940518>,
<Gene b3409 at 0x114940c18>,
<Gene b2392 at 0x114940d30>,
<Gene b4289 at 0x114947320>,
<Gene b4290 at 0x1149472b0>,
<Gene b4287 at 0x114947358>,
<Gene b4288 at 0x1149472e8>,
<Gene b4291 at 0x114947400>,
<Gene b0589 at 0x1149476a0>,
<Gene b0592 at 0x114947630>,
<Gene b0588 at 0x1149476d8>,
<Gene b0590 at 0x114947668>,
<Gene b0805 at 0x114947a20>,
<Gene b2155 at 0x114947978>,
<Gene b0150 at 0x114947c50>,
<Gene b0584 at 0x114950748>,
<Gene b0591 at 0x1149506d8>,
<Gene b4367 at 0x1149508d0>,
<Gene b4209 at 0x1149590f0>,
<Gene b2483 at 0x114959c18>,
<Gene b2485 at 0x114959e10>,
<Gene b2721 at 0x114959e48>,
<Gene b2486 at 0x114959c50>,
<Gene b2488 at 0x114959c88>,
<Gene b2484 at 0x114959ac8>,
<Gene b2719 at 0x114959cc0>,
<Gene b2482 at 0x114959cf8>,
<Gene b2489 at 0x114959b00>,
<Gene b2723 at 0x114959b38>,
<Gene b2490 at 0x114959d30>,
<Gene b2481 at 0x114959d68>,
<Gene b4079 at 0x114959b70>,
<Gene b2487 at 0x114959ba8>,
<Gene b2720 at 0x114959da0>,
<Gene b2724 at 0x114959dd8>,
<Gene b2722 at 0x114959be0>,
<Gene b3924 at 0x114959898>,
<Gene b0684 at 0x114959828>,
<Gene b2895 at 0x114959860>,
<Gene b3288 at 0x114959e80>,
```

```
<Gene b0025 at 0x114959f98>,
<Gene b0937 at 0x11495d128>,
<Gene b2912 at 0x11495d208>,
<Gene b2374 at 0x11495d400>,
<Gene b2492 at 0x11495d5c0>,
<Gene b0904 at 0x11495d5f8>,
<Gene b4151 at 0x11495da90>,
<Gene b4153 at 0x11495da20>,
<Gene b4154 at 0x11495da58>,
<Gene b4152 at 0x11495d9e8>,
<Gene b2168 at 0x11495dc50>,
<Gene b3371 at 0x11495dcf8>,
<Gene b4474 at 0x11495de10>,
<Gene b3374 at 0x11495df60>,
<Gene b3370 at 0x114967080>,
<Gene b4321 at 0x114967278>,
<Gene b2167 at 0x114967710>,
<Gene b2169 at 0x1149676a0>,
<Gene b1232 at 0x1149678d0>,
<Gene b2801 at 0x114967ba8>,
<Gene b1611 at 0x114967dd8>,
<Gene b1612 at 0x114967d68>,
<Gene b0621 at 0x114967f98>,
<Gene b3730 at 0x11496f358>,
<Gene b1002 at 0x11496f550>,
<Gene b3789 at 0x11496f710>,
<Gene b2039 at 0x11496f6d8>,
<Gene b0154 at 0x11496f908>,
<Gene b2533 at 0x11496fa20>,
<Gene b4055 at 0x11496fb38>,
<Gene b4041 at 0x11496fc50>,
<Gene b3451 at 0x114977320>,
<Gene b3452 at 0x1149772b0>,
<Gene b3453 at 0x1149772e8>,
<Gene b3450 at 0x114977278>,
<Gene b3608 at 0x114977470>,
<Gene b3426 at 0x114977780>,
<Gene b2241 at 0x114977710>,
<Gene b2242 at 0x1149777b8>,
<Gene b2243 at 0x114977748>,
<Gene b0243 at 0x11497e5c0>,
<Gene b0678 at 0x11497e6d8>,
<Gene b1852 at 0x11497e7b8>,
<Gene b3128 at 0x11497eeb8>,
<Gene b4358 at 0x11497ef98>,
<Gene b4478 at 0x114986160>,
<Gene b4356 at 0x114986208>,
<Gene b3691 at 0x114986400>,
<Gene b3127 at 0x1149866a0>,
<Gene b2789 at 0x114986668>,
<Gene b0757 at 0x114986908>,
<Gene b2045 at 0x114986940>,
<Gene b0756 at 0x1149869e8>,
<Gene b4119 at 0x114986a90>,
<Gene b3628 at 0x114986be0>,
<Gene b2094 at 0x114986e80>,
<Gene b2092 at 0x114986eb8>,
<Gene b2093 at 0x114986ef0>,
```

```
<Gene b3093 at 0x11498e048>,
<Gene b1236 at 0x11498e278>,
<Gene b4485 at 0x11498e668>,
<Gene b2150 at 0x11498e6a0>,
<Gene b4231 at 0x11498e6d8>,
<Gene b2149 at 0x11498e710>,
<Gene b2148 at 0x11498e748>,
<Gene b4227 at 0x11498e780>,
<Gene b4230 at 0x11498e7b8>,
<Gene b2943 at 0x11498e550>,
<Gene b2500 at 0x11498eeb8>,
<Gene b1415 at 0x114995198>,
<Gene b2052 at 0x1149952b0>,
<Gene b2784 at 0x114995438>,
<Gene b3650 at 0x114995470>,
<Gene b2051 at 0x114995550>,
<Gene b2467 at 0x114995630>,
<Gene b3729 at 0x114995898>,
<Gene b1298 at 0x114995b38>,
<Gene b1301 at 0x114995c88>,
<Gene b1297 at 0x114995da0>,
<Gene b3882 at 0x114995eb8>,
<Gene b3432 at 0x11499b198>,
<Gene b0459 at 0x11499b2e8>,
<Gene b0837 at 0x11499b4a8>,
<Gene b0124 at 0x11499b470>,
<Gene b3415 at 0x11499b6a0>,
<Gene b4476 at 0x11499b5f8>,
<Gene b3417 at 0x11499b908>,
<Gene b3428 at 0x11499b8d0>,
<Gene b3126 at 0x11499ba58>,
<Gene b2787 at 0x11499bc18>,
<Gene b2788 at 0x11499bbe0>,
<Gene b3429 at 0x11499beb8>,
<Gene b3631 at 0x11499bfd0>,
<Gene b3627 at 0x1149a4128>,
<Gene b3626 at 0x1149a4240>,
<Gene b1621 at 0x1149a4ac8>,
<Gene b3431 at 0x1149a4be0>,
<Gene b3430 at 0x1149a4d30>,
<Gene b3870 at 0x1149a4ef0>,
<Gene b0680 at 0x1149a4f60>,
<Gene b0811 at 0x1149a9198>,
<Gene b0810 at 0x1149a91d0>,
<Gene b0809 at 0x1149a9160>,
<Gene b2091 at 0x1149a9358>,
<Gene b0242 at 0x1149a9470>,
<Gene b1492 at 0x1149a9550>,
<Gene b2688 at 0x1149a96d8>,
<Gene b3517 at 0x1149a9828>,
<Gene b1493 at 0x1149a9860>,
<Gene b1761 at 0x1149a9940>,
<Gene b0485 at 0x1149a9b00>,
<Gene b1524 at 0x1149a9b38>,
<Gene b2312 at 0x1149a9c50>,
<Gene b3967 at 0x1149a9da0>,
<Gene b3212 at 0x1149a9f28>,
<Gene b3213 at 0x1149a9ef0>,
```

```
<Gene b1210 at 0x1149a9fd0>,
<Gene b2400 at 0x1149b0160>,
<Gene b3653 at 0x1149b0438>,
<Gene b0507 at 0x1149b06a0>,
<Gene b3927 at 0x1149b0780>,
<Gene b3617 at 0x1149b09b0>,
<Gene b2240 at 0x1149b6048>,
<Gene b0514 at 0x1149b65f8>,
<Gene b3124 at 0x1149b6710>,
<Gene b2905 at 0x1149b69b0>,
<Gene b2904 at 0x1149b6940>,
<Gene b2903 at 0x1149b6978>,
<Gene b1033 at 0x1149b6a20>,
<Gene b4468 at 0x1149b6f28>,
<Gene b2979 at 0x1149b6eb8>,
<Gene b4467 at 0x1149b6ef0>,
<Gene b3926 at 0x1149bf470>,
<Gene b0212 at 0x1149bf588>,
<Gene b3559 at 0x1149bf780>,
<Gene b3560 at 0x1149bf7b8>,
<Gene b2053 at 0x1149bfba8>,
<Gene b3052 at 0x1149bfcc0>,
<Gene b0200 at 0x1149bfeb8>,
<Gene b0104 at 0x1149c7048>,
<Gene b2507 at 0x1149c7160>,
<Gene b2029 at 0x1149c7278>,
<Gene b3437 at 0x1149c7518>,
<Gene b4268 at 0x1149c7550>,
<Gene b3449 at 0x1149c77b8>,
<Gene b2239 at 0x1149c7898>,
<Gene b0849 at 0x1149ce2b0>,
<Gene b3610 at 0x1149ce240>,
<Gene b1654 at 0x1149ce278>,
<Gene b0477 at 0x1149ce2e8>,
<Gene b2988 at 0x1149ce518>,
<Gene b3500 at 0x1149ce940>,
<Gene b1710 at 0x1149cea58>,
<Gene b3447 at 0x1149ceb00>,
<Gene b0829 at 0x1149cee80>,
<Gene b0831 at 0x1149cee10>,
<Gene b0830 at 0x1149ceeb8>,
<Gene b0832 at 0x1149cee48>,
<Gene b2947 at 0x1149d4080>,
<Gene b2153 at 0x1149d4160>,
<Gene b1277 at 0x1149d4278>,
<Gene b3779 at 0x1149d4358>,
<Gene b2883 at 0x1149d4860>,
<Gene b0125 at 0x1149d4a20>,
<Gene b0238 at 0x1149d49e8>,
<Gene b3092 at 0x1149d4c88>,
<Gene b0957 at 0x1149db2e8>,
<Gene b3875 at 0x1149db358>,
<Gene b1319 at 0x1149db390>,
<Gene b0875 at 0x1149db1d0>,
<Gene b1395 at 0x1149dbfd0>,
<Gene b4040 at 0x1149e5160>,
<Gene b0353 at 0x1149e5240>,
<Gene b0126 at 0x1149e5518>,
```

```
<Gene b0339 at 0x1149e54e0>,
<Gene b0261 at 0x1149e5588>,
<Gene b0428 at 0x1149e5908>,
<Gene b3630 at 0x1149e59e8>,
<Gene b3625 at 0x1149e5b00>,
<Gene b3621 at 0x1149e5c18>,
<Gene b3620 at 0x1149e5d30>,
<Gene b3632 at 0x1149e5e48>,
<Gene b3623 at 0x1149e5f98>,
<Gene b2104 at 0x1149eb0f0>,
<Gene b2388 at 0x1149eb240>,
<Gene b0394 at 0x1149eb3c8>,
<Gene b2020 at 0x1149eb710>,
<Gene b2022 at 0x1149eb940>,
<Gene b2514 at 0x1149eba58>,
<Gene b2309 at 0x1149ebc18>,
<Gene b0112 at 0x1149ebb70>,
<Gene b0349 at 0x1149ebeb8>,
<Gene b3805 at 0x1149f2160>,
<Gene b2418 at 0x1149f22b0>,
<Gene b2103 at 0x1149f22e8>,
<Gene b0813 at 0x1149f2400>,
<Gene b3824 at 0x1149f23c8>,
<Gene b0352 at 0x1149f2630>,
<Gene b0142 at 0x1149f2780>,
<Gene b0508 at 0x1149f2ac8>,
<Gene b0003 at 0x1149f2e80>,
<Gene b4013 at 0x1149f2f98>,
<Gene b2021 at 0x1149f9128>,
<Gene b2866 at 0x1149f9390>,
<Gene b2867 at 0x1149f9320>,
<Gene b2868 at 0x1149f9358>,
<Gene b2996 at 0x1149f9e48>,
<Gene b2994 at 0x1149f9c50>,
<Gene b2995 at 0x1149f9c88>,
<Gene b0974 at 0x1149f9cf8>,
<Gene b0973 at 0x1149f9d30>,
<Gene b0972 at 0x1149f9ba8>,
<Gene b2997 at 0x1149f9dd8>,
<Gene b2530 at 0x114a00400>,
<Gene b2529 at 0x114a003c8>,
<Gene b3807 at 0x114a00518>,
<Gene b2528 at 0x114a00710>,
<Gene b1136 at 0x114a009b0>,
<Gene b2265 at 0x114a00ac8>,
<Gene b0593 at 0x114a00be0>,
<Gene b0595 at 0x114a00d68>,
<Gene b4015 at 0x114a00e48>,
<Gene b4267 at 0x114a07080>,
<Gene b2025 at 0x114a07518>,
<Gene b2023 at 0x114a074e0>,
<Gene b1262 at 0x114a076a0>,
<Gene b3770 at 0x114a07780>,
<Gene b0026 at 0x114a07908>,
<Gene b0401 at 0x114a079b0>,
<Gene b2508 at 0x114a07e48>,
<Gene b3266 at 0x114a0f198>,
<Gene b3265 at 0x114a0f160>,
```

```
<Gene b3161 at 0x114a0f128>,
<Gene b3679 at 0x114a0f400>,
<Gene b2889 at 0x114a0fa90>,
<Gene b0073 at 0x114a0fc50>,
<Gene b0072 at 0x114a0fe10>,
<Gene b0071 at 0x114a0fe48>,
<Gene b0074 at 0x114a0ffd0>,
<Gene b0918 at 0x114a16940>,
<Gene b3198 at 0x114a16a58>,
<Gene b1215 at 0x114a16b70>,
<Gene b3581 at 0x114a16cc0>,
<Gene b4196 at 0x114a16cf8>,
<Gene b0697 at 0x114a1c080>,
<Gene b4513 at 0x114a1c128>,
<Gene b0696 at 0x114a1c0b8>,
<Gene b0698 at 0x114a1c0f0>,
<Gene b3290 at 0x114a1c400>,
<Gene b3747 at 0x114a1c438>,
<Gene b1363 at 0x114a1c470>,
<Gene b1250 at 0x114a1c358>,
<Gene b3849 at 0x114a1c390>,
<Gene b1291 at 0x114a1c3c8>,
<Gene b3350 at 0x114a1c518>,
<Gene b0842 at 0x114a1c320>,
<Gene b0047 at 0x114a1c4e0>,
<Gene b0306 at 0x114a1c898>,
<Gene b0307 at 0x114a1c828>,
<Gene b3605 at 0x114a1c860>,
<Gene b0308 at 0x114a1c7f0>,
<Gene b2257 at 0x114a1cb38>,
<Gene b0344 at 0x114a1cc50>,
<Gene b2132 at 0x114a1cd68>,
<Gene b1326 at 0x114a1ce80>,
<Gene b0709 at 0x114a242b0>,
<Gene b1634 at 0x114a24240>,
<Gene b3496 at 0x114a242e8>,
<Gene b4130 at 0x114a24278>,
<Gene b2799 at 0x114a248d0>,
<Gene b2170 at 0x114a24a20>,
<Gene b0070 at 0x114a24a58>,
<Gene b0343 at 0x114a24c50>,
<Gene b2133 at 0x114a24e10>,
<Gene b1380 at 0x114a24e48>,
<Gene b4054 at 0x114a2a048>,
<Gene b0642 at 0x114a2a160>,
<Gene b3458 at 0x114a2a588>,
<Gene b1651 at 0x114a2a5f8>,
<Gene b0622 at 0x114a2a748>,
<Gene b4386 at 0x114a2a908>,
<Gene b0630 at 0x114a2abe0>,
<Gene b0628 at 0x114a2ae10>,
<Gene b0182 at 0x114a31128>,
<Gene b0494 at 0x114a31240>,
<Gene b3825 at 0x114a3b080>,
<Gene b0186 at 0x114a43940>,
<Gene b4131 at 0x114a43978>,
<Gene b2890 at 0x114a43ac8>,
<Gene b2156 at 0x114a43b38>,
```

```
<Gene b3903 at 0x114a43f60>,
<Gene b3907 at 0x114a4c0b8>,
<Gene b3600 at 0x114a4c320>,
<Gene b0777 at 0x114a4c4e0>,
<Gene b1800 at 0x114a4c630>,
<Gene b4014 at 0x114a4c9b0>,
<Gene b2976 at 0x114a4c9e8>,
<Gene b2049 at 0x114a54898>,
<Gene b1613 at 0x114a549e8>,
<Gene b4323 at 0x114a54c50>,
<Gene b0731 at 0x114a54e10>,
<Gene b0732 at 0x114a54f98>,
<Gene b0334 at 0x114a5c3c8>,
<Gene b0331 at 0x114a5c4a8>,
<Gene b0333 at 0x114a5c5f8>,
<Gene b1092 at 0x114a5c710>,
<Gene b2521 at 0x114a5c828>,
<Gene b0084 at 0x114a5ca90>,
<Gene b0635 at 0x114a5ca20>,
<Gene b3396 at 0x114a5cac8>,
<Gene b0149 at 0x114a5ca58>,
<Gene b0632 at 0x114a5ce80>,
<Gene b2010 at 0x114a5ce10>,
<Gene b3182 at 0x114a5ce48>,
<Gene b0839 at 0x114a5cdd8>,
<Gene b2134 at 0x114a63400>,
<Gene b2328 at 0x114a63438>,
<Gene b3236 at 0x114a63780>,
<Gene b2210 at 0x114a63860>,
<Gene b1479 at 0x114a63a90>,
<Gene b2463 at 0x114a63ba8>,
<Gene b2515 at 0x114a63da0>,
<Gene b2746 at 0x114a63d30>,
<Gene b4120 at 0x114a63e80>,
<Gene b2747 at 0x114a6b3c8>,
<Gene b2942 at 0x114a6b518>,
<Gene b0197 at 0x114a6b710>,
<Gene b0199 at 0x114a6b6a0>,
<Gene b0198 at 0x114a6b6d8>,
<Gene b3829 at 0x114a6bb00>,
<Gene b4019 at 0x114a6bb38>,
<Gene b4219 at 0x114a73128>,
<Gene b1778 at 0x114a6bfd0>,
<Gene b2114 at 0x114a6bf60>,
<Gene b4242 at 0x114a736a0>,
<Gene b0963 at 0x114a737f0>,
<Gene b0403 at 0x114a73e48>,
<Gene b1193 at 0x114a7d630>,
<Gene b2963 at 0x114a7d518>,
<Gene b2701 at 0x114a7d550>,
<Gene b2813 at 0x114a7d588>,
<Gene b2558 at 0x114a7d5c0>,
<Gene b4392 at 0x114a7d5f8>,
<Gene b2919 at 0x114a7dd30>,
<Gene b0260 at 0x114a7de10>,
<Gene b2917 at 0x114a840b8>,
<Gene b3599 at 0x114a84518>,
<Gene b4322 at 0x114a84748>,
```

```
<Gene b0784 at 0x114a84a90>,
<Gene b3633 at 0x114a84b38>,
<Gene b3624 at 0x114a84d30>,
<Gene b2423 at 0x114a8b400>,
<Gene b0764 at 0x114a8b438>,
<Gene b2424 at 0x114a8b470>,
<Gene b2425 at 0x114a8b2e8>,
<Gene b0763 at 0x114a8b320>,
<Gene b3917 at 0x114a8b358>,
<Gene b2422 at 0x114a8b390>,
<Gene b0765 at 0x114a8b3c8>,
<Gene b2877 at 0x114a8b208>,
<Gene b0134 at 0x114a8b6a0>,
<Gene b0009 at 0x114a8b828>,
<Gene b2519 at 0x114a8bb00>,
<Gene b1069 at 0x114a8bba8>,
<Gene b0785 at 0x114a8bbe0>,
<Gene b0826 at 0x114a8bd68>,
<Gene b1008 at 0x114a8be80>,
<Gene b0529 at 0x114a91320>,
<Gene b3941 at 0x114a914e0>,
<Gene b1059 at 0x114a916a0>,
<Gene b3996 at 0x114a91d30>,
<Gene b2411 at 0x114a91cf8>,
<Gene b1109 at 0x114a91e10>,
<Gene b2280 at 0x114a9a630>,
<Gene b2283 at 0x114a9a668>,
<Gene b2284 at 0x114a9a470>,
<Gene b2286 at 0x114a9a4a8>,
<Gene b2288 at 0x114a9a6a0>,
<Gene b2279 at 0x114a9a6d8>,
<Gene b2285 at 0x114a9a4e0>,
<Gene b2282 at 0x114a9a518>,
<Gene b2281 at 0x114a9a710>,
<Gene b2276 at 0x114a9a550>,
<Gene b2277 at 0x114a9a588>,
<Gene b2287 at 0x114a9a5c0>,
<Gene b2278 at 0x114a9a5f8>,
<Gene b2615 at 0x114a9a438>,
<Gene b3028 at 0x114a9ae10>,
<Gene b1740 at 0x114a9f198>,
<Gene b3962 at 0x114a9f390>,
<Gene b1603 at 0x114a9f3c8>,
<Gene b1602 at 0x114a9f358>,
<Gene b0931 at 0x114a9f438>,
<Gene b1186 at 0x114a9f518>,
<Gene b0019 at 0x114a9f5f8>,
<Gene b2518 at 0x114a9f9e8>,
<Gene b0451 at 0x114aa8278>,
<Gene b2710 at 0x114aa8390>,
<Gene b2711 at 0x114aa83c8>,
<Gene b3479 at 0x114aa8a58>,
<Gene b3478 at 0x114aa8a90>,
<Gene b3480 at 0x114aa8ac8>,
<Gene b3476 at 0x114aa8b00>,
<Gene b3477 at 0x114aa8b38>,
<Gene b0639 at 0x114aa8ba8>,
<Gene b4390 at 0x114aa8b70>,
```

```
 <Gene b0751 at 0x114aa8cf8>,
 <Gene b1768 at 0x114aa8fd0>,
 <Gene b1991 at 0x114aaf208>,
 <Gene b0109 at 0x114aaf320>,
 <Gene b3367 at 0x114aaf4a8>,
 <Gene b1223 at 0x114aaf470>,
 <Gene b2205 at 0x114aaf908>,
 <Gene b2202 at 0x114aaf898>,
 <Gene b2203 at 0x114aaf940>,
 <Gene b2204 at 0x114aaf8d0>,
 ...]
```

A few additional attributes have been added that are not available in a cobrapy model. For example, exchange reactions that allow certain metabolites to enter or leave the model can be accessed through `model.exchanges`.

```
model.exchanges
```

```
[<Reaction DM_4CRSOL at 0x112d5a4e0>,
 <Reaction DM_5DRIB at 0x112d5a518>,
 <Reaction DM_AACALD at 0x112d5a550>,
 <Reaction DM_AMOB at 0x112d5a358>,
 <Reaction DM_MTHTHF at 0x112d5a390>,
 <Reaction DM_OXAM at 0x112d5a3c8>,
 <Reaction EX_12ppd_dsh_R_lp_e_rp_ at 0x112d5a240>,
 <Reaction EX_12ppd_dsh_S_lp_e_rp_ at 0x112d5a278>,
 <Reaction EX_14glucan_lp_e_rp_ at 0x112d5a2b0>,
 <Reaction EX_15dap_lp_e_rp_ at 0x112d5a2e8>,
 <Reaction EX_23camp_lp_e_rp_ at 0x112d5a320>,
 <Reaction EX_23ccmp_lp_e_rp_ at 0x112d5a048>,
 <Reaction EX_23cgmp_lp_e_rp_ at 0x112d5a0f0>,
 <Reaction EX_23cump_lp_e_rp_ at 0x112d5a1d0>,
 <Reaction EX_23dappa_lp_e_rp_ at 0x112d5a208>,
 <Reaction EX_26dap_dsh_M_lp_e_rp_ at 0x11215dbe0>,
 <Reaction EX_2ddglcn_lp_e_rp_ at 0x11215dcf8>,
 <Reaction EX_34dhpac_lp_e_rp_ at 0x11215de10>,
 <Reaction EX_3amp_lp_e_rp_ at 0x11215def0>,
 <Reaction EX_3cmp_lp_e_rp_ at 0x11215deb8>,
 <Reaction EX_3gmp_lp_e_rp_ at 0x11215de80>,
 <Reaction EX_3hcinnm_lp_e_rp_ at 0x1121cf400>,
 <Reaction EX_3hpp_lp_e_rp_ at 0x1121cfac8>,
 <Reaction EX_3hpppn_lp_e_rp_ at 0x1121cff28>,
 <Reaction EX_3ump_lp_e_rp_ at 0x1121cfa90>,
 <Reaction EX_4abut_lp_e_rp_ at 0x1121cfb70>,
 <Reaction EX_4hoxpacd_lp_e_rp_ at 0x1121cf550>,
 <Reaction EX_5dglcn_lp_e_rp_ at 0x1121cf080>,
 <Reaction EX_5mtr_lp_e_rp_ at 0x1121cf128>,
 <Reaction EX_LalaDglu_lp_e_rp_ at 0x1121cf518>,
 <Reaction EX_LalaDgluMdap_lp_e_rp_ at 0x1121cf4e0>,
 <Reaction EX_LalaDgluMdapDala_lp_e_rp_ at 0x1121cf208>,
 <Reaction EX_LalaLglu_lp_e_rp_ at 0x1121cf470>,
 <Reaction EX_ac_lp_e_rp_ at 0x1121cf438>,
 <Reaction EX_acac_lp_e_rp_ at 0x1121cf240>,
 <Reaction EX_acald_lp_e_rp_ at 0x1121cf278>,
 <Reaction EX_acgal_lp_e_rp_ at 0x1121cf0f0>,
 <Reaction EX_acgal1p_lp_e_rp_ at 0x1121cf2e8>,
 <Reaction EX_acgam_lp_e_rp_ at 0x1121cf3c8>,
 <Reaction EX_acgam1p_lp_e_rp_ at 0x1121cf2b0>,
 <Reaction EX_acmana_lp_e_rp_ at 0x1121cf358>,
```

```
<Reaction EX_acmum_lp_e_rp_ at 0x1121cf4a8>,
<Reaction EX_acnam_lp_e_rp_ at 0x1121cf0b8>,
<Reaction EX_acolipa_lp_e_rp_ at 0x1121cf390>,
<Reaction EX_acser_lp_e_rp_ at 0x1121cf320>,
<Reaction EX_ade_lp_e_rp_ at 0x1121533c8>,
<Reaction EX_adn_lp_e_rp_ at 0x112153400>,
<Reaction EX_adocbl_lp_e_rp_ at 0x112153390>,
<Reaction EX_ag_lp_e_rp_ at 0x1121532b0>,
<Reaction EX_agm_lp_e_rp_ at 0x1121539b0>,
<Reaction EX_akg_lp_e_rp_ at 0x112153320>,
<Reaction EX_ala_dsh_B_lp_e_rp_ at 0x112153da0>,
<Reaction EX_ala_dsh_D_lp_e_rp_ at 0x112153240>,
<Reaction EX_ala_dsh_L_lp_e_rp_ at 0x1121535c0>,
<Reaction EX_alaala_lp_e_rp_ at 0x112153518>,
<Reaction EX_all_dsh_D_lp_e_rp_ at 0x1121731d0>,
<Reaction EX_alltn_lp_e_rp_ at 0x10734a240>,
<Reaction EX_amp_lp_e_rp_ at 0x112b0d400>,
<Reaction EX_anhgm_lp_e_rp_ at 0x112b0d320>,
<Reaction EX_arab_dsh_L_lp_e_rp_ at 0x112b0d278>,
<Reaction EX_arbt_lp_e_rp_ at 0x112a5a240>,
<Reaction EX_arbtn_lp_e_rp_ at 0x112a5a6a0>,
<Reaction EX_arbtn_dsh_fe3_lp_e_rp_ at 0x114823908>,
<Reaction EX_arg_dsh_L_lp_e_rp_ at 0x112a81160>,
<Reaction EX_ascb_dsh_L_lp_e_rp_ at 0x112a814a8>,
<Reaction EX_asn_dsh_L_lp_e_rp_ at 0x112a73400>,
<Reaction EX_aso3_lp_e_rp_ at 0x11482bda0>,
<Reaction EX_asp_dsh_L_lp_e_rp_ at 0x112a9b320>,
<Reaction EX_btn_lp_e_rp_ at 0x112a9bd30>,
<Reaction EX_but_lp_e_rp_ at 0x112a9b780>,
<Reaction EX_butso3_lp_e_rp_ at 0x112a9b8d0>,
<Reaction EX_ca2_lp_e_rp_ at 0x112a9b278>,
<Reaction EX_cbi_lp_e_rp_ at 0x112a34eb8>,
<Reaction EX_cbl1_lp_e_rp_ at 0x112a34668>,
<Reaction EX_cd2_lp_e_rp_ at 0x112a34b00>,
<Reaction EX_cgly_lp_e_rp_ at 0x112a34550>,
<Reaction EX_chol_lp_e_rp_ at 0x112a34cc0>,
<Reaction EX_chtbs_lp_e_rp_ at 0x112a3b438>,
<Reaction EX_cit_lp_e_rp_ at 0x112a3b4a8>,
<Reaction EX_cl_lp_e_rp_ at 0x112a3b358>,
<Reaction EX_cm_lp_e_rp_ at 0x112a04898>,
<Reaction EX_cmp_lp_e_rp_ at 0x112a046d8>,
<Reaction EX_co2_lp_e_rp_ at 0x112a04f98>,
<Reaction EX_cobalt2_lp_e_rp_ at 0x112a04a58>,
<Reaction EX_colipa_lp_e_rp_ at 0x112a04b38>,
<Reaction EX_colipap_lp_e_rp_ at 0x112a04978>,
<Reaction EX_cpgn_lp_e_rp_ at 0x112aae470>,
<Reaction EX_cpgn_dsh_un_lp_e_rp_ at 0x112aaec50>,
<Reaction EX_crn_lp_e_rp_ at 0x112aae358>,
<Reaction EX_crn_dsh_D_lp_e_rp_ at 0x112aaee10>,
<Reaction EX_csn_lp_e_rp_ at 0x112aaef60>,
<Reaction EX_cu_lp_e_rp_ at 0x112aae6a0>,
<Reaction EX_cu2_lp_e_rp_ at 0x112aaea90>,
<Reaction EX_cyan_lp_e_rp_ at 0x112ad6f28>,
<Reaction EX_cynt_lp_e_rp_ at 0x112ad6518>,
<Reaction EX_cys_dsh_D_lp_e_rp_ at 0x112ad6c18>,
<Reaction EX_cys_dsh_L_lp_e_rp_ at 0x112ad6470>,
<Reaction EX_cytd_lp_e_rp_ at 0x112ad6198>,
<Reaction EX_dad_dsh_2_lp_e_rp_ at 0x112ad6668>,
```

```
<Reaction EX_damp_lp_e_rp_ at 0x112ad6780>,
<Reaction EX_dca_lp_e_rp_ at 0x112a4da20>,
<Reaction EX_dcmp_lp_e_rp_ at 0x112a4d160>,
<Reaction EX_dcyt_lp_e_rp_ at 0x112a4dfd0>,
<Reaction EX_ddca_lp_e_rp_ at 0x112a4d898>,
<Reaction EX_dgmp_lp_e_rp_ at 0x112a0b2b0>,
<Reaction EX_dgsn_lp_e_rp_ at 0x112a0b470>,
<Reaction EX_dha_lp_e_rp_ at 0x112a0bc50>,
<Reaction EX_dimp_lp_e_rp_ at 0x112a0b128>,
<Reaction EX_din_lp_e_rp_ at 0x112a0b390>,
<Reaction EX_dms_lp_e_rp_ at 0x11483a5c0>,
<Reaction EX_dmso_lp_e_rp_ at 0x11483a1d0>,
<Reaction EX_dopa_lp_e_rp_ at 0x112a287b8>,
<Reaction EX_doxrbcn_lp_e_rp_ at 0x112a28dd8>,
<Reaction EX_dtmp_lp_e_rp_ at 0x112a28630>,
<Reaction EX_dump_lp_e_rp_ at 0x112ad0f98>,
<Reaction EX_duri_lp_e_rp_ at 0x112ad0940>,
<Reaction EX_eca4colipa_lp_e_rp_ at 0x112ad07f0>,
<Reaction EX_enlipa_lp_e_rp_ at 0x112ad05c0>,
<Reaction EX_enter_lp_e_rp_ at 0x112ad04e0>,
<Reaction EX_etha_lp_e_rp_ at 0x112ad0c18>,
<Reaction EX_ethso3_lp_e_rp_ at 0x112ad0d68>,
<Reaction EX_etoh_lp_e_rp_ at 0x112ad0710>,
<Reaction EX_f6p_lp_e_rp_ at 0x112ad0fd0>,
<Reaction EX_fald_lp_e_rp_ at 0x112a6bc18>,
<Reaction EX_fe2_lp_e_rp_ at 0x112a6bb70>,
<Reaction EX_fe3_lp_e_rp_ at 0x112a6bf60>,
<Reaction EX_fe3dcit_lp_e_rp_ at 0x112a7cfd0>,
<Reaction EX_fe3dhbzs_lp_e_rp_ at 0x112a7c908>,
<Reaction EX_fe3hox_lp_e_rp_ at 0x112a7ce10>,
<Reaction EX_fe3hox_dsh_un_lp_e_rp_ at 0x112a7c6d8>,
<Reaction EX_fecrm_lp_e_rp_ at 0x112a7cf60>,
<Reaction EX_fecrm_dsh_un_lp_e_rp_ at 0x112a7cef0>,
<Reaction EX_feenter_lp_e_rp_ at 0x112a7cbe0>,
<Reaction EX_feoxam_lp_e_rp_ at 0x112a7c2e8>,
<Reaction EX_feoxam_dsh_un_lp_e_rp_ at 0x112a7ccc0>,
<Reaction EX_for_lp_e_rp_ at 0x114848160>,
<Reaction EX_fru_lp_e_rp_ at 0x114848828>,
<Reaction EX_frulys_lp_e_rp_ at 0x114848f60>,
<Reaction EX_fruur_lp_e_rp_ at 0x112adcb00>,
<Reaction EX_fuc_dsh_L_lp_e_rp_ at 0x112adcd68>,
<Reaction EX_fum_lp_e_rp_ at 0x112adc198>,
<Reaction EX_fusa_lp_e_rp_ at 0x112adc128>,
<Reaction EX_g1p_lp_e_rp_ at 0x112adcc50>,
<Reaction EX_g3pc_lp_e_rp_ at 0x112a97630>,
<Reaction EX_g3pe_lp_e_rp_ at 0x112a974e0>,
<Reaction EX_g3pg_lp_e_rp_ at 0x112a97ac8>,
<Reaction EX_g3pi_lp_e_rp_ at 0x112a97be0>,
<Reaction EX_g3ps_lp_e_rp_ at 0x112a97748>,
<Reaction EX_g6p_lp_e_rp_ at 0x112a97f28>,
<Reaction EX_gal_lp_e_rp_ at 0x112a97dd8>,
<Reaction EX_gal_dsh_bD_lp_e_rp_ at 0x112a1c518>,
<Reaction EX_gal1p_lp_e_rp_ at 0x112a1c0f0>,
<Reaction EX_galct_dsh_D_lp_e_rp_ at 0x112a1c358>,
<Reaction EX_galctn_dsh_D_lp_e_rp_ at 0x112a1ca20>,
<Reaction EX_galctn_dsh_L_lp_e_rp_ at 0x112a1ce10>,
<Reaction EX_galt_lp_e_rp_ at 0x112a1cba8>,
<Reaction EX_galur_lp_e_rp_ at 0x112a1c438>,
```

```
<Reaction EX_gam_lp_e_rp_ at 0x112ae2240>,
<Reaction EX_gam6p_lp_e_rp_ at 0x112ae2ef0>,
<Reaction EX_gbbtn_lp_e_rp_ at 0x112ae2898>,
<Reaction EX_gdp_lp_e_rp_ at 0x112ae2588>,
<Reaction EX_glc_lp_e_rp_ at 0x112ae2940>,
<Reaction EX_glcn_lp_e_rp_ at 0x112ae2da0>,
<Reaction EX_glcr_lp_e_rp_ at 0x112ae2438>,
<Reaction EX_glcur_lp_e_rp_ at 0x112ae2128>,
<Reaction EX_glcur1p_lp_e_rp_ at 0x112a87898>,
<Reaction EX_gln_dsh_L_lp_e_rp_ at 0x112a879b0>,
<Reaction EX_glu_dsh_L_lp_e_rp_ at 0x112a87128>,
<Reaction EX_gly_lp_e_rp_ at 0x112a877b8>,
<Reaction EX_glyald_lp_e_rp_ at 0x112a876a0>,
<Reaction EX_glyb_lp_e_rp_ at 0x112a87dd8>,
<Reaction EX_glyc_lp_e_rp_ at 0x112a87a90>,
<Reaction EX_glyc_dsh_R_lp_e_rp_ at 0x112a8c438>,
<Reaction EX_glyc2p_lp_e_rp_ at 0x112a8c668>,
<Reaction EX_glyc3p_lp_e_rp_ at 0x112a8c588>,
<Reaction EX_glyclt_lp_e_rp_ at 0x112a8c7b8>,
<Reaction EX_gmp_lp_e_rp_ at 0x112a8ccc0>,
<Reaction EX_gsn_lp_e_rp_ at 0x112a8cd30>,
<Reaction EX_gthox_lp_e_rp_ at 0x112a8ce48>,
<Reaction EX_gthrd_lp_e_rp_ at 0x112a8cbe0>,
<Reaction EX_gtp_lp_e_rp_ at 0x112a8ca90>,
<Reaction EX_gua_lp_e_rp_ at 0x112a8c358>,
<Reaction EX_h_lp_e_rp_ at 0x112a5f4a8>,
<Reaction EX_h2_lp_e_rp_ at 0x112a5ff28>,
<Reaction EX_h2o_lp_e_rp_ at 0x112a5fe48>,
<Reaction EX_h2o2_lp_e_rp_ at 0x112a5f8d0>,
<Reaction EX_h2s_lp_e_rp_ at 0x112a5f9b0>,
<Reaction EX_hacolipa_lp_e_rp_ at 0x112a5f5c0>,
<Reaction EX_halipa_lp_e_rp_ at 0x112a5fcc0>,
<Reaction EX_hdca_lp_e_rp_ at 0x112a16fd0>,
<Reaction EX_hdcea_lp_e_rp_ at 0x112a16b38>,
<Reaction EX_hg2_lp_e_rp_ at 0x112a16f28>,
<Reaction EX_his_dsh_L_lp_e_rp_ at 0x112aa4e10>,
<Reaction EX_hom_dsh_L_lp_e_rp_ at 0x112aa4240>,
<Reaction EX_hxa_lp_e_rp_ at 0x112aa43c8>,
<Reaction EX_hxan_lp_e_rp_ at 0x112aa4a58>,
<Reaction EX_idon_dsh_L_lp_e_rp_ at 0x112aa4fd0>,
<Reaction EX_ile_dsh_L_lp_e_rp_ at 0x112a10da0>,
<Reaction EX_imp_lp_e_rp_ at 0x112a10e48>,
<Reaction EX_indole_lp_e_rp_ at 0x112a106a0>,
<Reaction EX_inost_lp_e_rp_ at 0x112a104a8>,
<Reaction EX_ins_lp_e_rp_ at 0x112af14a8>,
<Reaction EX_isetac_lp_e_rp_ at 0x112af1668>,
<Reaction EX_k_lp_e_rp_ at 0x112af10f0>,
<Reaction EX_kdo2lipid4_lp_e_rp_ at 0x112af1d30>,
<Reaction EX_lac_dsh_D_lp_e_rp_ at 0x112af1ef0>,
<Reaction EX_lac_dsh_L_lp_e_rp_ at 0x112af1780>,
<Reaction EX_lcts_lp_e_rp_ at 0x112af1fd0>,
<Reaction EX_leu_dsh_L_lp_e_rp_ at 0x112af1dd8>,
<Reaction EX_lipa_lp_e_rp_ at 0x112ab8550>,
<Reaction EX_lipa_cold_lp_e_rp_ at 0x112ab88d0>,
<Reaction EX_lipoate_lp_e_rp_ at 0x112ab8630>,
<Reaction EX_lys_dsh_L_lp_e_rp_ at 0x112ab8b70>,
<Reaction EX_lyx_dsh_L_lp_e_rp_ at 0x112ab8278>,
<Reaction EX_mal_dsh_D_lp_e_rp_ at 0x112ab87b8>,
```

```
<Reaction EX_mal_dsh_L_lp_e_rp_ at 0x112ab8978>,
<Reaction EX_malt_lp_e_rp_ at 0x112aa07f0>,
<Reaction EX_malthx_lp_e_rp_ at 0x112aa01d0>,
<Reaction EX_maltpt_lp_e_rp_ at 0x112aa06d8>,
<Reaction EX_malttr_lp_e_rp_ at 0x112aa0518>,
<Reaction EX_maltttr_lp_e_rp_ at 0x112aa09b0>,
<Reaction EX_man_lp_e_rp_ at 0x112aa0c18>,
<Reaction EX_man6p_lp_e_rp_ at 0x112aa02b0>,
<Reaction EX_manglyc_lp_e_rp_ at 0x112aa0da0>,
<Reaction EX_melib_lp_e_rp_ at 0x112aa0438>,
<Reaction EX_meoh_lp_e_rp_ at 0x112aa0f60>,
<Reaction EX_met_dsh_D_lp_e_rp_ at 0x112aa05f8>,
<Reaction EX_met_dsh_L_lp_e_rp_ at 0x112a902e8>,
<Reaction EX_metsox_dsh_R_dsh_L_lp_e_rp_ at 0x112a90208>,
<Reaction EX_metsox_dsh_S_dsh_L_lp_e_rp_ at 0x112a90dd8>,
<Reaction EX_mg2_lp_e_rp_ at 0x112a90ba8>,
<Reaction EX_mincyc_lp_e_rp_ at 0x112a90d68>,
<Reaction EX_minohp_lp_e_rp_ at 0x112a90400>,
<Reaction EX_mmet_lp_e_rp_ at 0x112a90160>,
<Reaction EX_mn2_lp_e_rp_ at 0x112a90898>,
<Reaction EX_mnl_lp_e_rp_ at 0x112a42710>,
<Reaction EX_mobd_lp_e_rp_ at 0x112a420f0>,
<Reaction EX_mso3_lp_e_rp_ at 0x112a42e10>,
<Reaction EX_n2o_lp_e_rp_ at 0x112a42f98>,
<Reaction EX_na1_lp_e_rp_ at 0x112a429e8>,
<Reaction EX_nac_lp_e_rp_ at 0x112aaacc0>,
<Reaction EX_nh4_lp_e_rp_ at 0x112aaada0>,
<Reaction EX_ni2_lp_e_rp_ at 0x112aaa128>,
<Reaction EX_nmn_lp_e_rp_ at 0x112aaab38>,
<Reaction EX_no_lp_e_rp_ at 0x112aaa390>,
<Reaction EX_no2_lp_e_rp_ at 0x112aaa550>,
<Reaction EX_no3_lp_e_rp_ at 0x112aaa9e8>,
<Reaction EX_novbcn_lp_e_rp_ at 0x112aaa710>,
<Reaction EX_o16a4colipa_lp_e_rp_ at 0x112aaa668>,
<Reaction EX_o2_lp_e_rp_ at 0x112aaa438>,
<Reaction EX_o2s_lp_e_rp_ at 0x112aaa940>,
<Reaction EX_ocdca_lp_e_rp_ at 0x112aaafd0>,
<Reaction EX_ocdcea_lp_e_rp_ at 0x112aaa828>,
<Reaction EX_octa_lp_e_rp_ at 0x112afd9e8>,
<Reaction EX_orn_lp_e_rp_ at 0x112afdc18>,
<Reaction EX_orot_lp_e_rp_ at 0x112afd8d0>,
<Reaction EX_pacald_lp_e_rp_ at 0x112afdf60>,
<Reaction EX_peamn_lp_e_rp_ at 0x112a22630>,
<Reaction EX_phe_dsh_L_lp_e_rp_ at 0x112a22c50>,
<Reaction EX_pheme_lp_e_rp_ at 0x112a22198>,
<Reaction EX_pi_lp_e_rp_ at 0x112a22f28>,
<Reaction EX_pnto_dsh_R_lp_e_rp_ at 0x112a22240>,
<Reaction EX_ppa_lp_e_rp_ at 0x112a22550>,
<Reaction EX_ppal_lp_e_rp_ at 0x112a22a90>,
<Reaction EX_pppn_lp_e_rp_ at 0x112a22080>,
<Reaction EX_ppt_lp_e_rp_ at 0x112b04898>,
<Reaction EX_pro_dsh_L_lp_e_rp_ at 0x112b04a90>,
<Reaction EX_progly_lp_e_rp_ at 0x112b04208>,
<Reaction EX_psclys_lp_e_rp_ at 0x112b04940>,
<Reaction EX_pser_dsh_L_lp_e_rp_ at 0x112b046d8>,
<Reaction EX_ptrc_lp_e_rp_ at 0x112b04e80>,
<Reaction EX_pydam_lp_e_rp_ at 0x112b04518>,
<Reaction EX_pydx_lp_e_rp_ at 0x112b043c8>,
```

```
<Reaction EX_pydxn_lp_e_rp_ at 0x112acaa58>,
<Reaction EX_pyr_lp_e_rp_ at 0x112aca2e8>,
<Reaction EX_quin_lp_e_rp_ at 0x112acab38>,
<Reaction EX_r5p_lp_e_rp_ at 0x112acaef0>,
<Reaction EX_rfamp_lp_e_rp_ at 0x112aca978>,
<Reaction EX_rib_dsh_D_lp_e_rp_ at 0x112aca860>,
<Reaction EX_rmn_lp_e_rp_ at 0x112ab3d68>,
<Reaction EX_sbt_dsh_D_lp_e_rp_ at 0x112ab3ac8>,
<Reaction EX_sel_lp_e_rp_ at 0x112ab3518>,
<Reaction EX_ser_dsh_D_lp_e_rp_ at 0x112ab3160>,
<Reaction EX_ser_dsh_L_lp_e_rp_ at 0x112ab3320>,
<Reaction EX_skm_lp_e_rp_ at 0x112ab3ef0>,
<Reaction EX_slnt_lp_e_rp_ at 0x112ab33c8>,
<Reaction EX_so2_lp_e_rp_ at 0x112b07f98>,
<Reaction EX_so3_lp_e_rp_ at 0x112b07fd0>,
<Reaction EX_so4_lp_e_rp_ at 0x112b07320>,
<Reaction EX_spmd_lp_e_rp_ at 0x112b07e80>,
<Reaction EX_succ_lp_e_rp_ at 0x112b074a8>,
<Reaction EX_sucr_lp_e_rp_ at 0x112b07be0>,
<Reaction EX_sulfac_lp_e_rp_ at 0x112b07cf8>,
<Reaction EX_tartr_dsh_D_lp_e_rp_ at 0x112b077f0>,
<Reaction EX_tartr_dsh_L_lp_e_rp_ at 0x112a48898>,
<Reaction EX_taur_lp_e_rp_ at 0x112a48978>,
<Reaction EX_tcynt_lp_e_rp_ at 0x112a48f60>,
<Reaction EX_thm_lp_e_rp_ at 0x112a48630>,
<Reaction EX_thr_dsh_L_lp_e_rp_ at 0x112a48518>,
<Reaction EX_thrp_lp_e_rp_ at 0x112a48f28>,
<Reaction EX_thym_lp_e_rp_ at 0x112a48be0>,
<Reaction EX_thymd_lp_e_rp_ at 0x112a48c88>,
<Reaction EX_tma_lp_e_rp_ at 0x112a48b00>,
<Reaction EX_tmao_lp_e_rp_ at 0x112a482b0>,
<Reaction EX_tre_lp_e_rp_ at 0x112a48390>,
<Reaction EX_trp_dsh_L_lp_e_rp_ at 0x112a48dd8>,
<Reaction EX_tsul_lp_e_rp_ at 0x112a65c50>,
<Reaction EX_ttdca_lp_e_rp_ at 0x112a65278>,
<Reaction EX_ttdcea_lp_e_rp_ at 0x112a657b8>,
<Reaction EX_ttrcyc_lp_e_rp_ at 0x112a652b0>,
<Reaction EX_tungs_lp_e_rp_ at 0x112a65a58>,
<Reaction EX_tym_lp_e_rp_ at 0x112a65b00>,
<Reaction EX_tyr_dsh_L_lp_e_rp_ at 0x114850d30>,
<Reaction EX_tyrp_lp_e_rp_ at 0x114850f98>,
<Reaction EX_uacgam_lp_e_rp_ at 0x114850e10>,
<Reaction EX_udpacgal_lp_e_rp_ at 0x114850908>,
<Reaction EX_udpg_lp_e_rp_ at 0x114850c50>,
<Reaction EX_udpgal_lp_e_rp_ at 0x114850b38>,
<Reaction EX_udpglcur_lp_e_rp_ at 0x114850668>,
<Reaction EX_ump_lp_e_rp_ at 0x114850518>,
<Reaction EX_ura_lp_e_rp_ at 0x114850f60>,
<Reaction EX_urea_lp_e_rp_ at 0x1148419b0>,
<Reaction EX_uri_lp_e_rp_ at 0x1148413c8>,
<Reaction EX_val_dsh_L_lp_e_rp_ at 0x114841780>,
<Reaction EX_xan_lp_e_rp_ at 0x1148412e8>,
<Reaction EX_xmp_lp_e_rp_ at 0x114841a58>,
<Reaction EX_xtsn_lp_e_rp_ at 0x114841630>,
<Reaction EX_xyl_dsh_D_lp_e_rp_ at 0x114841208>,
<Reaction EX_xylu_dsh_L_lp_e_rp_ at 0x112a53710>,
<Reaction EX_zn2_lp_e_rp_ at 0x112a53fd0>]
```

Or, the current medium can be accessed through `model.medium`.

```
model.medium
```

It is also possible to get a list of essential reactions ...

```
model.essential_reactions()
```

```
[<Reaction DM_4CRSOL at 0x112d5a4e0>,
 <Reaction DM_5DRIB at 0x112d5a518>,
 <Reaction DM_AMOB at 0x112d5a358>,
 <Reaction DM_MTHTHF at 0x112d5a390>,
 <Reaction Ec_biomass_iJO1366_core_53p95M at 0x112d5a438>,
 <Reaction EX_ca2_lp_e_rp_ at 0x112a9b278>,
 <Reaction EX_cl_lp_e_rp_ at 0x112a3b358>,
 <Reaction EX_cobalt2_lp_e_rp_ at 0x112a04a58>,
 <Reaction EX_cu2_lp_e_rp_ at 0x112aaea90>,
 <Reaction EX_glc_lp_e_rp_ at 0x112ae2940>,
 <Reaction EX_k_lp_e_rp_ at 0x112af10f0>,
 <Reaction EX_meoh_lp_e_rp_ at 0x112aa0f60>,
 <Reaction EX_mg2_lp_e_rp_ at 0x112a90ba8>,
 <Reaction EX_mn2_lp_e_rp_ at 0x112a90898>,
 <Reaction EX_mobd_lp_e_rp_ at 0x112a420f0>,
 <Reaction EX_nh4_lp_e_rp_ at 0x112aaada0>,
 <Reaction EX_ni2_lp_e_rp_ at 0x112aaa128>,
 <Reaction EX_pi_lp_e_rp_ at 0x112a22f28>,
 <Reaction EX_so4_lp_e_rp_ at 0x112b07320>,
 <Reaction EX_zn2_lp_e_rp_ at 0x112a53fd0>,
 <Reaction 3OAR140 at 0x114bed630>,
 <Reaction 3OAS140 at 0x114be5da0>,
 <Reaction 5DOAN at 0x114bdf0b8>,
 <Reaction A5PISO at 0x114bdfe10>,
 <Reaction ACCOAC at 0x114bc8080>,
 <Reaction ACGK at 0x114bc8748>,
 <Reaction ACGS at 0x114bc8780>,
 <Reaction ACHBS at 0x114bc87b8>,
 <Reaction ACLS at 0x114bc8518>,
 <Reaction ACODA at 0x114bc0da0>,
 <Reaction ACONTa at 0x114bc0ba8>,
 <Reaction ACONTb at 0x114bc0b38>,
 <Reaction ACOTA at 0x114bc0be0>,
 <Reaction ADCL at 0x114bc0400>,
 <Reaction ADCS at 0x114bc0390>,
 <Reaction ADSK at 0x114bb2ba8>,
 <Reaction ADSL1r at 0x114bb2be0>,
 <Reaction ADSL2r at 0x114bb2a58>,
 <Reaction ADSS at 0x114bb2908>,
 <Reaction AGPAT160 at 0x114bb2390>,
 <Reaction AGPAT161 at 0x114bab080>,
 <Reaction AGPR at 0x114babe10>,
 <Reaction AHCYSNS at 0x114babcf8>,
 <Reaction AICART at 0x114babc88>,
 <Reaction AIRC2 at 0x114babd30>,
 <Reaction AIRC3 at 0x114babcc0>,
 <Reaction ALAALAr at 0x114bab898>,
 <Reaction ALAR at 0x114bab630>,
 <Reaction AMAOTr at 0x114b9d828>,
 <Reaction AMPMS2 at 0x114b9d4e0>,
 <Reaction ANPRT at 0x114b9d390>,
```

```
<Reaction ANS at 0x114b9d3c8>,
<Reaction AOXSr2 at 0x114b9d0b8>,
<Reaction APRAUR at 0x114b95940>,
<Reaction ARGSL at 0x114b8db00>,
<Reaction ARGSS at 0x114b8db38>,
<Reaction ASAD at 0x114b8d4a8>,
<Reaction ASP1DC at 0x114b84da0>,
<Reaction ASPCT at 0x114b84dd8>,
<Reaction ASPK at 0x114b84b70>,
<Reaction ASPTA at 0x114b84908>,
<Reaction ATPPRT at 0x114b84518>,
<Reaction BMOCOS at 0x114b7c828>,
<Reaction BMOGDS1 at 0x114b7c860>,
<Reaction BMOGDS2 at 0x114b7c438>,
<Reaction BPNT at 0x114b78198>,
<Reaction BTS5 at 0x114b78b70>,
<Reaction CA2tex at 0x114b78320>,
<Reaction CAt6pp at 0x114b78240>,
<Reaction CDPMEK at 0x114b724a8>,
<Reaction CHORM at 0x114b66d30>,
<Reaction CHORS at 0x114b66cc0>,
<Reaction CHRPL at 0x114b66d68>,
<Reaction CLt3_2pp at 0x114b66588>,
<Reaction CLtex at 0x114b665c0>,
<Reaction COBALT2tex at 0x114b66320>,
<Reaction COBALT2tpp at 0x114b5feb8>,
<Reaction CPMPS at 0x114b5f630>,
<Reaction CS at 0x114b5bcc0>,
<Reaction CTPS2 at 0x114b54ac8>,
<Reaction CU2tex at 0x114b54978>,
<Reaction CU2tpp at 0x114b547f0>,
<Reaction CYSS at 0x114b4bf60>,
<Reaction CYSTL at 0x114b4bcc0>,
<Reaction DAPDC at 0x114b3da20>,
<Reaction DAPE at 0x114b3d940>,
<Reaction DASYN160 at 0x114b3d278>,
<Reaction DASYN161 at 0x114b3d2b0>,
<Reaction DB4PS at 0x114b37ef0>,
<Reaction DBTS at 0x114b37f98>,
<Reaction DDPA at 0x114b37908>,
<Reaction DHAD1 at 0x114b31ef0>,
<Reaction DHAD2 at 0x114b31e80>,
<Reaction DHDPRy at 0x114b31940>,
<Reaction DHDPS at 0x114b318d0>,
<Reaction DHFR at 0x114b31748>,
<Reaction DHFS at 0x114b31518>,
<Reaction DHNPA2r at 0x114b2ae80>,
<Reaction DHORTS at 0x114b2a550>,
<Reaction DHPPDA2 at 0x114b2a518>,
<Reaction DHPS2 at 0x114b2a5c0>,
<Reaction DHPTDCs2 at 0x114b2a400>,
<Reaction DHQS at 0x114b2a0b8>,
<Reaction DHQTi at 0x114b230b8>,
<Reaction DMATT at 0x114b23550>,
<Reaction DNMPPA at 0x114b19e80>,
<Reaction DNTPPA at 0x114b19dd8>,
<Reaction DPCOAK at 0x114b19a90>,
<Reaction DPR at 0x114b199e8>,
```

```
<Reaction DTMPK at 0x114b19278>,
<Reaction DXPRIi at 0x114b11c50>,
<Reaction DXPS at 0x114b11ba8>,
<Reaction E4PD at 0x114b117f0>,
<Reaction EGMEACPR at 0x114b02c18>,
<Reaction EPMEACPR at 0x114b02748>,
<Reaction FCLT at 0x114ae2e10>,
<Reaction FMNAT at 0x114ace748>,
<Reaction G1PACT at 0x114abf9e8>,
<Reaction G1SAT at 0x114abf898>,
<Reaction G3PD2 at 0x114abf320>,
<Reaction G5SADs at 0x114ab7c50>,
<Reaction GCALDD at 0x114aa8a20>,
<Reaction GF6PTA at 0x114aa8518>,
<Reaction GK1 at 0x114a9ffd0>,
<Reaction GLNS at 0x114a9ac18>,
<Reaction GLUPRT at 0x114a9a7f0>,
<Reaction GLUR at 0x114a9aa20>,
<Reaction GLUTRR at 0x114a9a898>,
<Reaction GLUTRS at 0x114a9a8d0>,
<Reaction GMPS2 at 0x114a84978>,
<Reaction GRTT at 0x114a7dfd0>,
<Reaction GTPCI at 0x114a7d898>,
<Reaction GTPCII2 at 0x114a7d8d0>,
<Reaction HBZOPT at 0x114a73278>,
<Reaction HCO3E at 0x114a73048>,
<Reaction HISTD at 0x114a6b278>,
<Reaction HISTP at 0x114a6b208>,
<Reaction HMBS at 0x114a63f28>,
<Reaction HPPK2 at 0x114a636a0>,
<Reaction HSDy at 0x114a634a8>,
<Reaction HSK at 0x114a633c8>,
<Reaction HSST at 0x114a63278>,
<Reaction HSTPT at 0x114a63320>,
<Reaction ICDHyr at 0x114a5cc50>,
<Reaction ICYSDS at 0x114a5c390>,
<Reaction IG3PS at 0x114a5c240>,
<Reaction IGPDH at 0x114a5c1d0>,
<Reaction IGPS at 0x114a54198>,
<Reaction ILETA at 0x114a54ef0>,
<Reaction IMPC at 0x114a54e48>,
<Reaction IPMD at 0x114a54400>,
<Reaction IPPMIa at 0x114a544a8>,
<Reaction IPPMIb at 0x114a54438>,
<Reaction IPPS at 0x114a542e8>,
<Reaction K2L4Aabcpp at 0x114a54358>,
<Reaction K2L4Aabctex at 0x114a54080>,
<Reaction KARA1 at 0x114a54160>,
<Reaction KARA2 at 0x114a54128>,
<Reaction KDOCT2 at 0x114a4ce80>,
<Reaction KDOPP at 0x114a4cf60>,
<Reaction KDOPS at 0x114a4cf98>,
<Reaction Ktex at 0x114a4ce10>,
<Reaction LEUTAi at 0x114a43b70>,
<Reaction LPADSS at 0x114a3bf60>,
<Reaction MALCOAMT at 0x114a24c18>,
<Reaction MCOATA at 0x114a16828>,
<Reaction MCTP1App at 0x114a16780>,
```

```
<Reaction MECDPDH5 at 0x114a16320>,
<Reaction MECDPS at 0x114a0f080>,
<Reaction MEOHtex at 0x114a0f978>,
<Reaction MEOHtrpp at 0x114a0f898>,
<Reaction MEPCT at 0x114a0f7f0>,
<Reaction METAT at 0x114a0f748>,
<Reaction METS at 0x114a0f4e0>,
<Reaction MG2tex at 0x114a07cf8>,
<Reaction MNtex at 0x1149f9f60>,
<Reaction MOADSUx at 0x1149f9f98>,
<Reaction MOAT at 0x1149f9b70>,
<Reaction MOAT2 at 0x1149f9e80>,
<Reaction MOBDabcpp at 0x1149f9eb8>,
<Reaction MOBDtex at 0x1149f9ac8>,
<Reaction MOCOS at 0x1149f9b38>,
<Reaction MOHMT at 0x1149f9c18>,
<Reaction MPTAT at 0x1149f9cc0>,
<Reaction MPTG at 0x1149f9d68>,
<Reaction MPTS at 0x1149f9668>,
<Reaction MPTSS at 0x1149f96a0>,
<Reaction MTHFR2 at 0x1149f2dd8>,
<Reaction MTHTHFSs at 0x1149f2e10>,
<Reaction NADK at 0x1149eb438>,
<Reaction NADS1 at 0x1149ebbe0>,
<Reaction NDPK2 at 0x1149eb4e0>,
<Reaction NDPK4 at 0x1149e57b8>,
<Reaction NH4tex at 0x1149e53c8>,
<Reaction NH4tpp at 0x1149db400>,
<Reaction NI2tex at 0x1149dbe80>,
<Reaction NNATr at 0x1149dba20>,
<Reaction NNDPR at 0x1149db940>,
<Reaction OCBT at 0x1149bf198>,
<Reaction OCTDPS at 0x1149b6080>,
<Reaction OGMEACPD at 0x1149b6da0>,
<Reaction OGMEACPR at 0x1149b6d30>,
<Reaction OGMEACPS at 0x1149b6d68>,
<Reaction OHPBAT at 0x1149b6be0>,
<Reaction OMCDC at 0x1149b6ac8>,
<Reaction OMPDC at 0x1149b69e8>,
<Reaction OPHBDC at 0x1149b64a8>,
<Reaction OPMEACPD at 0x1149b6320>,
<Reaction OPMEACPR at 0x1149b6278>,
<Reaction OPMEACPS at 0x1149b62b0>,
<Reaction ORPT at 0x1149b0320>,
<Reaction P5CR at 0x1149b0e80>,
<Reaction PANTS at 0x1149b0b38>,
<Reaction PAPPT3 at 0x1149a9b70>,
<Reaction PDX5PS at 0x1149a4908>,
<Reaction PE160abcpp at 0x1149a4a20>,
<Reaction PE161abcpp at 0x1149a4a58>,
<Reaction PERD at 0x1149a4668>,
<Reaction PGAMT at 0x11499be10>,
<Reaction PHETA1 at 0x11498ea20>,
<Reaction PItex at 0x11498e8d0>,
<Reaction PMDPHT at 0x11497e208>,
<Reaction PMEACPE at 0x11497e240>,
<Reaction PMPK at 0x11497e1d0>,
<Reaction PNTK at 0x11497e0f0>,
```

```
<Reaction PPBNGS at 0x114977d30>,
<Reaction PPCDC at 0x114977d68>,
<Reaction PPNCL2 at 0x114977ac8>,
<Reaction PPND at 0x114977978>,
<Reaction PPNDH at 0x114977908>,
<Reaction PRAGSr at 0x1149770b8>,
<Reaction PRAIS at 0x11496f128>,
<Reaction PRAIi at 0x11496ffd0>,
<Reaction PRAMPC at 0x11496ff98>,
<Reaction PRASCSi at 0x11496fef0>,
<Reaction PRATPP at 0x11496ff28>,
<Reaction PRFGS at 0x11496fe48>,
<Reaction PRMICI at 0x11496fe80>,
<Reaction PSCVT at 0x11496f4a8>,
<Reaction PSD160 at 0x11496f240>,
<Reaction PSD161 at 0x11496f1d0>,
<Reaction PSSA160 at 0x114967b00>,
<Reaction PSSA161 at 0x114967a90>,
<Reaction PTPATi at 0x1149676d8>,
<Reaction QULNS at 0x114950fd0>,
<Reaction RBFK at 0x114950dd8>,
<Reaction RBFSa at 0x114950b38>,
<Reaction RBFSb at 0x114950be0>,
<Reaction RHCCE at 0x114950588>,
<Reaction SADT2 at 0x114947438>,
<Reaction SDPDS at 0x114940e10>,
<Reaction SDPTA at 0x114940b38>,
<Reaction SERAT at 0x11493a860>,
<Reaction SHCHD2 at 0x11493a198>,
<Reaction SHCHF at 0x11493a0f0>,
<Reaction SHK3Dr at 0x11493a0b8>,
<Reaction SHKK at 0x11493a048>,
<Reaction SHSL1 at 0x11492f080>,
<Reaction SO4tex at 0x11492fb00>,
<Reaction SULRi at 0x1149287f0>,
<Reaction TDSK at 0x1149214e0>,
<Reaction THDPS at 0x114921390>,
<Reaction THRD_L at 0x11491ab00>,
<Reaction THRS at 0x11491aa20>,
<Reaction THZPSN3 at 0x11491a2b0>,
<Reaction TMDS at 0x114914898>,
<Reaction TMPK at 0x1149146d8>,
<Reaction TMPPP at 0x114914668>,
<Reaction TYRL at 0x114906550>,
<Reaction TYRTA at 0x1149064e0>,
<Reaction U23GAAT at 0x1148ffd68>,
<Reaction UAAGDS at 0x1148ffdd8>,
<Reaction UAGAAT at 0x1148ffbe0>,
<Reaction UAGCVT at 0x1148ffc18>,
<Reaction UAGDP at 0x1148ffc50>,
<Reaction UAGPT3 at 0x1148ff278>,
<Reaction UAMAGS at 0x1148ff208>,
<Reaction UAMAS at 0x1148ff0b8>,
<Reaction UAPGR at 0x1148ff080>,
<Reaction UDCPDP at 0x1148ff0f0>,
<Reaction UDCPDPS at 0x1148ff128>,
<Reaction UGMDDS at 0x1148f1198>,
<Reaction UHGADA at 0x1148f11d0>,
```

```
 <Reaction UMPK at 0x1148eaa90>,
 <Reaction UPP3MT at 0x1148ea908>,
 <Reaction UPP3S at 0x1148ea898>,
 <Reaction UPPDC1 at 0x1148ea8d0>,
 <Reaction USHD at 0x1148e3940>,
 <Reaction Zn2tex at 0x1148d5e10>]
```

... and essential genes.

```
model.essential_genes()
```

```
[<Gene b0420 at 0x1149140b8>,
 <Gene b2400 at 0x1149b0160>,
 <Gene b2153 at 0x1149d4160>,
 <Gene b0475 at 0x114940198>,
 <Gene b4245 at 0x11486c1d0>,
 <Gene b3939 at 0x114b84208>,
 <Gene b1277 at 0x1149d4278>,
 <Gene b2574 at 0x11486c2b0>,
 <Gene b0774 at 0x112bf8358>,
 <Gene b1281 at 0x114adc3c8>,
 <Gene b2530 at 0x114a00400>,
 <Gene b2472 at 0x114b78400>,
 <Gene b1288 at 0x1149144a8>,
 <Gene b0777 at 0x114a4c4e0>,
 <Gene b3807 at 0x114a00518>,
 <Gene b1098 at 0x11490c550>,
 <Gene b3994 at 0x112bf8588>,
 <Gene b2019 at 0x1148705f8>,
 <Gene b3040 at 0x1148885f8>,
 <Gene b1093 at 0x112b886a0>,
 <Gene b1092 at 0x114a5c710>,
 <Gene b3843 at 0x114adc7f0>,
 <Gene b2311 at 0x114adc828>,
 <Gene b0928 at 0x11486c898>,
 <Gene b3634 at 0x114b44898>,
 <Gene b1136 at 0x114a009b0>,
 <Gene b0179 at 0x114bc89b0>,
 <Gene b2600 at 0x114890a20>,
 <Gene b2599 at 0x114890a58>,
 <Gene b0784 at 0x114a84a90>,
 <Gene b0085 at 0x114bc8ac8>,
 <Gene b3633 at 0x114a84b38>,
 <Gene b2329 at 0x114890b70>,
 <Gene b0639 at 0x114aa8ba8>,
 <Gene b4039 at 0x114890c50>,
 <Gene b0750 at 0x114b54cc0>,
 <Gene b0827 at 0x114870cf8>,
 <Gene b1208 at 0x114888d68>,
 <Gene b3368 at 0x114b7cda0>,
 <Gene b1263 at 0x112bf8e48>,
 <Gene b3607 at 0x114b78f28>,
 <Gene b0173 at 0x11490cf60>,
 <Gene b3991 at 0x114bc0f98>,
 <Gene b1264 at 0x112bf8fd0>,
 <Gene b0417 at 0x114bb9048>,
 <Gene b2320 at 0x114af90b8>,
 <Gene b1094 at 0x112b9d128>,
```

```
<Gene b2021 at 0x1149f9128>,
<Gene b0182 at 0x114a31128>,
<Gene b4040 at 0x1149e5160>,
<Gene b2762 at 0x114af1160>,
<Gene b1415 at 0x114995198>,
<Gene b0915 at 0x114ba51d0>,
<Gene b3993 at 0x114bb9198>,
<Gene b0908 at 0x114b3d320>,
<Gene b4160 at 0x114b3d400>,
<Gene b3941 at 0x114a914e0>,
<Gene b3850 at 0x114b31668>,
<Gene b0031 at 0x1148f1748>,
<Gene b0524 at 0x114be5748>,
<Gene b0166 at 0x114ba57b8>,
<Gene b2478 at 0x1148f1898>,
<Gene b3729 at 0x114995898>,
<Gene b0052 at 0x114af1898>,
<Gene b2564 at 0x114af1860>,
<Gene b2750 at 0x112bd19e8>,
<Gene b0086 at 0x114bd9a90>,
<Gene b2315 at 0x1148f1b00>,
<Gene b1131 at 0x112bd1b70>,
<Gene b0096 at 0x114bd9ba8>,
<Gene b0088 at 0x114bd2518>,
<Gene b2312 at 0x1149a9c50>,
<Gene b3176 at 0x114af9d30>,
<Gene b4177 at 0x112bd1d68>,
<Gene b3967 at 0x1149a9da0>,
<Gene b2585 at 0x114b3deb8>,
<Gene s0001 at 0x112ba5ef0>,
<Gene b0131 at 0x114865f28>,
<Gene b1260 at 0x114bb9f28>,
<Gene b4005 at 0x114b31f60>,
<Gene b1261 at 0x114bb9f60>,
<Gene b0025 at 0x114959f98>,
<Gene b1210 at 0x1149a9fd0>,
<Gene b3990 at 0x114bb20f0>,
<Gene b0181 at 0x114bd20f0>,
<Gene b0423 at 0x114bb2128>,
<Gene b3857 at 0x11487a160>,
<Gene b3805 at 0x1149f2160>,
<Gene b3992 at 0x114bb2160>,
<Gene b4407 at 0x114bb2198>,
<Gene b1096 at 0x112bca1d0>,
<Gene b0776 at 0x112bfe1d0>,
<Gene b3642 at 0x114ae2208>,
<Gene b3189 at 0x114bd2208>,
<Gene b2323 at 0x112b8e240>,
<Gene b4214 at 0x11487a2b0>,
<Gene b0133 at 0x114aea2e8>,
<Gene b2103 at 0x1149f22e8>,
<Gene b3360 at 0x112bca320>,
<Gene b0414 at 0x114856320>,
<Gene b1812 at 0x112bca358>,
<Gene b0004 at 0x112b96400>,
<Gene b0090 at 0x114bd2400>,
<Gene b2615 at 0x114a9a438>,
<Gene b3256 at 0x112bae4e0>,
```

```
<Gene b2764 at 0x11493a4e0>,
<Gene b0185 at 0x112bae518>,
<Gene b2763 at 0x11493a518>,
<Gene b3255 at 0x112bae550>,
<Gene b2316 at 0x112bae588>,
<Gene b3196 at 0x114882630>,
<Gene b0091 at 0x114bd2630>,
<Gene b0103 at 0x1149066a0>,
<Gene b0775 at 0x11487a710>,
<Gene b3648 at 0x1148ea710>,
<Gene b3972 at 0x114bd2710>,
<Gene b0142 at 0x1149f2780>,
<Gene b0386 at 0x114ae27b8>,
<Gene b0369 at 0x114b2a7f0>,
<Gene b0720 at 0x1148be860>,
<Gene b3774 at 0x114906908>,
<Gene b0918 at 0x114a16940>,
<Gene b0174 at 0x114bd29b0>,
<Gene b3198 at 0x114a16a58>,
<Gene b1091 at 0x112bbea58>,
<Gene b3187 at 0x114ad6a90>,
<Gene b3639 at 0x114b2ab00>,
<Gene b3957 at 0x112bbeb38>,
<Gene b1215 at 0x114a16b70>,
<Gene b2838 at 0x1148deba8>,
<Gene b0159 at 0x112b96c50>,
<Gene b3771 at 0x1148eacc0>,
<Gene b3809 at 0x1148decf8>,
<Gene b2752 at 0x114b72cf8>,
<Gene b2751 at 0x114b72d30>,
<Gene b3201 at 0x112bbeda0>,
<Gene b4262 at 0x112bbedd8>,
<Gene b2827 at 0x114bb2dd8>,
<Gene b3200 at 0x112bbee10>,
<Gene b3199 at 0x112bbee48>,
<Gene b0907 at 0x114ad6e48>,
<Gene b4261 at 0x112bbee80>,
<Gene b0003 at 0x1149f2e80>,
<Gene b0087 at 0x114aeaeb8>,
<Gene b0175 at 0x1148def60>,
<Gene b4013 at 0x1149f2f98>,
<Gene b3058 at 0x1148f7048>,
<Gene b3959 at 0x112bb30b8>,
<Gene b2499 at 0x114b370f0>,
<Gene b2507 at 0x1149c7160>,
<Gene b1740 at 0x114a9f198>,
<Gene b2818 at 0x112bb31d0>,
<Gene b2780 at 0x1148c71d0>,
<Gene b2026 at 0x114b37278>,
<Gene b3958 at 0x112bdf2b0>,
<Gene b0109 at 0x114aaf320>,
<Gene b3359 at 0x112bc3358>,
<Gene b3730 at 0x11496f358>,
<Gene b0180 at 0x112b7f3c8>,
<Gene b2747 at 0x114a6b3c8>,
<Gene b0421 at 0x1148ff400>,
<Gene b2476 at 0x114b37400>,
<Gene b1662 at 0x114b5b400>,
```

```
 <Gene b3608 at 0x114977470>,
 <Gene b2023 at 0x114a074e0>,
 <Gene b1062 at 0x1148f74e0>,
 <Gene b0029 at 0x1148ff4e0>,
 <Gene b2025 at 0x114a07518>,
 <Gene b2942 at 0x114a6b518>,
 <Gene b0415 at 0x114b5b4e0>,
 <Gene b3960 at 0x11485f588>,
 <Gene b3041 at 0x1148e3588>,
 <Gene b2557 at 0x114b375f8>,
 <Gene b3172 at 0x11485f6a0>,
 <Gene b1262 at 0x114a076a0>,
 <Gene b0134 at 0x114a8b6a0>,
 <Gene b0783 at 0x1148b76d8>,
 <Gene b0778 at 0x1148e36d8>,
 <Gene b2024 at 0x114b376a0>,
 <Gene b0781 at 0x1148b7710>,
 <Gene b2020 at 0x1149eb710>,
 <Gene b3804 at 0x114bdf710>,
 <Gene b4006 at 0x112bdf748>,
 <Gene b3177 at 0x1148f7780>,
 <Gene b3770 at 0x114a07780>,
 <Gene b0522 at 0x112bdf828>,
 <Gene b0009 at 0x114a8b828>,
 <Gene b3997 at 0x114bdf828>,
 <Gene b3412 at 0x114b23860>,
 <Gene b0523 at 0x112bdf908>,
 <Gene b0154 at 0x11496f908>,
 <Gene b2022 at 0x1149eb940>,
 <Gene b3974 at 0x114b23a90>,
 <Gene b1069 at 0x114a8bba8>,
 <Gene b0785 at 0x114a8bbe0>,
 <Gene b3389 at 0x1148f7c50>,
 <Gene b0073 at 0x114a0fc50>,
 <Gene b3018 at 0x112bd7c88>,
 <Gene b0914 at 0x1148afc88>,
 <Gene b1693 at 0x1148f7d30>,
 <Gene b2746 at 0x114a63d30>,
 <Gene b2687 at 0x114b5bd30>,
 <Gene b0826 at 0x114a8bd68>,
 <Gene b2515 at 0x114a63da0>,
 <Gene b0072 at 0x114a0fe10>,
 <Gene b0071 at 0x114a0fe48>,
 <Gene b3433 at 0x11485fef0>,
 <Gene b0074 at 0x114a0ffd0>]
```

```
from cameo import webmodels
```

```
models = webmodels.index_models()
```

```
models
```

```
from pandas import options
options.display.max_rows = 8
from cameo import load_model
model = load_model("iJO1366")
```

1.3 Simulating models with

computer **a**ided **m**etabolic **e**ngineering and **o**ptimization

cameo uses and extends the model data structures defined by cobrapy, our favorite **CO**nstraints-**B**ased **R**econstruction and **A**nalysis tool for **Py**thon. **cameo** is thus 100% compatible with **cobrapy**. For efficiency reasons, however, **cameo** implements its own simulation methods that take advantage of a more advanced solver interface.

1.3.1 Primer: Constraint-Based Modeling

Constraint-based modeling is a powerful modeling framework for analyzing metabolism on the genome scale (McCloskey et al., 2013). For a model that encompasses n reactions that involve m metabolites, $\mathbf{S}$ is a matrix of dimension $m \times n$ that encodes the stoichiometry of the metabolic reaction system; it is usually referred to as stoichiometric matrix. Assuming that the system is in a steady state—the concentration of metabolites are constant—the system of flux-balances can be formulated as

$$\mathbf{S}\mathbf{v} = 0\,, \tag{1.1}$$

where $\mathbf{v}$ is the vector of flux rates. With the addition of a biologically meaningful objective, flux capacity constraints, information about the reversibility of reactions under physiological conditions, an optimization problem can be formulated that can easily be solved using linear programming.

, e.g., maximimization of biomass production,Given the maximization of growth rate as one potential biological objective $v_{biomass}$, i.e., the flux of an artificial reaction that consumes biomass components in empirically determined proportions, and assuming that the cell is evolutionary optimized to achieve that objective, and incorporating knowledge about reaction reversibility, uptake and secretion rates, and maximum flux capacities in the form of lower and uppers bounds ($\mathbf{v}_{lb}$ and $\mathbf{v}_{ub}$) on the flux variables $\mathbf{v}$, one can formulate and solve an optimization problem to identify an optimal set of flux rates using flux balance analysis (FBA):

$$\begin{aligned} Max \;\; & Z_{obj} = \mathbf{c}^T\mathbf{v} && (1.2)\\ \text{s.t.} \;\; & \mathbf{S}\mathbf{v} = 0 && (1.3)\\ & \mathbf{v}_{lb} \leq \mathbf{v} \leq \mathbf{v}_{ub} && (1.4) \end{aligned}$$

1.3.2 Flux Balance Analysis

In **cameo**, flux balance analysis can be performed with the function `fba`.

```
from cameo import fba
fba_result = fba(model)
```

Basically, `fba` calls `model.solve()` and wraps the optimization solution in a `FluxDistributionResult` object. The maximum objective values (corresponding to a maximum growth rate) can obtained throug `result.objective_value`.

```
fba_result.objective_value
```

```
0.9823718127269799
```

1.3.3 Parsimonious Flux Balance Analysis

Parsimonious flux balance analysis (Lewis et al., 2010), a variant of FBA, performs FBA in in a first step to determine the maximum objective value Z_{obj}, fixes it in form of an additional model constraint ($\mathbf{c}^T\mathbf{v} \geq Z_{obj}$), and then minimizes

in a second optimization the L_1 norm of $\mathbf{v}$. The assumption behind the pFBA is that cells try to minimize flux magnitude as well in order to keep the costs of protein low.

$$
\begin{aligned}
Max \quad & |\mathbf{v}| && (1.5)\\
\text{s.t.} \quad & \mathbf{S}\mathbf{v} = 0 && (1.6)\\
& \mathbf{c}^T\mathbf{v} \geq Z_{obj} && (1.7)\\
& \mathbf{v}_{lb} \leq \mathbf{v} \leq \mathbf{v}_{ub} && (1.8)
\end{aligned}
$$

In **cameo**, pFBA can be performed with the function `pfba`.

```
from cameo import pfba
pfba_result = pfba(model)
```

The `objective_function` value is $|\mathbf{v}|$ ...

```
pfba_result.objective_value
```

```
699.0222751839377
```

... whis is significantly smaller than flux vector of the original FBA solution.

```
abs(fba_result.data_frame.flux).sum()
```

```
764.91487969777245
```

1.3.4 Setp 2: Simulate knockouts phenotypes

Although PFBA and FBA can be used to simulate the effect of knockouts, other methods have been proven more valuable for that task: MOMA and ROOM. In *cameo* we implement a linear version of MOMA.

Simulating knockouts:

- Manipulate the bounds of the reaction (or use the shorthand method knock_out)

```
model.reactions.PGI
```

```
model.reactions.PGI.knock_out()
model.reactions.PGI
```

- Simulate using different methods:

```
%time
fba_knockout_result = simulation.fba(model)
fba_knockout_result[model.objective]
```

```
CPU times: user 2 µs, sys: 0 ns, total: 2 µs
Wall time: 5.01 µs
```

```
0.905983
```

```
pfba_knockout_result = simulation.pfba(model)
pfba_knockout_result[model.objective]
```

```
0.905983
```

MOMA and ROOM relly on a reference (wild-type) flux distribution and we can use the one previously computed.

Parsimonious FBA references seem to produce better results using this methods

```
lmoma_result["2 * EX_glc_lp_e_rp_"]
```

```
-18.7358
```

```
%time
lmoma_result = simulation.lmoma(model, reference=pfba_result.fluxes)
lmoma_result[model.objective]
```

```
CPU times: user 2 µs, sys: 1 µs, total: 3 µs
Wall time: 5.01 µs
```

```
0.791393
```

```
%time
room_result = simulation.room(model, reference=pfba_result.fluxes)
room_result[model.objective]
```

```
CPU times: user 2 µs, sys: 1 µs, total: 3 µs
Wall time: 5.01 µs
```

```
0.887440
```

```
room_result
```

```
<cameo.core.result.FluxDistributionResult at 0x10aa75b50>
```

1.4 Analyzing models with

computer **a**ided **m**etabolic **e**ngineering and **o**ptimization

cameo uses and extends the model data structures defined by cobrapy, our favorite **CO**nstraints-**B**ased **R**econstruction and **A**nalysis tool for **Py**thon. **cameo** is thus 100% compatible with **cobrapy**. For efficiency reasons though **cameo** implements its own analysis methods that take advantage of a more advanced solver interface.

```
from cameo import load_model
model = load_model("iJO1366")
```

1.4.1 Flux Variability Analysis

Flux variability analysis (FVA) enables the computation of lower and upper bounds of reaction fluxes.

```
from cameo import flux_variability_analysis
```

```
flux_variability_analysis(model, reactions=[model.reactions.PGI, model.reactions.EX_glc_lp_e_rp_])
```

One very useful application of FVA is determining if alternative optimal solution exist.

```
flux_variability_analysis(model, reactions=[model.reactions.PGI, model.reactions.EX_glc_lp_e_rp_],
                          fraction_of_optimum=1.)
```

1.4.2 Phenotpic Phase Plane

```
model.reactions.EX_o2_lp_e_rp_.lower_bound = -10
result = analysis.phenotypic_phase_plane(model,
                                         variables=[model.reactions.BiomassEcoli],
                                         objective=model.reactions.EX_succ_lp_e_rp_,
                                         points=10)
```

```
result.plot(height=400)
```

```
result.data_frame
```

1.5 Differential flux variability analysis

```
from cameo import load_model
from cameo.flux_analysis.analysis import phenotypic_phase_plane
from cameo.strain_design.deterministic import DifferentialFVA
```

```
:0 [1;31mFutureWarning[0m: IPython widgets are experimental and may change in the future.
```

1.5.1 E. coli model and succinate production

Load the E. coli core model.

```
model = load_model('iJO1366')
```

The production envelope looks like this.

```
production_envelope = phenotypic_phase_plane(model,
                                             variables=[model.reactions.Ec_biomass_iJO1366_core_53p95
                                             objective=model.reactions.EX_succ_lp_e_rp_)
production_envelope.plot(height=300)
```

Set up a model that represents a reference state (in this case a model with a constrained growth rate).

```
reference_model = model.copy()
biomass_rxn = reference_model.reactions.Ec_biomass_iJO1366_core_53p95M
biomass_rxn.lower_bound = 0.3
target = reference_model.reactions.EX_succ_lp_e_rp_
target.lower_bound = 2
```

Set up the differential flux variability analysis strain design method.

```
diffFVA = DifferentialFVA(design_space_model=model,
                          reference_model=reference_model,
                          objective=target,
                          variables=[biomass_rxn],
                          normalize_ranges_by=biomass_rxn,
                          points=10)
```

Run differential flux variability analysis (only on the surface of the production envelope)

```
result = diffFVA.run(surface_only=True)
result.plot(height=300)
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
result.display_on_map("iJO1366.Central metabolism")
```

```
<IPython.core.display.Javascript object>
```

1.6 E. coli core model

```
import cameo
from cameo import models
from cameo.strain_design.heuristic import GeneKnockoutOptimization, ReactionKnockoutOptimization
from cameo.strain_design.heuristic.objective_functions import biomass_product_coupled_yield, product_
from cameo.flux_analysis.simulation import fba
from cameo.parallel import SequentialView
import inspyred
```

```
model = models.bigg.e_coli_core
```

```
objective1 = biomass_product_coupled_yield(
    model.reactions.Biomass_Ecoli_core_w_GAM,
    model.reactions.EX_ac_e,
    model.reactions.EX_glc_e)

objective2 = number_of_knockouts()
objective = [objective1, objective2]
```

```
ko = GeneKnockoutOptimization(model=model,
                                    simulation_method=fba,
                                    objective_function=objective,
                                    heuristic_method=inspyred.ec.emo.NSGA2,
                                    seed=1234)
```

```
results = ko.run(max_evaluations=3000, popuplation_size=100, view=SequentialView())
```

```
Starting optimization at Fri, 17 Jul 2015 13:53:04
```

```
Using saved session configuration for http://localhost:5006/
To override, pass 'load_from_config=False' to Session
```

```
/Users/niko/.virtualenvs/cameo_py3/lib/python3.4/site-packages/bokeh/session.py:319 [1;31mUserWarning
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
Finished after 00:00:16
```

```
results
```

1.7 iJO1366 model

```
model = models.bigg.iJO1366
```

```
of1 = product_yield(model.reactions.Ec_biomass_iJO1366_core_53p95M,
                    model.reactions.EX_glc_e)
of2 = number_of_knockouts()
of3 = biomass_product_coupled_yield(model.reactions.Ec_biomass_iJO1366_core_53p95M,
                                    model.reactions.EX_ac_e,
                                    model.reactions.EX_glc_e)
```

```
ko = GeneKnockoutOptimization(model=model, objective_function=[of1, of2, of3],
                                  simulation_method=fba, heuristic_method=inspyred.ec.emo.NSGA2)
```

```
ko.run(max_evaluations=5000, n=10, mutation_rate=0.3, population_size=100)
```

```
Starting optimization at Fri, 17 Jul 2015 13:54:18
```

```
Using saved session configuration for http://localhost:5006/
To override, pass 'load_from_config=False' to Session
```

```
/Users/niko/.virtualenvs/cameo_py3/lib/python3.4/site-packages/bokeh/session.py:319 [1;31mUserWarning
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
<IPython.core.display.Javascript object>
```

```
Finished after 00:07:08
```

```
from IPython.display import display
import re
```

```
from cameo import models
from cameo.strain_design import pathway_prediction
```

```
model = models.bigg.iMM904
```

```
predictor = pathway_prediction.PathwayPredictor(model=model, compartment_regexp=re.compile(".*_c$"))
```

```
pathways = predictor.run(product="vanillin", max_predictions=5)
```

```
from cameo import phenotypic_phase_plane
from cameo.util import TimeMachine
from cameo.visualization.plotting import Grid
```

```
with Grid(nrows=3) as grid:
    for i, pathway in enumerate(pathways):
        with TimeMachine() as tm:
            pathway.plug_model(model, tm=tm)
            ppp = phenotypic_phase_plane(model, variables=[model.reactions.biomass_SC5_notrace], obje
            ppp.plot(grid=grid, width=450, height=350, title="Pathway %i" % (i+1), axis_font_size="12
```

1.8 Parallelization

Most methods in cameo can be parallelized using views.

1.9 cameo vs. cobrapy

1.9.1 Importing a model

cobrapy (load a model in SBML format):

```
from cobra.io import read_sbml_model
model = read_sbml_model('path/to/model.xml')
```

cameo (load models from different formats):

```
from cameo import load_model
# read SBML model
model = load_model('path/to/model.xml')
# ... or read a pickled model
model = load_model('path/to/model.pickle')
# ... or just import a model by ID from http://darwin.di.uminho.pt/models
iAF1260 = load_model('iAF1260')
```

1.9.2 Solving models

cobrapy:

```
solution = model.optimize()
if solution.status == 'optimal':
    # proceed
```

```
try:
    solution = model.solve()
except cameo.exceptions.SolverError:
    print "A non-optimal solution was returned by the solver"
else:
    # proceed
```

It is important to note that cameo models maintain *optimize* to maintain compatibility with cobrapy but we discourage its use.

1.10 How to ...

- ... run differential flux-variability analysis
- ... perform a heuristic gene knockout optimization (single-objective)
- ... perform a heuristic gene knockout optimization (multi-objective)

1.11 API

1.11.1 cameo package

Subpackages

cameo.api package

Submodules

cameo.api.designer module

cameo.api.hosts module

cameo.api.products module

Module contents

cameo.core package

Submodules

cameo.core.reaction module

cameo.core.result module

cameo.core.solution module

cameo.core.solver_based_model module

Module contents

cameo.data package

Submodules

cameo.data.metanetx module

Module contents

cameo.flux_analysis package

Submodules

cameo.flux_analysis.analysis module

cameo.flux_analysis.distance module

cameo.flux_analysis.simulation module

Module contents

cameo.models package

Submodules

cameo.models.universal module

cameo.models.webmodels module

Module contents

cameo.network_analysis package

Submodules

cameo.network_analysis.networkx_based module

cameo.network_analysis.util module

Module contents

cameo.strain_design package

Subpackages

cameo.strain_design.deterministic package

Submodules

cameo.strain_design.deterministic.flux_variability_based module

Module contents

cameo.strain_design.heuristic package

Subpackages

cameo.strain_design.heuristic.multiprocess package

Submodules

cameo.strain_design.heuristic.multiprocess.migrators module

cameo.strain_design.heuristic.multiprocess.observers module

cameo.strain_design.heuristic.multiprocess.optimization module

cameo.strain_design.heuristic.multiprocess.plotters module

Module contents

Submodules

cameo.strain_design.heuristic.archivers module

cameo.strain_design.heuristic.decoders module

cameo.strain_design.heuristic.generators module

cameo.strain_design.heuristic.genomes module

cameo.strain_design.heuristic.metrics module

cameo.strain_design.heuristic.objective_functions module

cameo.strain_design.heuristic.observers module

cameo.strain_design.heuristic.optimization module

cameo.strain_design.heuristic.plotters module

cameo.strain_design.heuristic.stats module

cameo.strain_design.heuristic.variators module

Module contents

cameo.strain_design.pathway_prediction package

Submodules

cameo.strain_design.pathway_prediction.util module

Module contents

Module contents

cameo.ui package

Module contents

cameo.visualization package

Submodules

cameo.visualization.escher_ext module

cameo.visualization.plotting module

cameo.visualization.visualization module

Module contents

Submodules

cameo.config module

cameo.exceptions module

cameo.io module

cameo.parallel module

cameo.stuff module

cameo.util module

Module contents

CHAPTER 2

Indices and tables

- genindex
- modindex
- search