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# **modelx Documentation**

*Release 0.0.21*

**Fumito Hamamura**

**Mar 24, 2019**



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*Escape from spreadsheet models!*

The screenshot displays the Spyder interface for the modelx plugin. It is divided into several panes:

- MxExplorer:** A tree view showing the project structure. The 'OuterProj' space is expanded, showing 'Dynamic Spaces' with 'Space1' (Parameters: PolicyID, ScenID) and various cells like 'InsServiceResult', 'CovUnitsEnd', 'InsurFinIncomeExps', etc.
- Code Editor:** Contains two Python functions:
 

```

def InsurFinIncomeExps(t):
    """Insurance Finance Income or Expenses (80(b), 87-92, B128-B136)
    Warning:
    Accounting Policy Choice 88(b) not implemented.
    """
    chg_discrate = (PV_Cashflow(t + 1, t + 1, t + 1)
                    - PV_Cashflow(t + 1, t + 1, t))
    return (EstIntonCF(t) + chg_discrate
            - IntAccrCSM(t) + IntAccumCF(t))

def AsmpChangeImpact(t):
    """Non-financial assumption changes"""
    return PV_Cashflow(t + 1, t + 1, 0) - PV_Cashflow(t, t + 1, 0)
            
```
- IPython console:** Shows the execution of the expression `ifrs.to_frame()`, resulting in a data table:

t	InsurRevenue	InsurServiceExps	InsurFinIncomeExps	ProfitBefIax
0	2135.49	1027.91	-1.42109e-14	1107.58
1	2027.24	1008.86	-3.01981e-14	1018.38
2	1925.53	989.211	1.77636e-15	936.322
3	1813.68	952.841	7.99361e-15	860.839
4	1700.88	909.463	1.15463e-14	791.418

- Visualizations:** Two bar charts are shown:
  - CSM Amortization:** A bar chart showing the amortization of CSM over time for various parameters like `CSM_Lintonee(0)`, `IntAccrCSM(0)`, etc.
  - Expected Cashflows:** A bar chart showing expected cashflows for parameters like `FutureCF(0)`, `Income(0)`, `IntonCF(0)`, etc.

Fig. 1: Spyder plugin for modelx



# CHAPTER 1

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## Latest Updates

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- *24 March 2019*: spyder-modelx v0.0.9 is released. See *Release Notes* for details.
- *24 March 2019*: modelx v0.0.21 is released. See *Release Notes* for details.
- *2 February 2019*: modelx v0.0.20 is released. See *Release Notes* for details.
- *13 January 2019*: spyder-modelx v0.0.8 is released. See *Release Notes* for details.
- *13 January 2019*: modelx v0.0.19 is released. See *Release Notes* for details.
- *31 December 2018*: spyder-modelx v0.0.7 is released. See *Release Notes* for details.
- *31 December 2018*: modelx v0.0.18 is released. See *Release Notes* for details.

... *See more updates*



## CHAPTER 2

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### What is modelx?

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**modelx** is a Python package to build object-oriented models containing formulas and values to carry out complex calculations. You can think of it as a hierarchical and multidimensional extension of spreadsheet, but there's so much more to it!



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## Feature highlights

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**modelx** comes with features that enable users to interactively develop, run and scrutinize complex models in smart ways:

- Only little Python knowledge required
- Model composed of a tree of Spaces containing Cells
- Cells containing formulas and data
- Dynamic name binding for evaluating formulas within a Space
- Space inheritance
- Dynamic parametrized spaces created interactively
- GUI as Spyder plugin (spyder-modelx)
- Cells graph to track cells interdependency (Under development)
- Saving to / loading from files
- Conversion to Pandas objects
- Reading from Excel files



## CHAPTER 4

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### Who is modelx for?

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**modelx** is designed to be domain agnostic.

The **modelx** was created by **actuary**, and its primary use is to develop actuarial projection models. **lifelib** (<https://lifelib.io>) is a library of actuarial models that are built on top of **modelx**.

However, **modelx** is intentionally designed to eliminate domain specific features so that potential audience for **modelx** can be wider than actuaries, whoever needs to develop complex models of any sorts that are too much to deal with by spreadsheets.



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## How modelx works

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**modelx** exposes its API functions and classes such as Model, Space and Cells to its users, and the users build their models from those classes, by defining calculation formulas in the form of Python functions and associating those calculations with Cells objects.

Below is a very simple working example in which following operations are demonstrated:

- a new model is created,
- and in the model, a new space is created,
- and in the space, a new cells is created , which is associated with the Fibonacci series.

```
from modelx import *

model, space = new_model(), new_space()

@defcells
def fibo(n):
    if n == 0 or n == 1:
        return n
    else:
        return fibo(n - 1) + fibo(n - 2)
```

To get a Fibonacci number for, say 10, you can do:

```
>>> fibo(10)
55
>>> fibo.series
n
0    0
1    1
2    1
3    2
4    3
5    5
```

(continues on next page)

(continued from previous page)

```
6      8
7      13
8      21
9      34
10     55
Name: fibo, dtype: int64
```

Refer to **lifelib** (<https://lifelib.io>) fo more complex examples.

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## Python and modelx

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Aside from modelx being a Python package and written entirely in Python, modelx utilizes Python in that it lets users define formulas by writing Python functions and converting it to modelx formulas. However, there is a critical difference between how Python functions are interpreted by Python and how modelx formulas are interpreted by modelx.

Python employs lexical scoping, i.e. the namespace in which function code is executed is determined by textual context. The global namespace of a function is the module that the function is defined in. In contrast, the evaluation of modelx formulas is based on dynamic scoping. Each Cells belongs to a space, and the space has associated namespace (a mapping of names to objects). The formula associated with the cells is evaluated in that namespace. So, what module a formula is defined (in the form of a Python function) does not affect the result of formula evaluation. It is what space the cells belongs to that affects the result.



## CHAPTER 7

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### License

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Copyright 2017-2019, Fumito Hamamura

modelx is free software; you can redistribute it and/or modify it under the terms of [GNU Lesser General Public License v3 \(LGPLv3\)](#).

Contributions, productive comments, requests and feedback from the community are always welcome. Information on modelx development is found at Github <https://github.com/fumitoh/modelx>



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### Development State

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modelx is in its early alpha-release stage, and its specifications are subject to changes without consideration on backward compatibility. The source files of your models may need to be modified manually, if there are updates that break backward compatibility in newer versions of modelx.

Likewise, model files saved with one version may not load with a newer version. When updating modelx to a newer version, make sure you rebuild model files saved using older versions of modelx from their source code.

**Warning:** If you have embedded modelx in actuarial production processes, then it is encouraged to connect with the author [on linkedin](#) or [on github](#), as modelx features you rely on might change or be removed in future releases without the author knowing those features are in use.



## CHAPTER 9

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### History

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modelx was originally conceived and written by Fumito Hamamura and it was first released in October 2017.



- *Installation*
- *Tutorial*
- *Reference*

## 10.1 What's New

**Warning:** modelx is in its early alpha-release stage, and its specifications are subject to changes without consideration on backward compatibility. The source files of your models may need to be modified manually, if there are updates that break backward compatibility in newer versions of modelx.

Likewise, model files saved with one version may not load with a newer version. When updating modelx to a newer version, make sure you rebuild model files saved using older versions of modelx from their source code.

### 10.1.1 Updates

- *24 March 2019:* spyder-modelx v0.0.9 is released. See *Release Notes* for details.
- *24 March 2019:* modelx v0.0.21 is released. See *Release Notes* for details.
- *2 February 2019:* modelx v0.0.20 is released. See *Release Notes* for details.
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... See more updates

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- 13 January 2019: modelx v0.0.19 is released. See *Release Notes* for details.
- 31 December 2018: spyder-modelx v0.0.7 is released. See *Release Notes* for details.
- 31 December 2018: modelx v0.0.18 is released. See *Release Notes* for details.
- 2 December 2018: *Spyder plugin* page is added. A plugin image is added in the landing page.
- 2 December 2018: spyder-modelx v0.0.6 is released. See *Release Notes* for details.
- 2 December 2018: modelx v0.0.17 is released. See *Release Notes* for details.
- 27 October 2018: The *Overview* page of this site is updated and merged into the landing page.
- 21 October 2018: modelx v0.0.16 is released. See *Release Notes* for details.
- 20 September 2018: modelx v0.0.15 is released. See *Release Notes* for details.
- 8 September 2018: The *Installation* page is updated and *Installing Spyder plugin for modelx* section is added.
- 3 September 2018: modelx v0.0.14 is released. See *Release Notes* for details.
- 5 August 2018: *modelx v0.0.13* is released.
- 5 August 2018: The *Reference* guide is updated so that base class members are also described in their concrete classes' pages.
- 16 June 2018: *modelx v0.0.12* is released.
- 27 May 2018: modelx v0.0.11 is released.
- 6 May 2018: modelx v0.0.10 is released.
- 20 April 2018: The *modelx Concepts* section is added.

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## 10.1.2 Releases: modelx

### v0.0.21 (23 March 2019)

Updates include refactoring to separate static and dynamic space classes, use tuple for CellNode implementation, gaining approximately 20% performance improvement.

### Backwards Incompatible Changes

- Space class is now split into two separate concrete classes, *StaticSpace*, *DynamicSpace* and one base class *BaseSpace*.
- `module_` parameter of the methods below are renamed to `module`.
  - `import_module()`
  - `import_funcs()`

- `new_cells_from_module()`

- `new_space_from_module()`

- Methods and properties below on Space classes are renamed to be private, as these are expected not to be used directly by users for normal usage.

- `__is_base()`

- `__is_sub()`

- `__is_static()`

- `__is_derived()`

- `__is_defined()`

- `__is_root()`

- `__is_dynamic()`

- `__self_cells`

- `__derived_cells`

- `__self_spaces`

- `__derived_spaces`

## Enhancements

- IPython error traceback message is not suppressed by default. `setup_ipython()` is added to suppress the default message.
- `set_recursion()` is added to change the maximum depth of formula recursion.

## Bug Fixes

- Fix `formula` as setter by assignment expression i.e. alias to `set_formula()`.
- Fix `refs`.

## v0.0.20 (2 February 2019)

### Enhancements

- `CellNode` repr to show “parameter=arguments”.
- Add `formula` property.

### Bug Fixes

- Fix duplicate multiple bases of a dynamic space.

## v0.0.19 (13 January 2019)

Enhancements / bug fixes for defining and using dynamics spaces whose base includes dynamics spaces.

## Enhancements

- Add `name` parameter to `open_model()`.
- Pass dynamic arguments down to its children.
- Iterating over cells with single parameter returns values instead of tuples of single elements.
- View's `_baseattrs` to not include items with `_` prefixed names.

## Bug Fixes

- Fix bases of derived dynamic spaces. If dynamic spaces are to be the base spaces of a dynamic sub space, then the static base spaces of the dynamic spaces become the base spaces in replacement for the dynamic spaces.
- Fix `AttributeError: 'BoundFunction' object has no attribute 'altfunc'` on unpickled models.
- Dedent function definitions for those defined inside blocks of other function definition.
- Fix error in conversion to `DataFrame` when merging indexes with different types.

### v0.0.18 (31 December 2018)

This release is mainly for adding interface functions/methods to `spyder-modelx v0.0.7 (31 December 2018)`

## Enhancements

- Add `preds` and `succs` properties to `CellNode`.
- Add `node()` to `Cells`
- Rename `literaldict` property to `_baseattrs` for `Interface`, `BaseView` and their subclasses.
- Rename `set_keys` method of `SelectedView` to `_set_keys`.

## Bug Fixes

- Raise not `KeyError` but `AttributeError` upon `hasattr/getattr` on `Space`.

### v0.0.17 (2 December 2018)

This release is mainly for adding interface to functions to `spyder-modelx v0.0.6 (2 December 2018)`

## Enhancements

- `get_object()` to get a modelx object from its full name.

## Bug Fixes

- Error when modelx tries to get IPython shell before it becomes available.

### v0.0.16 (21 October 2018)

spyder-modelx plugin introduces a new widget to view cells values in a table. This release reflects some updates in modelx to make the new widget work.

#### Enhancements

- `cur_model()` and `cur_space()` now accept model and space objects as their arguments respectively, in addition to the names of model or space objects.
- Add `model` property to all Interface subclasses.
- Traceback messages upon erroneous formula calls are now limited to 6 trace stack entries.
- Error messages upon erroneous formula calls are now simplified not to show file traceback.

#### Backwards Incompatible Changes

- The parameters to `cur_model()` and `cur_space()` are renamed from `name` to `model` and `space` respectively, due to the enhancement for these functions to accept objects, in addition to the names of the objects.

### v0.0.15 (20 September 2018)

#### Enhancements

- Importing a module overrides formulas if their cells already exist.

### v0.0.14 (3 September 2018)

This version is mainly for updating modelx Qt widgets, in order for the widgets to work with the initial version of spyder-modelx, Spyder plugin for modelx.

#### Enhancements

- Add property `_baseattrs` and `BaseView._baseattrs`. This property is used by spyder-modelx.

#### Bug Fixes

- Fix crashes when `cur_model()` is called with `name` argument to change the current model.

### v0.0.13 (5 August 2018)

Space implementation has been largely rewritten in this release to make the inheritance logic more robust.

**Warning:** Support for Python 3.4, 3.5 is dropped in this release. Now only Python 3.6 and 3.7 are supported. This is mainly due to the fact that modelx utilizes the order preservation nature of `dict` introduced in Python 3.6. `dict` performance improvement in Python 3.6 is also the reason to drop support for older versions.

Support for NetworkX ver 1.x is also dropped in this release. NetworkX version 2.x is now required.

## Enhancements

- `add_bases()` and `remove_bases()` are added.
- `bases` is added.

## Backwards Incompatible Changes

- Support for Python older than 3.6 is dropped. Now Python 3.6 or above is required.
- Support for NetworkX version 1 is dropped. Now NetworkX version 2 is required.
- Dynamic spaces now inherit their parent spaces by default.
- `new_cells()` raises an error when the cells already exists.
- `formula` now returns Formula object instead of string.

## Bug Fixes

- `repr()` on SpaceView and CellsView now list only selected items.

## v0.0.12 (16 June 2018)

### Enhancements

- `cells` returns an immutable mapping of cells named `CellsView` supporting `to_frame()` method, which returns a DataFrame object containing cells values. If an iterator of arguments are given as `arg`, values of the cells for the arguments are calculated and only the given arguments are included in the DataFrame index(es). For more, see [the reference page](#)
- Cells are now of a Mapping type, which implements `keys()`, `values()`, `items()` methods to get their arguments and values.
- Subscription(`[]`) operator on `cells` now accepts multiple args of cell names and a sequence of cell names, such as `['foo', 'bar']` and `[['foo', 'bar']]`, which returns an immutable mapping (view) that includes only specified cells.

### Backwards Incompatible Changes

- `frame` returns does not include empty or all-None cells.

## Bug Fixes

- Fix issues specific to networkx v1.x.
- Fix `import_module()` to handle *bases* properly.

### v0.0.11 (27 May 2018)

## Bug Fixes

- Fix `Space.refs`
- Fix conversion of scalar cells to Pandas objects

### v0.0.10 (6 May 2018)

## Enhancements

- Add `is_*` methods to `Space`.
- Rename a model by adding `_BAKn` to its original name when another model with the same name is created.
- Add `rename()`.
- `name in space` expression is allowed where `name` is a string.
- `_space` local reference is available to refer to the parent space from its child cells.

## Backwards Incompatible Changes

- `get_self` function is removed.

## Bug Fixes

- Call stack max depth is set to 1000 to run all lifelib samples successfully.
- Fix an error around graph unpickling.
- Keep the same derived objects after they are updated.

### v0.0.9 (1 April 2018)

## Enhancements

- Add `show_tree` to show model tree in inline mode.
- Add `get_tree` to get model tree in automatic mode.

## Bug Fixes

- Make `get_modeltree` available directly under `modelx`.

## v0.0.8 (25 March 2018)

### Enhancements

- Make `get_modeltree` available directly under `modelx`.
- Add `import_module()` and `import_funcs()` properties.
- Add `all_spaces` to contain all child spaces, including dynamic spaces.
- Add `self_spaces` and `derived_spaces` properties.
- Add `configure_python()` and `restore_python()`.
- Add `reload()` to reload the source module.
- `Model` and `StaticSpace` to list their members on `dir()`.
- Raise an error upon zero division in formulas.
- Add `parent` property.

### Backwards Incompatible Changes

- Base spaces are now indelible.
- `spaces` now contains only statics spaces. Now `static_spaces` is an alias to `spaces`.

### Bug Fixes

- Remove overridden cells from `derived_cells`
- Update `self_cells` when new cells are added.
- Fix stack overflow with Anaconda 64-bit Python on Windows.

### Thanks

- Stanley Ng

## v0.0.7 (27 February 2018)

### Backwards Incompatible Changes

- Renamed `StaticSpace` constructor parameter `paramfunc` to `formula`.
- Renamed `new_cells()` parameter `func` to `formula`.
- Renamed Interface `can_have_none` to `allow_none`.

### Bug Fixes

- Fix `open_model()` to make `cur_model()` properly return unpickled model.

### 10.1.3 Releases: spyder-modelx

#### v0.0.9 (24 March 2019)

- MxExplorer and MxDataView now support multiple MxConsoles.
- Fix MxAnalyzer nodes holding Cells objects as their values.

#### v0.0.8 (13 January 2019)

- Fix MxAnalyzer crash.
- MxAnalyzer can now handle Cells with no arguments.

#### v0.0.7 (31 December 2018)

- Add MxAnalyzer widget. See *MxAnalyzer* section for details.
- MxExplorer now shows reference items.
- MxExplorer now displays dynamic spaces as parametrized expressions.

#### v0.0.6 (2 December 2018)

- Add Formula list widget to MxExplorer.
- Support Spyder 3.3.2.

#### v0.0.5 (21 October 2018)

- Add MxDataView widget. See *MxDataView* section for details.

## 10.2 Installation

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**Note:** For *lifelib* users, when installing *lifelib* using `pip`, *modelx* is automatically installed due to its dependency, so no need to install *modelx* separately.

---

### 10.2.1 Python version

*modelx* requires Python 3.6 or newer. *modelx* does not work with Python 3 older than version 3.6 or any version of Python 2.

### 10.2.2 Package dependency

The packages listed below are either required by *modelx*, or can be used with *modelx* to develop models more efficiently.

- NetworkX (>=2.0)

- Pandas
- OpenPyXL
- Spyder (>=3.2.5)

## networkx

NetworkX is a required package that modelx depends on. Version 2.0 or newer is required.

## Pandas

Although you can install modelx without Pandas, it is highly recommended that you have Pandas installed, together with other packages Pandas depends on, such as NumPy, so that you can export Spaces and Cells to Pandas DataFrame and Series.

## Openpyxl

OpenPyXL is a package that supports reading from and writing to Excel files. Openpyxl is also not required, but it is desirable to have it installed to enable modelx to interface with Excel files.

## Spyder

If you use modelx with [Spyder](#), a plugin for modelx is available. `spyder-modelx` is a separate package to add custom IPython consoles and Modelx explorer, a widget that shows the current model in a tree view. The supported Spyder version is 3.2.5 or newer. For how to install the plugin, see [here](#).

## 10.2.3 Installing modelx

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**Note:** If you install *Spyder plugin for modelx* as explained below, no need to install modelx separately as modelx is installed together with the plugin, so skip to the *Plugin installation* section.

---

Just like other Python packages, you can install `modelx` by running `pip` command from a terminal on Linux, or from a command prompt on Windows.

To install the current version of `modelx` with `pip`:

```
$ pip install modelx
```

To upgrade to a newer version using the `--upgrade` flag:

```
$ pip install --upgrade modelx
```

To make `modelx` available only to you but others, install it into your user directory using the `--user` flag:

```
$ pip install --user modelx
```

If you prefer to install `modelx` from files placed locally on your machine instead of directly fetching from the Web, you can manually download `modelx` files from [GitHub](#) or [PyPI](#).

Unpack the downloaded files and run the following command at the top of the source directory:

```
$ pip install .
```

## 10.2.4 Spyder integration

[Spyder](#) is a popular open-source Python IDE, and a Spyder plugin for modelx is available. To install and use the plugin, see the [Spyder plugin](#) page

## 10.3 Spyder plugin

[Spyder](#) is a popular open-source Python IDE, and it's bundled in with [Anaconda](#) by default. [Spyder](#) allows plugins to be installed to add extra features to itself.

**Spyder plugin for modelx** enriches user interface to modelx in Spyder. The plugin adds custom IPython consoles and GUI widgets for using modelx in Spyder.

The plugin is under active development, and currently comes with a primary version of components, including:

- MxConsole
- MxExplorer
- MxDataView
- MxAnalyzer

**MxConsole** appears as tabs in Spyder's default IPython console, and runs custom IPython shells. Users should use these shells instead of Spyder's default shells in order for the other plugin widgets to interface with the user's Python sessions. The plugin widgets do not interface with Python running in default IPython consoles.

**MxExplorer** is the main plugin widgets, and it shows the object tree of the current modelx model in the active MxConsole. It can also lists formulas of cells in a selected space next to the tree.

**MxDataView** shows data in modelx objects in a spreadsheet-like tabular format.

**MxAnalyzer** is for tracking dependency of calculations. The user enter a Cell node, a combination of a Cell and arguments, and MxAnalyzer currently shows a tree of Cell nodes directly or indirectly used in calculating the value of the specified node.

The plugin widgets are “dockable” as Spyder's default widgets, meaning you can detach those widgets from the Spyder's main window to have their own separate windows, and “dock” them back in the main window at different positions to rearrange the widgets positions in the main window as you like.

### 10.3.1 Configure Spyder

#### Disable User Module Reloader

When you use modelx with Spyder, sometimes you may want to re-run the same file in the editor window multiple times in the same IPython session. You don't want to reload modelx because reloading modelx module creates multiple instances of modelx systems within the same Python process, causing models created before and after a reload to reside in different modelx systems. To avoid that, you need to change *User Module Reloader (UMR)* setting.

From the Spyder menu, select *Tools->Preferences* to bring up Preferences window. Choose *Python interpreter* in the left pane, and you'll find an area titled *User Module Reloader (UMR)* on the bottom right side of the Preferences window. Leave *Enable UMR* option checked, click *Set UMR excluded(not reloaded) modules* and then UMR dialog box pops up as the figure blow. Enter “modelx” in the dialog box. This prevents Spyder from reloading the modelx module every time you re-run the same script from *Run* menu, while allowing other modules to be reloaded.

Note that you need to restart Spyder to bring the change into effect.

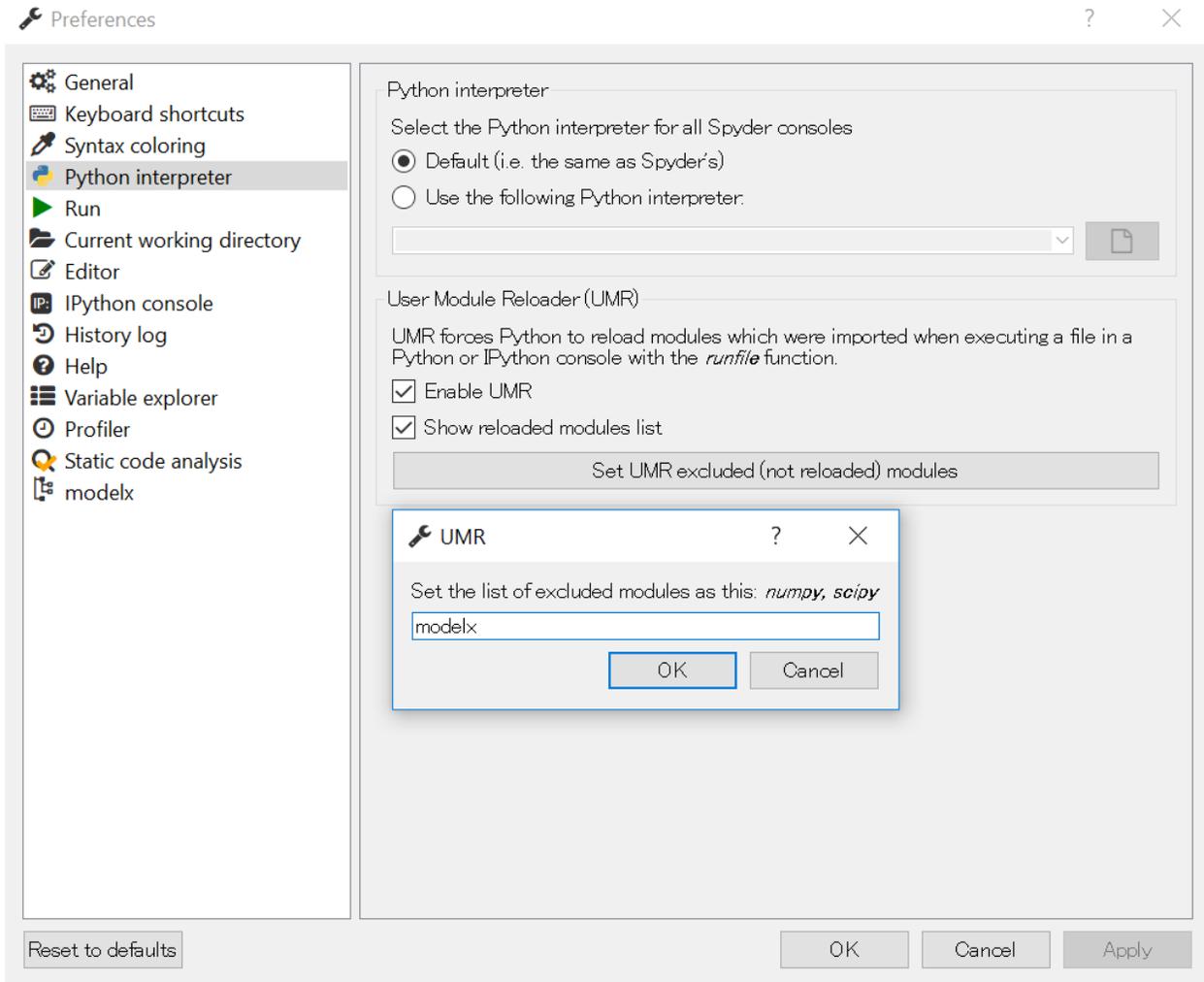


Fig. 1: User Module Reloader setting

### 10.3.2 Installing Spyder plugin for modelx

The plugin is available as a separate Python package named `spyder-modelx`.

The supported version of Spyder is 3.2.5 or newer. The plugin does not work with Spyder versions older than 3.2.5.

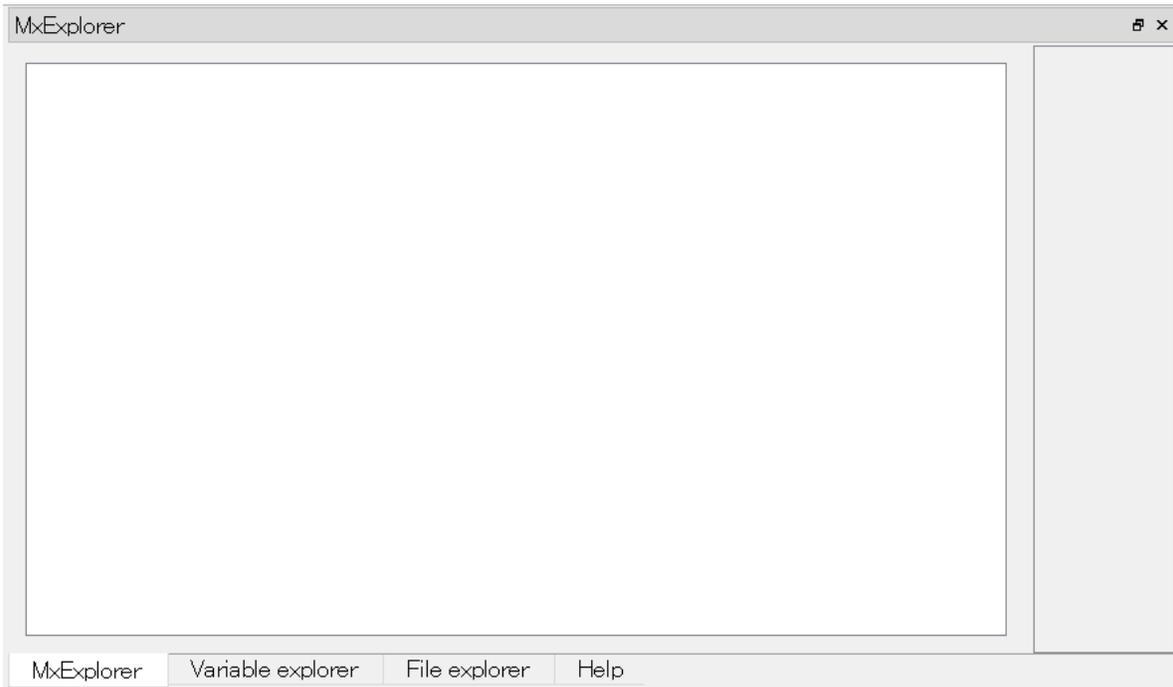
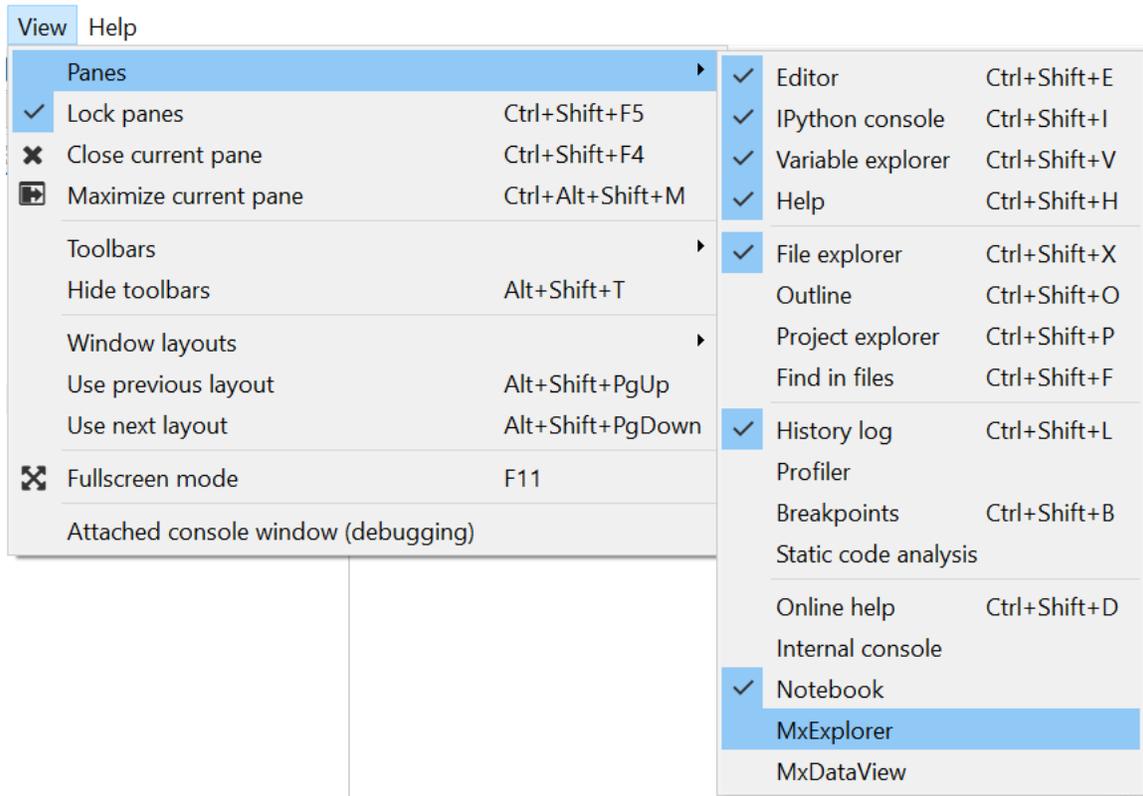
To install the plugin, run the following command in the command prompt:

```
$ pip install spyder-modelx
```

If Spyder is running while the plugin gets installed, close Spyder once and restart it to bring the plugin into effect.

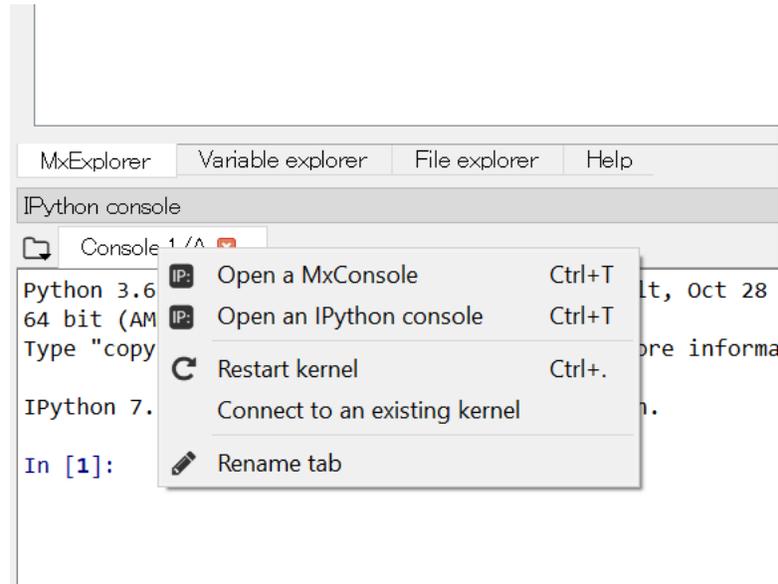
### 10.3.3 MxExplorer and MxConsole

To enable the modelx plugin, start Spyder, and go to *View->Panels* menu, and check *MxExplorer*.



Then the Modelx explorer tab appears in the upper right pane.

Right-click on the IPython console tab in the lower right pane, then click *Open a MxConsole* menu.



A modelx console named *MxConsole* starts. The modelx console works exactly the same as a regular IPython console, except that the modelx explorer shows the components of the current model in the IPython session of this console. To test the behaviour, create a new model and space in the modelx console like this:

```
>>> import modelx as mx
>>> model, space = mx.new_model(), mx.new_space()
>>> cells = space.new_cells()
```

The modelx explorer shows the component tree of the created space.

MxExplorer can also list the formulas of all cells in a selected space. To see the formulas in a space, select the space in the tree, right-click to bring up the context menu, and click *Show Formulas*. The list of the formulas appears to the right of the model tree in MxExplorer.

### 10.3.4 MxDataView

MxDataView widget lets you see a DataFrame object in a spreadsheet-like tabular format.

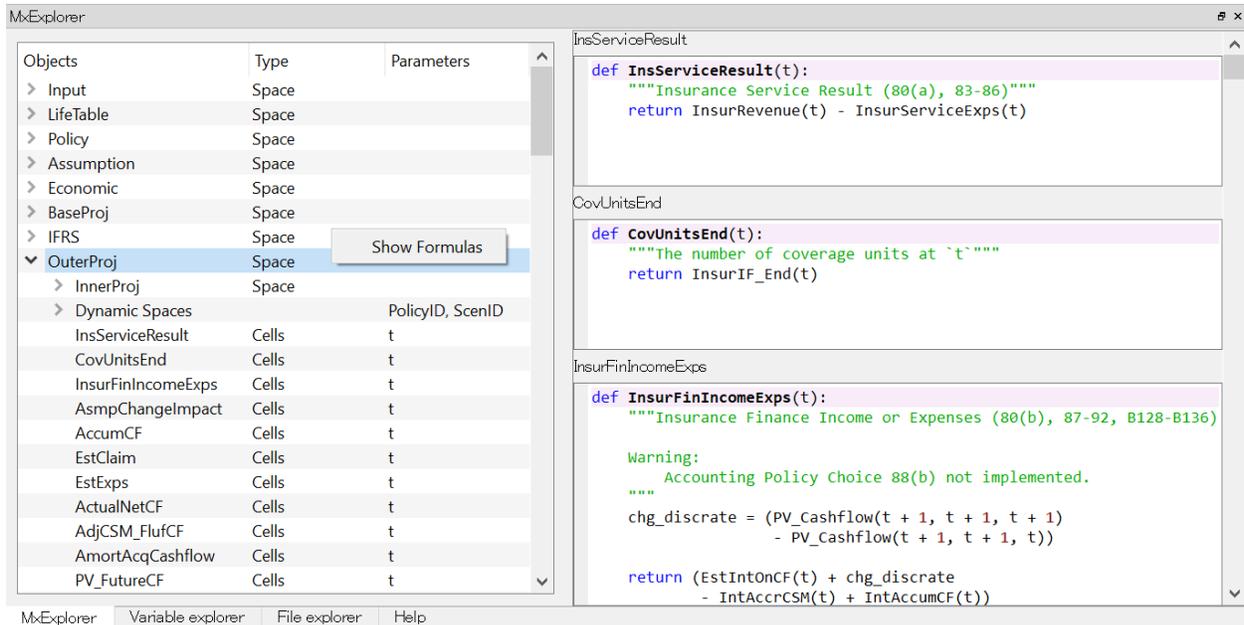
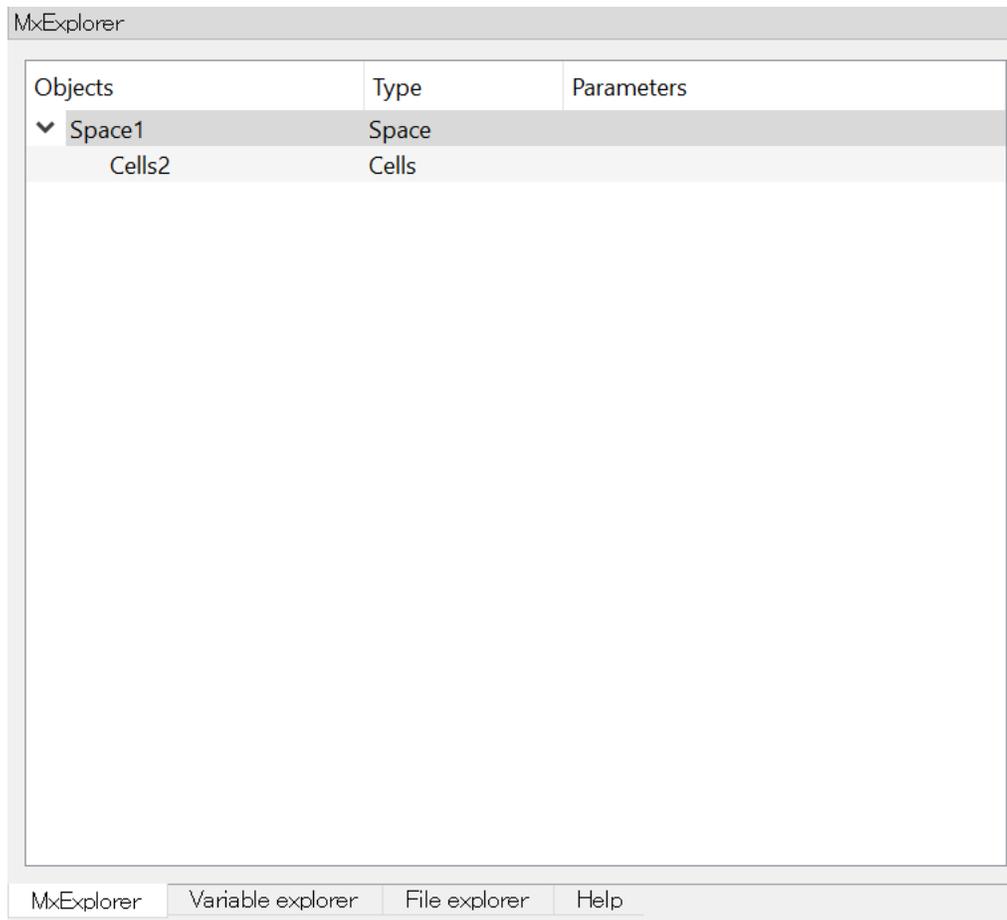
If MxDataView widget is not shown, Go to *View->Panels* menu as you did with MxExploer, and check *MxDataView*.

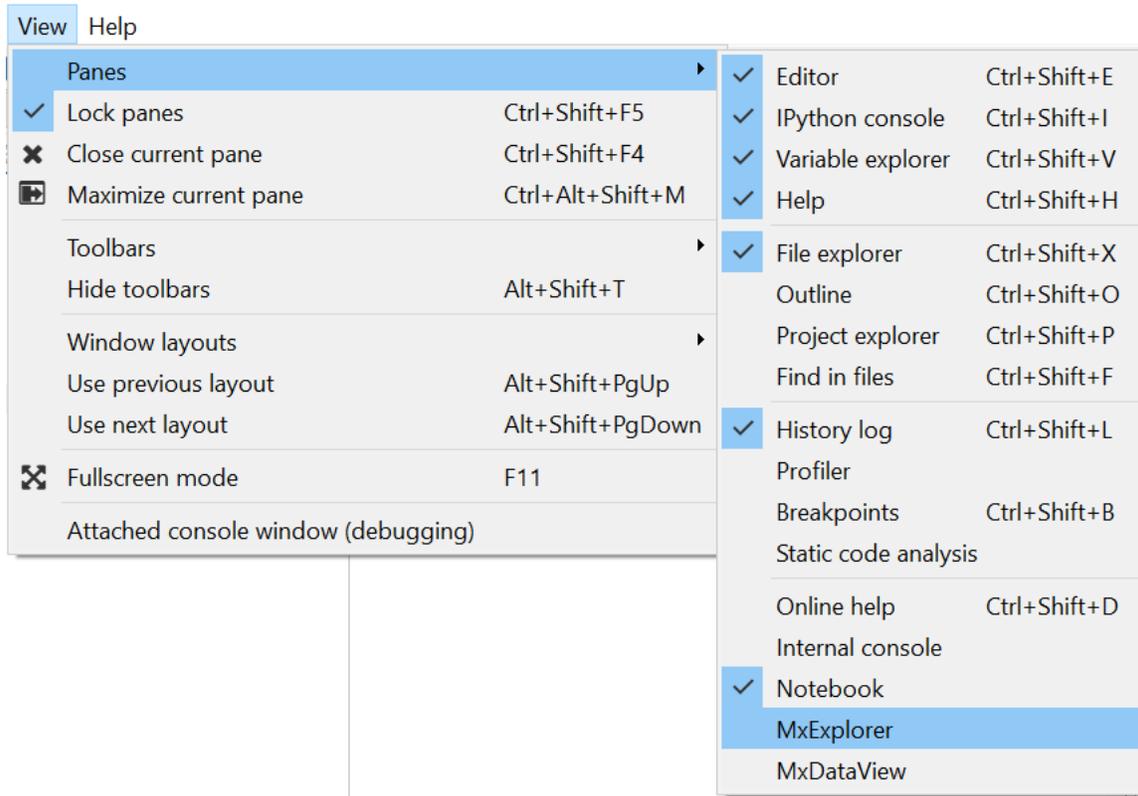
To specify a DataFrame object to display, enter a Python expression that returns the DataFrame object, in the text box labeled *Expression*. The Python expression is evaluated in the global namespace of the Python session in the active MxConsole. The expression is re-evaluated every time MxConsole execute a Python command.

### 10.3.5 MxAnalyzer

MxAnalyzer is used for checking calculation dependency.

If MxDataView widget is not shown, Go to *View->Panels* menu as you did with MxExploer, and check *MxAnalyzer*.

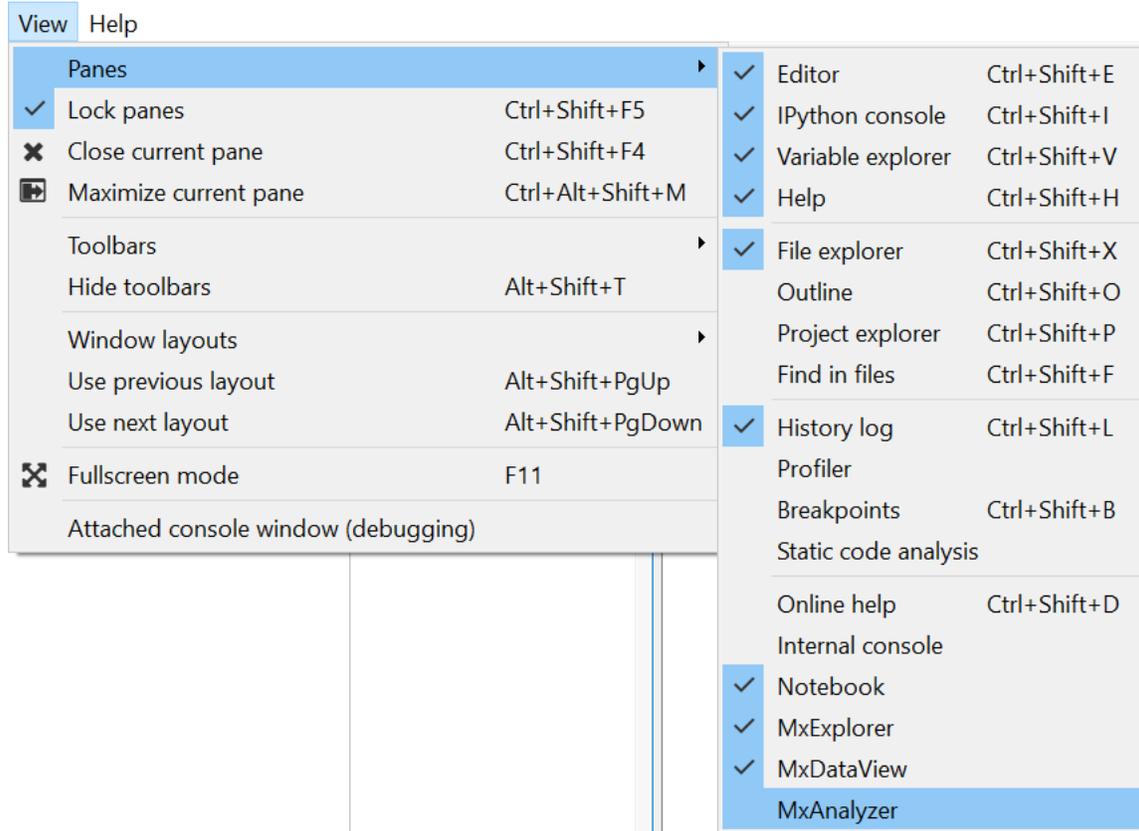




MxDataView

Expression: `ifrs.to_frame()`

t	InsurRevenue	InsurServiceExps	InsurFinIncomeExps	ProfitBefTax
0	2135.49	1027.91	-1.42109e-14	1107.58
1	2027.24	1008.86	-3.01981e-14	1018.38
2	1925.53	989.211	1.77636e-15	936.322
3	1813.68	952.841	7.99361e-15	860.839
4	1700.88	909.463	1.15463e-14	791.418



Enter an expression that returns a Cell object in the top-left box, and arguments to the Cell in the to-right box. The Python expression is evaluated in the global namespace of the Python session in the active MxConsole. Then MxAnalyzer shows a tree of Cell nodes directly or indirectly used in calculating the value of the specified node.

## 10.4 Tutorial

This tutorial aims to introduce core concepts and features of modelx, and demonstrate how to use modelx by going through some examples.

This tutorial supplements modelx reference, which is build from docstrings of the API functions and classes. The reference should cover the details of each API element, which may not be fully explained in this tutorial.

### 10.4.1 Typical workflow

modelx is a Python package, and you use it by writing a Python script and importing it, as you would normally do with any other Python package.

modelx is best suited for building complex numerical models composed of many formulas referencing each other, so when you start from scratch, the typical workflow would be to first write code for building a model, and then evaluate the model.

As we are going to see, it takes more than one line of code to build a model, so it's convenient to use a Python shell that allows you edit and execute a chunk of code at once for building a model, then get into an interactive mode for letting you examine the model one expression or statement at a time.

MxAnalyzer <span style="float: right;">x</span>					
Object	proj.PremIncome		Args	3	
Cells	Args	Value	Space	Model	
▼ PremIncome(t)		3	2777.94	OuterProj[1, 1]	ifrs17sim
▼ SizePremium(t)		3	3574.17	OuterProj[1, 1]	ifrs17sim
▼ SizeSumAssured(t)		3	1000000	OuterProj[1, 1]	ifrs17sim
SumAssured()			1000000	Input.PolicyData[1]	ifrs17sim
▼ GrossPremRate()			0.000297847	Policy[1]	ifrs17sim
> IntRate(RateBasis)		PREM	0.03	Policy[1]	ifrs17sim
> TableID(RateBasis)		PREM	3	Policy[1]	ifrs17sim
Sex()			M	Input.PolicyData[1]	ifrs17sim
Product()			TERM	Input.PolicyData[1]	ifrs17sim
IssueAge()			30	Input.PolicyData[1]	ifrs17sim
PolicyTerm()			15	Input.PolicyData[1]	ifrs17sim
> Axn(x, n, f)	30, 15, 0		0.0145718	LifeTable['M', 0.03, 3]	ifrs17sim
> LoadAcqSA()			0	Policy[1]	ifrs17sim
PremFreq()			12	Input.PolicyData[1]	ifrs17sim
> AnnDuenx(x, n, k, f)	30, 15, 12, 0		12.0468	LifeTable['M', 0.03, 3]	ifrs17sim
> LoadMaintSA()			0.002	Policy[1]	ifrs17sim
> AnnDuenx(x, n, k, f)	30, 0, 1, 15		0	LifeTable['M', 0.03, 3]	ifrs17sim
> LoadMaintSA2()			0	Policy[1]	ifrs17sim
> LoadMaintPrem()			0.1	Policy[1]	ifrs17sim
> LoadMaintPremWaiverP...			0.002	Policy[1]	ifrs17sim
PremFreq()			12	Input.PolicyData[1]	ifrs17sim
> PolsIF_Beg1(t)		3	0.777225	OuterProj[1, 1]	ifrs17sim

IDLE, the Tk/Tcl based simple Python GUI shell that comes with CPython lets you do that. You can open an editor window, and when the part of building a model is done, you can press F5 to save and run the script in a Python shell window where you are prompted to enter Python code to evaluate the model. Jupyter Notebook and many other popular Python shell environments have similar capability.

## 10.4.2 Model, Space and Cells

Before taking a look at the very first example, you might want to have an idea on what Model, Space and Cells are, as those three types of objects are central to modelx.

Model, Space and Cells are to modelx what workbook, worksheet and cells are to a spreadsheet program respectively, although there are differences. The diagram below illustrates containment relationships between those objects.

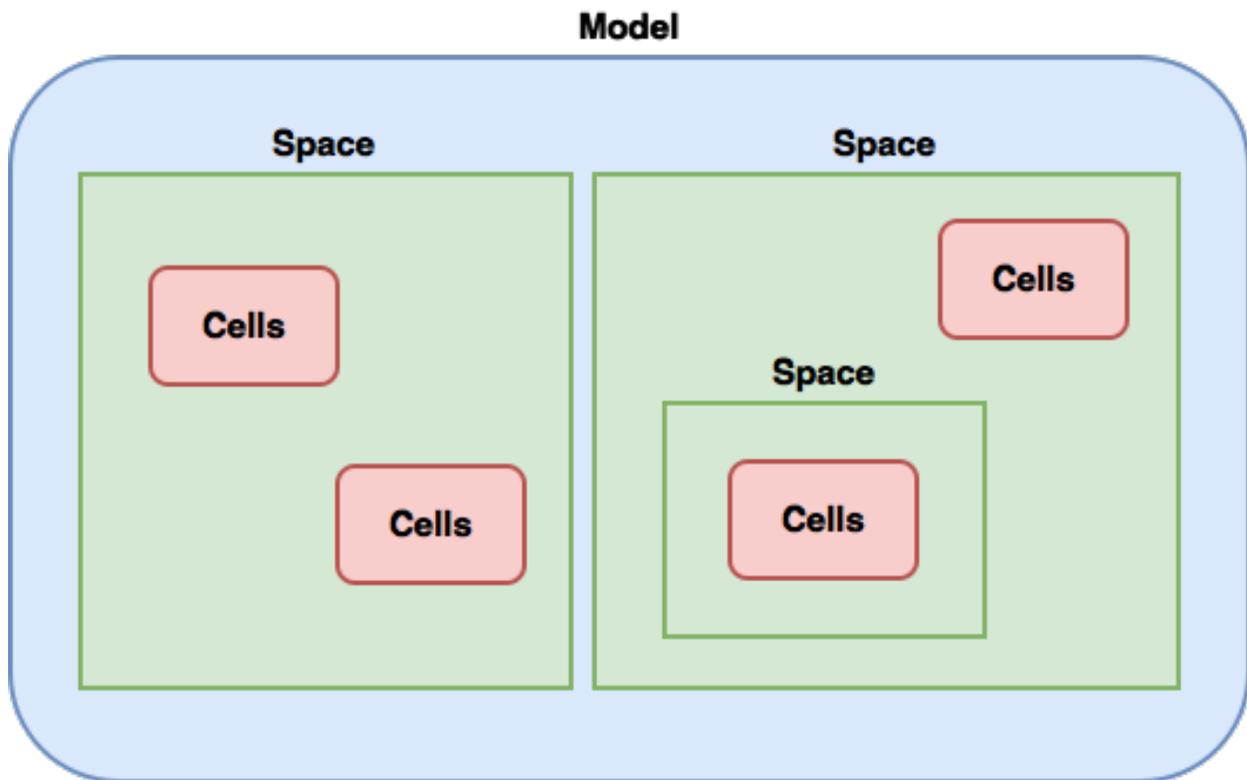


Fig. 2: Model, Space and Cells

A model is a workspace that contains all the modelx objects. It can be saved to a file and loaded again. A model contains spaces. In turn, spaces can contain cells and also other spaces (subspaces). Each cells ('cells' is singular here) belongs to one and only one space. We call the object that contains another object, the parent of the contained object. The parent of a cells is the space that contains the cells, and the parent of a space is the model or space that contains the space. Spaces also serves as the namespace for contained cells but we'll get to this later.

A Cells can have a formula that calculates the cells' values, just like spreadsheet cells can have formulas. Cells values are either calculated by the formula or assigned as an input. We will learn how to define cells formulas through the examples soon.

### 10.4.3 Basic Operation

In this section, we'll start learning how to perform basic operations, such as creating models, spaces and cells, by talking a closer look at the simple example we saw in the overview section.

```
from modelx import *

model, space = new_model(), new_space()

@defcells
def fibo(n):
    if n == 0 or n == 1:
        return n
    else:
        return fibo(n - 1) + fibo(n - 2)
```

#### Importing modelx

To start using modelx, import the package by the import statement, as is the case with any other package.

```
from modelx import *
```

By doing so, you get to use modelx API functions in `__main__` module. The entire list of modelx API functions are [Function Reference](#). If you're not comfortable with importing modelx API functions directly into the global namespace of `__main__` module, you can alternatively import modelx as an abbreviated name, such as `mx`, for example:

```
import modelx as mx
```

in which case you can use modelx API functions prepended with `mx..` We'll assume importing `*` in this tutorial, but be reminded that this is not a good practice when you write Python modules.

#### Creating a Model

The next statement performs two assignments in one line to make better use of horizontal space, but we'll decompose it into to the two assignment statements below for the sake of explanation:

```
model = new_model()
space = new_space()
```

In the first line, `new_model()` is a modelx API function that create a new model and returns it.

You can specify the name of the model by passing it as `name` argumet to the function, like `new_model(name='MyModel')`. If no name is given as the argument, the returned model is named automatically by modelx.

#### Creating a Space

```
space = new_space()
```

`new_space()`, in the line above creates a new space in the “current” model. In this case, the current model is set to the one we just created. modelx keeping track of the current model is somewhat analogous to how a spreadsheet program has “active” book.

Just as with the model, the name of the space can be specified by passing it to the method `name` argument, otherwise the space gets its name by modelx.

If you want to create a space in a model other than the current model, you can call `new_space()` method on the model, with or without the space name as its argument:

```
>>> space = model.new_space('MySpace')
```

## Getting Models

To get all existing models, you can use `get_models()` function, which returns a mapping of the names of all existing models to the model objects:

```
>>> get_models()
{'Model1': <Model Model1>}
```

To get the current model, use `cur_model()` without arguments.

## Getting Spaces

To get all spaces in a model mapped to their names, you can check `spaces` property of the model:

```
>>> model.spaces
mappingproxy({'Space1': <Space Space1 in Model1>})
```

The return `MappingProxy` objects acts like an immutable dictionary, so you can get `Space1` by `model.spaces['Space1']`. You can see the returned space is the same object as what is referred as `space`:

```
>>> space is model.spaces['Space1']
True
```

To get one space, its name is available as an attribute of the containing model:

```
>>> model.Space1
<Space Space1 in Model1>
```

You can get the current space of the current model by calling `cur_space()` without arguments.

## Creating Cells

There are a few ways to create a cells object and define the formula associated with the cells. As seen in the example above, one way is to define a python function with `defcells` decorator.

```
model, space = new_model(), new_space()

@defcells
def fibo(n):
    if n == 0 or n == 1:
        return n
    else:
        return fibo(n - 1) + fibo(n - 2)
```

By `defcells` decorator, the name `fibonacci` in this scope points to the `Cells` object that has just been created from the formula definition.

By this definition, the `cells` is created in the current space in the current model. `modelx` keeps the last operated model as the current model, and the last operated space for each model as the current space. `cur_model()` API function returns the current model, and `cur_space()` method of a model holds its current space.

To specify the space to create a `cells` in, you can pass the space object as an argument to the `defcells` decorator. Below is the same as the definition above, but explicitly specifies in what space to define the cell:

```
@defcells(space)
def fibonacci(n):
    if n == 0 or n == 1:
        return n
    else:
        return fibonacci(n - 1) + fibonacci(n - 2)
```

There are other ways to create `cells` by `defcells`. Refer to `defcells()` section in the reference manual for the details.

Another way to create a `cells` is to use `Space`'s `new_cells()` method. Note that the command below doesn't work in the current context as we've already defined `fibonacci`:

```
>> space.new_cells(formula=fibonacci)
```

The `func` parameter can either be a function object, or a string of function definition.

## Getting Cells

Similar to spaces in a model contained in the `spaces` property of the model, `cells` in a space are associated with their names and contained in the `cells` property of the model:

```
>>> fibonacci is space.cells['fibonacci']
True
```

As you can get a space in a model by attribute access with `.`, you can get a `cells` in a space by accessing the space attribute of the `cells` name with `.`:

```
>>> space.fibonacci
<Cells fibonacci(n) in Model1.Space1>
>>> fibonacci is space.fibonacci
True
```

## Getting Values

The `cells` `fibonacci` does not have values yet right after it is created. To get `cells`' value for a certain argument, simply call `fibonacci` with the parameter in parenthesis or in square brackets:

```
>>> fibonacci[10]
55
>>> fibonacci(10)
55
```

Its values are calculated automatically by the associated formula, when the `cells` values are requested. Note that values are calculated not only for the specified argument, but also for the arguments that recursively referenced by the formula

in order to get the value for the specified argument. To see for what arguments values are calculated, export `fibonacci` to a Pandas Series object. (You need to have Pandas installed, of course.):

```
>>> fibo[10]
55
>>> fibo.series
n
0      0
1      1
2      1
3      2
4      3
5      5
6      8
7     13
8     21
9     34
10    55
Name: fibo, dtype: int64
```

Since `fibo[10]` refers to `fibo[9]` and `fibo[8]`, `fibo[9]` refers to `fibo[8]` and `fibo[7]`, and the recursive reference goes on until it stops and `fibo[1]` and `fibo[0]`, values of `fibo` for argument 0 to 10 are calculated by just calling `fibo[10]`.

**Note:** It is important to understand in what namespace cells formulas are executed. Unlike Python functions, the global namespace of a cells formula has nothing to do with where in the source files the formula is defined. The names in the formula are resolved in the namespace associated with the cells' parent space. In that namespace, available names are cells contained in the space, spaces contained in the space (i.e. the subspaces of the space) and "references" accessible in the space.

## Clearing Values

To clear cells values, you can use `clear()` method. Below shows what happens when the value of `fibo` at `n = 5` is cleared:

```
>>> fibo.clear(5)
>>> fibo.series
n
0      0
1      1
2      1
3      2
4      3
Name: fibo, dtype: int64
```

As you can see, not only at `n = 5`, but also for `n = 6` to 10 values of `fibo` are cleared. This is because the calculations of `fibo[6]` to `fibo[10]` depend on the value of `fibo[5]`. Dependent values are cleared all together with the specified value.

To clear all values, simply call `clear()` without arguments:

```
>>> fibo.clear()
>>> fibo.series
Series([], Name: fibo, dtype: float64)
```

## Setting Values

Other than letting the formula calculate cells values, you can input cells values manually by the set item (`[] =`) operation. If the cells already has a value at the specified parameter value, then the values of dependent cells are cleared first, then the specified value is assigned:

```
>>> fibo[10]
55
>>> fibo.series
n
0      0
1      1
2      1
3      2
4      3
5      5
6      8
7     13
8     21
9     34
10    55
Name: fibo, dtype: int64

>>> fibo[5] = 0
>>> fibo.series
n
0      0
1      1
2      1
3      2
4      3
5      0
Name: fibo, dtype: int64
```

## 10.4.4 Advanced Concepts

In this section, more concepts we haven't yet covered are introduced. Some of them are demonstrated by examples in the following section.

### Space Members

Spaces can contain cells and other spaces. In fact, spaces have 3 kinds of their “members”. You can get those members as if they are attributes of the containing spaces, by attribute access (`.`) expression.

**Cells** As we have seen in the previous example, spaces contain cells, and the cells belong to spaces. One cells must belong to one and only one space.

The `cells` property of Space returns a dictionary of all the cells associated with their names.

**(Sub)spaces** As previously mentioned, spaces can be created in another space. Spaces in another space are called subspaces of the containing space. There 2 kinds of subspaces, static subspaces and dynamic subspace.

Static subspaces are those that are created manually, just like those created in models. There is no difference between spaces created directly under a model and static spaces created under a space, except for their parents being different types.

You can create a static subspace by calling `new_space` method of their parents:

```

model, space = new_model(), new_space()

space.new_space('Subspace1')

@defcells
def foo():
    return 123

```

You can get a subspace as an attribute of the parent space, or by accessing the parent space's `spaces` property:

```

>>> space.spaces['Subspace1'].foo()
123

>>> space.Subspace1.foo()
123

```

The other kind of subspaces, is dynamic subspaces. Unlike static subspaces, dynamic subspaces can only be created in spaces, but not directly in models.

Dynamic spaces are parametrized spaces that are created on-the-fly when requested through `call()` or `subscript([])` operation on their parent spaces. We'll explore more on dynamic spaces in the next section, in conjunction with space inheritance by going through an example.

**References** Often times you want access from cells formulas in a space to other objects than cells or subspaces in the same space. References are names bound to arbitrary objects that are accessible from within the same space:

```

model, space = new_model(), new_space()

@defcells
def bar():
    return 2 * n

```

`bar` cells above refers to `n`, which has not yet been defined. Without `n` being defined, calling `bar` will raise an error. To define a reference `n`, you can simply assign a value to `n` attribute of `space`:

```

>>> space.n = 3
>>> bar()
6

```

The `refs` property of space returns a mapping of reference names to their objects:

```

>>> list(space.refs.keys())
['__builtins__', 'n', '_self']

```

By default, `__builtins__` and `_self` are defined in any space. In fact, `__builtins__` is defined by default as a “global” reference in the model. Global references are names accessible from any space in a model. Other than the default reference, you can define your own, by simply assigning a value as an attribute of the model:

```

>>> model.z = 4
>>> list(model.refs.keys())
['z', '__builtins__']

>>> list(space.refs.keys())
['z', '__builtins__', 'n', '_self']

```

`__builtins__` points to Python builtin module. It is defined to allow cells formulas to use builtin functions. `_self` points to the space itself. This allows cells formulas to get access to its parent space.

As mentioned earlier, formulas of cells are evaluated in the namespace that is associated with their parent spaces.

The namespace of a space is a mapping of names to the space members. As explained in the previous section, space members are either cells of the space, or subspaces of the space or references accessible from the space.

The table below breaks down all the members in the namespace by its types and sub-types.

cells	self cells	Cells defined in or overridden in the space
	derived cells	Cells inherited from one of the base spaces
spaces	self spaces	Subspace defined in or overridden in the space
	derived spaces	Subspace inherited from one of the base spaces
references (refs)	self references	References defined in or overridden in the space
	derived references	References inherited from one of the base spaces
	global references	Global references defined in the parent model
	local references	Only <code>_self</code> that refers to the space itself
	parameters	(Only in dynamic spaces) Space parameters

Each type of the members has “self” members and “derived” members. Those distinctions stem from space inheritance explained in the next section.

## Space Inheritance

Space inheritance is a concept analogous to class inheritance in object-oriented programming languages. By making full use of space inheritance, you can organize multiple spaces sharing similar features into an inheritance tree of spaces, minimizing duplicated formula definitions, keeping your model organized and transparent while maintaining model integrity.

Inheritance lets one space use (inherit) other spaces, as base spaces. The inheriting space is called a derived space of the base spaces. The cells in the base spaces are copied automatically in the derived space. In the derived space, formulas of cells from base spaces can be overridden. You can also add cells to the derived space, that do not exist in any of the base spaces.

A space can have multiple base spaces. This is called multiple inheritance. The base spaces can have their base spaces, and derived-base relationships between spaces make up a directional graph of dependency. In case of multiple inheritance, we need a way to order base spaces to determine the priority of base spaces. `modelx` uses the same algorithm as Python for ordering bases, which is, C3 superclass linearization algorithm (a.k.a C3 Method Resolution Order or MRO). The links below are provided in case you want to know more about C3 MRO.

- [https://en.wikipedia.org/wiki/C3\\_linearization](https://en.wikipedia.org/wiki/C3_linearization)
- <https://www.python.org/download/releases/2.3/mro/>

### 10.4.5 More complex example

Let’s see how inheritance works by a simple code of pricing life insurance policies. First, we are going to create a very simple life model as a space and name it `Life`. Then we’ll populate the space with cells that calculate the number of death and remaining lives by age.

Then to price a term life policy, we will derive a `TermLife` space from the `Life` space, and add some cells to calculate death benefits paid to the insured, and their present value.

Next, we want to model an endowment policy. Since the endowment policy pays out a maturity benefit in addition to the death benefits covered by the term life policy, we derive a `Endowment` space from `TermLife`, and make a residual change to the `benefits` formula.

## Creating the Life space

Below is a mathematical representation of the life model we'll build as a `Life` space.

$$l(x) = l(x - 1) - d(x - 1)$$

$$d(x) = l(x) * q$$

where,  $l(x)$  denotes the number of lives at age  $x$ ,  $d(x)$  denotes the number of death occurring between the age  $x$  and age  $x + 1$ ,  $q$  denotes the annual mortality rate (for simplicity, we'll assume a constant mortality rate of 0.003 for all ages for the moment.) One letter names like  $l$ ,  $d$ ,  $q$  would be too short for real world practices, but we use them here just for simplicity, as they often appear in classic actuarial textbooks. Yet another simplification is, we set the starting age of  $x$  at 50, just to get output shorter. As long as we use a constant mortality age, it shouldn't affect the results whether the starting age is 0 or 50. Below the modelx code for this life model:

```
model, life = new_model(), new_space('Life')

def l(x):
    if x == x0:
        return 100000
    else:
        return l(x - 1) - d(x - 1)

def d(x):
    return l(x) * q

def q():
    return 0.003

l, d, q = defcells(l, d, q)
life.x0 = 50
```

The second to last line of the code above has the same effect as putting `@defcells` decorator on top of each of the 3 function definitions. This line creates 3 new cells from the 3 functions in the `Life` space, and rebind names `l`, `d`, `q` to the 3 cells in the current scope.

You must have noticed that  $l(x)$  formula is referring to the name `x0`, which is not defined yet. The last line is for defining `x0` as the issue age in the `Life` model and assigning a value to it.

To examine the space, we can check values of the cells in `Life` as below:

```
>>> l(60)
97040.17769489168

>>> life.frame
           l           d           q
x
50.0  100000.000000  300.000000  NaN
51.0   99700.000000  299.100000  NaN
52.0   99400.900000  298.202700  NaN
53.0   99102.697300  297.308092  NaN
54.0   98805.389208  296.416168  NaN
55.0   98508.973040  295.526919  NaN
56.0   98213.446121  294.640338  NaN
57.0   97918.805783  293.756417  NaN
58.0   97625.049366  292.875148  NaN
59.0   97332.174218  291.996523  NaN
60.0   97040.177695         NaN  NaN
NaN          NaN          NaN  0.003
```

## Deriving the Term Life space

Next, we'll see how we can extend this space to represent a term life policy. To simplify things, here we focus on one policy with the sum assured of 1 (in whatever unit of currency). With this assumption, if we define `benefits(x)` as the expected value at issue of benefits paid between the age  $x$  and  $x + 1$ , then it should equate to the probability of death between age  $x$  and  $x + 1$ , of the insured at the point of issue. In a math expression, this should be written:

$$benefits(x) = d(x)/l(x_0)$$

where  $l(x)$  and  $d(x)$  are the same definition from the preceding example, and  $x_0$  denotes the issue age of the policy. And further we define the present value of benefits at age  $x$  as:

$$pv\_benefits(x) = \sum_{x'=x}^{x_0+n} benefits(x') / (1 + disc\_rate)^{x'-x}$$

$n$  denotes the policy term in years, and `disc_rate` denotes the discounting rate for the present value calculation.

Continued from the previous code, we are going to derive the `TermLife` space from the `Life` space, to add the benefits and present value calculations.

```
term_life = model.new_space(name='TermLife', bases=life)

@defcells
def benefits(x):
    if x < x0 + n:
        return d(x) / l(x0)
    if x <= x0 + n:
        return 0

@defcells
def pv_benefits(x):
    if x < x0:
        return 0
    elif x <= x0 + n:
        return benefits(x) + pv_benefits(x + 1) / (1 + disc_rate)
    else:
        return 0
```

The first line in the sample above creates `TermLife` space derived from the `Life` space, by passing the `Life` space as `bases` parameter to the `new_space` method of the model. The `TermLife` space at this point has the same cells as its sole base space `Life` space.

The following 2 cells definitions (2 function definitions with `defcells` decorators), are for adding the cells that did not exist in `Life` space. The formulas are referring to the names that are not defined yet. Those are `n`, `disc_rate`. We need to define those in the `TermLife` space. The reference `x0` is inherited from the `Life` space.

```
term_life.n = 10
term_life.disc_rate = 0
```

You get the following results by examining the `TermLife` space (The order of the columns in the `DataFrame` may be different on your screen):

```
>>> term_life.pv_benefits(50)
0.02959822305108317

>>> term_life.frame
```

(continues on next page)

(continued from previous page)

	d	q	l	pv_benefits	benefits
x					
50.0	300.000000	NaN	100000.000000	0.029598	0.003000
51.0	299.100000	NaN	99700.000000	0.026598	0.002991
52.0	298.202700	NaN	99400.900000	0.023607	0.002982
53.0	297.308092	NaN	99102.697300	0.020625	0.002973
54.0	296.416168	NaN	98805.389208	0.017652	0.002964
55.0	295.526919	NaN	98508.973040	0.014688	0.002955
56.0	294.640338	NaN	98213.446121	0.011733	0.002946
57.0	293.756417	NaN	97918.805783	0.008786	0.002938
58.0	292.875148	NaN	97625.049366	0.005849	0.002929
59.0	291.996523	NaN	97332.174218	0.002920	0.002920
60.0	NaN	NaN	NaN	0.000000	0.000000
61.0	NaN	NaN	NaN	0.000000	NaN
NaN	NaN	0.003	NaN	NaN	NaN

You can see that the values of `l`, `d`, `q` cells are the same as those in `Life` space, as `Life` and `LifeTerm` have exactly the same formulas for those cells, but be aware that those cells are not shared between the base and derived spaces. Unlike class inheritance in OOP languages, space inheritance is in terms of space instances(or objects), not classes, so cells are copied from the base spaces to derived space upon creating the derived space.

### Deriving the Endowment space

We're going to create another space to test overriding inherited cells. We will derive `Endowment` space from `LifeTerm` space. The diagram below shows the relationships of the 3 spaces considered here. A space from which an arrow originates is derived from the space the arrow points to.

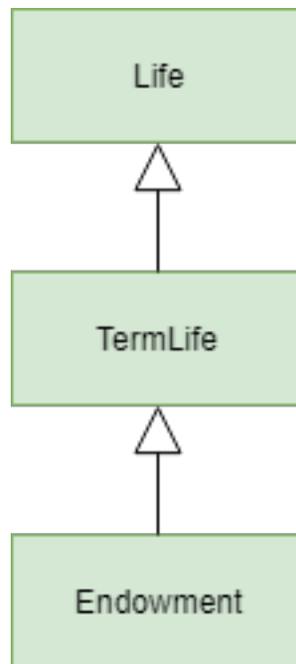


Fig. 3: Life, TermLife and Endowment

The endowment policy pays out the maturity benefit of 1 at the end of its policy term. We have defined `benefits` cells as the expected value of benefits, so in addition to the death benefits considered in `LifeTerm` space, we'll add the maturity benefit by overriding the `benefits` definition in `Endowment` space. In reality, the insured will not get

both death and maturity benefits, but here we are considering an probabilistic model, so the benefits would be the sum of expected value of death and maturity benefits:

```

endowment = model.new_space(name='Endowment', bases=term_life)

@defcells
def benefits(x):
    if x < x0 + n:
        return d(x) / l(x0)
    elif x == x0 + n:
        return l(x) / l(x0)
    else:
        return 0
    
```

And the same operations on the Endowment space produces the following results:

```

>>> endowment.pv_benefits(50)
1.0
>>> endowment.frame
    pv_benefits  benefits          l      q      d
x
50.0      1.000000  0.003000  100000.000000  NaN  300.000000
51.0      0.997000  0.002991  99700.000000  NaN  299.100000
52.0      0.994009  0.002982  99400.900000  NaN  298.202700
53.0      0.991027  0.002973  99102.697300  NaN  297.308092
54.0      0.988054  0.002964  98805.389208  NaN  296.416168
55.0      0.985090  0.002955  98508.973040  NaN  295.526919
56.0      0.982134  0.002946  98213.446121  NaN  294.640338
57.0      0.979188  0.002938  97918.805783  NaN  293.756417
58.0      0.976250  0.002929  97625.049366  NaN  292.875148
59.0      0.973322  0.002920  97332.174218  NaN  291.996523
60.0      0.970402  0.970402  97040.177695  NaN      NaN
61.0      0.000000      NaN      NaN      NaN      NaN
NaN      NaN      NaN      NaN  0.003      NaN
    
```

You can see `pv_benefits` for all ages and `benefits` for age 60 show values different from `TermLife` as we overrode `benefits`.

`pv_benefits(50)` being 1 is not surprising. The `disc_rate` set to 1 in `TermLife` space is also inherited to the `Endowment` space. The discounting rate of benefits being 1 means by taking the present value of the benefits, we are simply taking the sum of all expected values of future benefits, which must equate to 1, because the insured gets 1 by 100% chance.

## Dynamic spaces

In many situations, you want to apply a set of calculations in a space, or a tree of spaces, to different data sets. You can achieve that by applying the space inheritance on dynamic spaces.

Dynamic spaces are parametrized spaces that are created on-the-fly when requested through `call()` or `subscript()` operation on their parent spaces.

To define dynamic spaces in a parent space, you create the space with a parameter function whose signature is used to define space parameters. The parameter function should return, if any, a mapping of parameter names to their arguments, to be pass on to the `new_space` method, when the dynamic spaces are created.

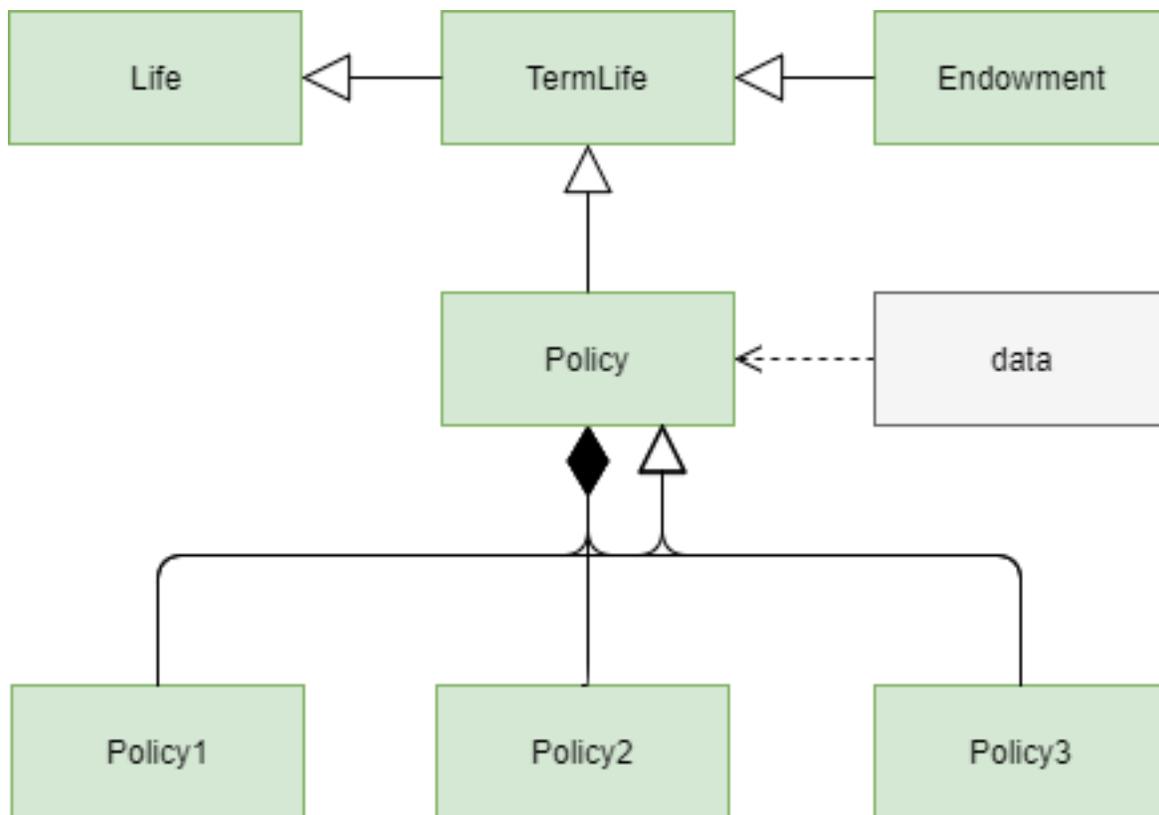
To see how this works, let's continue with the previous example. In the last example, we manually set the issue age `x0` of the policy to 50, and the policy term `n` to 10. We'll extend this example and create policies as dynamic spaces with with different policy attributes. Assume we have 3 term life polices with the following attributes:

Policy ID	Issue Age	Policy Term
1	50	10
2	60	15
3	70	5

We'll create this sample data as a nested list:

```
data = [[1, 50, 10], [2, 60, 15], [3, 70, 5]]
```

The diagram shows the design of the model we are going to create. The lines with a filled diamond shape on one end indicates that `Policy` model is the parent space of the 3 dynamic spaces, `Policy1`, `Policy2`, `Policy3`, each of which represents each of the 3 policies above. While `Policy` is the parent space of the 3 dynamic space, it is also the base space of them. `Policy` space inherits its members from `Term` model, and in turn `Policy` is inherited by the 3 dynamic spaces. This inheritance is represented by the unfilled arrowhead next the filled diamond.



Below is a script to extend the model as we designed above.

```
def params(policy_id):
    return {'name': 'Policy%s' % policy_id,
           'bases': _self}

policy = model.new_space(name='Policy', bases=term_life, formula=params)

policy.data = data

@defcells
def x0():
```

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(continued from previous page)

```

    return data[policy_id - 1][1]

@defcells
def n():
    return data[policy_id - 1][2]

```

The `params` function is passed to the constructor of the `Policy` space as the argument of `formula` parameter. The signature of `params` func is used to determine the parameter of the dynamic spaces, and the returned dictionary is passed to the `new_space` as arguments when the dynamic spaces are created. `params` is called when you create the dynamic subspaces of `Policy`, by calling the `n`-th element of `Policy`. `params` is evaluated in the `Policy`'s namespace. `_self` is a spacial reference that points to `Policy`.

The parameter `policy_id` becomes available within the namespace of each dynamic space.

In each of the dynamic spaces, the values of `x0` and `n` are taken from `data` for each policy:

```

>>> policy(1).pv_benefits(50)
0.02959822305108317

>>> policy(2).pv_benefits(60)
0.04406717516109439

>>> policy(3).pv_benefits(70)
0.014910269595243001

>>> policy(3).frame
      n      x0      d  benefits      l  pv_benefits      q
x
NaN   5.0  70.0      NaN      NaN      NaN      NaN  0.003
70.0 NaN   NaN  300.000000  0.003000  100000.000000  0.014910  NaN
71.0 NaN   NaN  299.100000  0.002991   99700.000000  0.011910  NaN
72.0 NaN   NaN  298.202700  0.002982   99400.900000  0.008919  NaN
73.0 NaN   NaN  297.308092  0.002973   99102.697300  0.005937  NaN
74.0 NaN   NaN  296.416168  0.002964   98805.389208  0.002964  NaN
75.0 NaN   NaN      NaN  0.000000      NaN  0.000000  NaN
76.0 NaN   NaN      NaN      NaN      NaN  0.000000  NaN

>>> policy.spaces
{'Policy1': <Space Policy[1] in Model1>,
 'Policy2': <Space Policy[2] in Model1>,
 'Policy3': <Space Policy[3] in Model1>}

```

Dynamic spaces of a base space are not passed on to the derived spaces. When a space is derived from a base space that has dynamically created subspaces, those dynamically created subspaces themselves are not passed on to the derived spaces. Instead, the parameter function of the base space is inherited, so subspaces of the derived space are created upon call(using `()`) or subscript (using `[]`) operators the derived space with arguments.

### 10.4.6 Reading Excel files

You can read data stored in an Excel file into newly created cells. `Space` has two methods `new_cells_from_excel` and `new_space_from_excel`. `new_space_from_excel` is also available on `Model`. You need to have `Openpyxl` package available in your Python environment to use these methods.

`new_cells_from_excel` method reads values from a range in an Excel file, creates cells and populates them with the values in the range.

`new_space_from_excel` methods reads values from a range in an Excel file, creates a space, and in that space, creates dynamic spaces using one or some of the index rows and/or columns as space parameters, and creates cells in the dynamics spaces populating them with the values in the range.

Refer to the modelx reference for concrete description of those methods.

### 10.4.7 Exporting to Pandas objects

If you have Pandas installed in your Python environment, you can export values of cells to Pandas' DataFrame or Series objects. Spaces have `frame` property, which generates a DataFrame object whose columns are cells names, and whose indexes are cells parameters. Multiple cells in a space may have different sets of parameters. Generated

## 10.5 modelx Concepts

**modelx** embodies software engineering concepts in Object-oriented programming (OOP) paradigm, such as composition and inheritance. However, modelx is not a programming language, rather it is a system of objects. So, some of the OOP terminologies are redefined for the purpose of describing modelx specifications below, although there is strong resemblance. In reading the specifications, readers should be aware that the meanings of the terms in modelx may differ from those in the context of OOP.

### 10.5.1 Core modelx Types

Model, Space, and Cells are the core modelx types exposed to users for manipulation. Models are the top level objects that contain spaces. Spaces can contain other spaces, so a tree of spaces originating a model can be formed in the model. See '[Space Composition](#)' section for more details.

Spaces are intermediate objects that come between models and cells in the object composition hierarchy of modelx. Spaces can contain cells, other spaces and references.

A cells can have a formula that calculates the cells' values, just like spreadsheet cells can have formulas. Cells values can be either calculated by the formula or assigned as input.

### 10.5.2 Space Composition

#### *Parent and Child spaces*

As mentioned above, spaces can contain other spaces. A space that contains other spaces is called the *parent* space of the other spaces, and the other spaces are called *child* spaces of the parent space.

By recursively creating child spaces in another space's child spaces, you can create a tree of spaces. A tree of spaces originating a space are called *descendant* spaces of the space. In turn *ascendant* spaces of a space are those that have the space as their descendant space.

Child spaces can not 'outlive' their parent space. In other words, a parent space owns its child spaces i.e. when the parent space is deleted, its child spaces, if there are any, are deleted too.

---

**Note:** In OOP contexts, the terms 'parent' and 'child' are sometimes used interchangeably with 'base' and 'sub' respectively. The readers should be aware that here in this reference for modelx, we use the terms 'parent' and 'child' in composition contexts exclusively, and the terms 'sub' and 'base' exclusively in inheritance contexts.

---

### 10.5.3 Space Inheritance

#### *Base and Sub spaces*

If a space inherits other spaces, the inherited spaces are called *base* spaces of the inheriting space, and the inheriting space is called a *sub* space of the inherited spaces. Multiple inheritance is allowed, i.e. a space can have more than one base spaces.

Since a space that inherits base spaces can in turn be the base space of other spaces, you can create a directional graph of the inheritance relationship. We use the term base spaces of a space to mean not just those spaces that are directly inherited by the space, but also those that are inherited indirectly, through chains of inheritance. In turn, if a space is a base space of another space, then the other space is a sub space of the space either directly or indirectly.

When a space inherits another space that has descendant spaces, descendant spaces are created in the sub space. The descendant spaces in the sub space compose the same tree hierarchy as that in the base space. Each descendant space in the sub space inherits the corresponding space in the space tree of the base space.

A space cannot inherit its descendant spaces. Later in this document, the distinction between static and dynamic spaces is introduced. Static spaces cannot be inherited by their descendant spaces, as that would form circular inheritance. Dynamic spaces can be inherited by their descendant spaces.

---

**Note:** The space inheritance concept explained above is analogous to that in OOP. However, the term ‘derived’ has a special meaning in modelx context. In OOP contexts, ‘a class deriving another class’ is synonymous with ‘the other class inheriting the class’.

---

### 10.5.4 Defined and Derived spaces

If a space inherits another space, the child spaces, cells and refs of the base space are derived in the sub space. Furthermore, the descendant spaces and their members of the descendant spaces are derived. The derived spaces have the original corresponding spaces in the base space as their base spaces.

Every static space is either a defined space or a derived space.

### 10.5.5 Overriding members

Derived cells and refs are overridden when new cells and refs are defined with the same name as the derived cells and refs.

Derived spaces cannot be overridden, however, members of derived spaces can be added or overridden. When members of a derived space are added or overridden, the derived space and its derived ascendant spaces become defined.

Spaces that are directly contained in a model, i.e. spaces that are not child spaces of any other spaces, are always defined spaces.

### 10.5.6 Static and Dynamic spaces

Every space is either a static space or a dynamic space.

Static spaces are those that are created explicitly by calling their parents’ methods, or automatically by the space inheritance mechanism. Spaces that are directly contained in a model, i.e. spaces that are not child spaces of any other spaces, are always static spaces. Since they are always defined, they are always defined and static spaces.

Dynamic spaces, a.k.a parametrized spaces, are those that are created upon the first call or subscription operations on their parent spaces. Such parent spaces must have associated formulas that define parameters of the dynamic spaces and return arguments to be passed to the dynamic spaces for their initialization.

Dynamic spaces can have child spaces just like static spaces, either by calling their methods, or automatically by inheriting base spaces. A dynamic space and its descendants are collectively called a dynamic space tree.

A dynamic space can also have dynamic spaces in its dynamic space tree.

Spaces that are in dynamic space trees cannot be base spaces of other spaces.

Dynamic spaces are not inherited, i.e. if a static ascendant space of dynamic spaces are inherited, no derived spaces in the sub space are created, that correspond to the dynamic spaces in the base space.

## 10.6 Reference

### 10.6.1 Function Reference

<code>new_model([name])</code>	Create and return a new model.
<code>new_space([name, bases, formula])</code>	Create and return a new space in the current model.
<code>defcells([space, name])</code>	Decorator/function to create cells from Python functions.
<code>get_models()</code>	Returns a dict that maps model names to models.
<code>get_object(name)</code>	Get a modelx object from its full name.
<code>cur_model([model])</code>	Get and/or set the current model.
<code>cur_space([space])</code>	Get and/or set the current space of the current model.
<code>open_model(path[, name])</code>	Load a model saved from a file and return it.
<code>setup_ipython()</code>	Set up IPython shell for modelx.
<code>restore_ipython()</code>	Restore IPython' default error message.
<code>set_recursion([maxdepth])</code>	Set formula recursion limit.

#### modelx.new\_model

`modelx.new_model` (*name=None*)

Create and return a new model.

The current model is set set to the created model.

**Parameters** *name* (*str*, optional) – The name of the model to create. Defaults to `ModelN`, with `N` being an automatically assigned integer.

**Returns** The new model.

#### modelx.new\_space

`modelx.new_space` (*name=None, bases=None, formula=None*)

Create and return a new space in the current model.

The `currentspace` of the current model is set to the created model.

**Parameters** *name* (*str*, optional) – The name of the space to create. Defaults to `SpaceN`, with `N` being an automatically assigned integer.

**Returns** The new space.

## modelx.defcells

modelx.**defcells** (*space=None, name=None, \*funcs*)

Decorator/function to create cells from Python functions.

Convenience decorator/function to create new cells directly from function definitions or function objects substituting for calling *new\_cells* method of the parent space.

There are 3 ways to use *defcells* to define cells from functions.

### 1. As a decorator without arguments

To create a cells from a function definition in the current space of the current model with the same name as the function's:

```
@defcells
def foo(x):
    return x
```

### 2. As a decorator with arguments

To create a cells from a function definition in a given space and/or with a given name:

```
@defcells(space=space, name=name)
def foo(x):
    return x
```

### 3. As a function

To create a multiple cells from a multiple function definitions:

```
def foo(x):
    return x

def bar(y):
    return foo(y)

foo, bar = defcells(foo, bar)
```

#### Parameters

- **space** (*optional*) – For the 2nd usage, a space to create the cells in. Defaults to the current space of the current model.
- **name** (*optional*) – For the 2nd usage, a name of the created cells. Defaults to the function name.
- **\*funcs** – For the 3rd usage, function objects. (*space* and *name* also take function objects for the 3rd usage.)

**Returns** For the 1st and 2nd usage, the newly created single cells is returned. For the 3rd usage, a list of newly created cells are returned.

## modelx.get\_models

modelx.**get\_models** ()

Returns a dict that maps model names to models.

### modelx.get\_object

`modelx.get_object` (*name: str*)

Get a modelx object from its full name.

### modelx.cur\_model

`modelx.cur_model` (*model=None*)

Get and/or set the current model.

If `model` is given, set the current model to `model` and return it. `model` can be the name of a model object, or a model object itself. If `model` is not given, the current model is returned.

### modelx.cur\_space

`modelx.cur_space` (*space=None*)

Get and/or set the current space of the current model.

If `name` is given, the current space of the current model is set to `name` and return it. If `name` is not given, the current space of the current model is returned.

### modelx.open\_model

`modelx.open_model` (*path, name=None*)

Load a model saved from a file and return it.

#### Parameters

- **path** (*str*) – Path to the file to load the model from.
- **name** (*optional*) – If specified, the model is renamed to this name.

**Returns** A new model created from the file.

### modelx.setup\_ipython

`modelx.setup_ipython` ()

Set up IPython shell for modelx.

Suppress IPython's default traceback messages upon error.

### modelx.restore\_ipython

`modelx.restore_ipython` ()

Restore IPython' default error message.

Bring back IPython's default traceback message upon error for debugging.

### modelx.set\_recursion

`modelx.set_recursion` (*maxdepth=1000*)

Set formula recursion limit.

**Parameters** **maxdepth** – The maximum depth of the modelx interpreter stack.

## 10.6.2 Class Reference

<i>Model</i>	Top-level container in modelx object hierarchy.
<i>StaticSpace</i>	Container of cells, other spaces, and cells namespace.
<i>DynamicSpace</i>	Dynamically created space.
<i>Cells</i>	Data container with a formula to calculate its own values.
<i>SpaceView</i> (data)	A mapping of space names to space objects.
<i>CellsView</i> (data[, keys])	A mapping of cells names to cells objects.
<i>CellNode</i> (node)	A combination of a cells, its args and its value.

### Model

**class** modelx.core.model.**Model**

Bases: modelx.core.spacecontainer.EditableSpaceContainer

Top-level container in modelx object hierarchy.

Model instances are the top-level objects and directly contain *StaticSpace* objects, which in turn contain other spaces or *Cells* objects.

A model can be created by *new\_model* API function.

### Methods

<i>close</i> ()	Close the model.
<i>cur_space</i> ([name])	Set the current space to Space name and return it.
<i>import_module</i> ([module, recursive])	Create a child space from an module.
<i>new_space</i> ([name, bases, formula, refs])	Create a child space.
<i>new_space_from_excel</i> (book, range_[, sheet, ...])	Create a child space from an Excel range.
<i>new_space_from_module</i> (module[, recursive])	Create a child space from an module.
<i>rename</i> (name)	Rename the model itself
<i>save</i> (filepath)	Save the model to a file.

### Attributes

<i>allow_none</i>	Whether a cells can have None as its value.
<i>cellgraph</i>	A directed graph of cells.
<i>fullname</i>	Dotted name of the object.
<i>model</i>	The model this object belongs to.
<i>name</i>	Name of the object.
<i>parent</i>	The parent of this object.
<i>properties</i>	
<i>refs</i>	Return a mapping of global references.
<i>spaces</i>	A mapping of the names of child spaces to the Space objects

**rename** (*name*)

Rename the model itself

**save** (*filepath*)

Save the model to a file.

**close** ()

Close the model.

**cellgraph**

A directed graph of cells.

**refs**

Return a mapping of global references.

**\_baseattrs**

A dict of members expressed in literals

**\_to\_attrdict** (*attrs=None*)

Get extra attributes

**allow\_none**

Whether a cells can have None as its value.

This is a property of Model, Space and Cells. If `allow_none` of a cells is False, the cells cannot have None as its value. Assigning None to the cells or its formula returning None raises an Error. If True, the cells can have None as their value. If set to None, `allow_none` of its parent is looked up, and the search continues until True or False is found.

**Returns** True if the cells can have None, False if it cannot, or None if a default value from the parent is to be used.

**cur\_space** (*name=None*)

Set the current space to Space `name` and return it.

If called without arguments, the current space is returned. Otherwise, the current space is set to the space named `name` and the space is returned.

**fullname**

Dotted name of the object.

Names joined by dots, such as 'Model1.Space1.Cells1', each element in the string is the name of the parent object of the next one joined by a dot.

**import\_module** (*module=None, recursive=False, \*\*params*)

Create a child space from an module.

**Parameters**

- **module** – a module object or name of the module object.
- **recursive** – Not yet implemented.
- **\*\*params** – arguments to pass to `new_space`

**Returns** The new child space created from the module.

**model**

The model this object belongs to.

This is a property of Model, Space and Cells. For models, this property is themselves.

**name**

Name of the object.

**new\_space** (*name=None, bases=None, formula=None, refs=None*)

Create a child space.

### Parameters

- **name** (*str*, *optional*) – Name of the space. Defaults to `SpaceN`, where `N` is a number determined automatically.
- **bases** (*optional*) – A space or a sequence of spaces to be the base space(s) of the created space.
- **formula** (*optional*) – Function to specify the parameters of dynamic child spaces. The signature of this function is used for setting parameters for dynamic child spaces. This function should return a mapping of keyword arguments to be passed to this method when the dynamic child spaces are created.

**Returns** The new child space.

```
new_space_from_excel(book, range_, sheet=None, name=None, names_row=None,
                    param_cols=None, space_param_order=None,
                    cells_param_order=None, transpose=False, names_col=None,
                    param_rows=None)
```

Create a child space from an Excel range.

To use this method, `openpyxl` package must be installed.

### Parameters

- **book** (*str*) – Path to an Excel file.
- **range** (*str*) – Range expression, such as “A1”, “\$G4:\$K10”, or named range “Name-dRange1”.
- **sheet** (*str*) – Sheet name (case ignored).
- **name** (*str*, *optional*) – Name of the space. Defaults to `SpaceN`, where `N` is a number determined automatically.
- **names\_row** (*optional*) – an index number indicating what row contains the names of cells and parameters. Defaults to the top row (0).
- **param\_cols** (*optional*) – a sequence of index numbers indicating parameter columns. Defaults to only the leftmost column ([0]).
- **names\_col** (*optional*) – an index number, starting from 0, indicating what column contains additional parameters.
- **param\_rows** (*optional*) – a sequence of index numbers, starting from 0, indicating rows of additional parameters, in case cells are defined in two dimensions.
- **transpose** (*optional*) – Defaults to `False`. If set to `True`, “row(s)” and “col(s)” in the parameter names are interpreted inversely, i.e. all indexes passed to “row(s)” parameters are interpreted as column indexes, and all indexes passed to “col(s)” parameters as row indexes.
- **space\_param\_order** – a sequence to specify space parameters and their orders. The elements of the sequence denote the indexes of `param_cols` elements, and optionally the index of `param_rows` elements shifted by the length of `param_cols`. The elements of this parameter and `cell_param_order` must not overlap.
- **cell\_param\_order** (*optional*) – a sequence to reorder the parameters. The elements of the sequence denote the indexes of `param_cols` elements, and optionally the index of `param_rows` elements shifted by the length of `param_cols`. The elements of this parameter and `cell_space_order` must not overlap.

**Returns** The new child space created from the Excel range.

**new\_space\_from\_module** (*module*, *recursive=False*, *\*\*params*)

Create a child space from an module.

Alias to *import\_module()*.

**Parameters**

- **module** – a module object or name of the module object.
- **recursive** – Not yet implemented.
- **\*\*params** – arguments to pass to *new\_space*

**Returns** The new child space created from the module.

**parent**

The parent of this object. None for models.

The parent object of a cells is a space that contains the cells. The parent object of a space is either a model or another space that contains the space.

**spaces**

A mapping of the names of child spaces to the Space objects

**StaticSpace**

**class** modelx.core.space.StaticSpace

Bases: modelx.core.space.BaseSpace, modelx.core.spacecontainer.EditableSpaceContainer

Container of cells, other spaces, and cells namespace.

StaticSpace objects can contain cells and other spaces. Spaces have mappings of names to objects that serve as global namespaces of the formulas of the cells in the spaces.

**Methods**

<i>add_bases</i> (*bases)	Add base spaces.
<i>cur_space</i> ([name])	Set the current space to Space name and return it.
<i>has_params</i> ()	Check if the parameter function is set.
<i>import_funcs</i> (module)	Create a cells from a module.
<i>import_module</i> ([module, recursive])	Create a child space from an module.
<i>new_cells</i> ([name, formula])	Create a cells in the space.
<i>new_cells_from_excel</i> (book, range_[, sheet, ...])	Create multiple cells from an Excel range.
<i>new_cells_from_module</i> (module)	Create a cells from a module.
<i>new_space</i> ([name, bases, formula, refs])	Create a child space.
<i>new_space_from_excel</i> (book, range_[, sheet, ...])	Create a child space from an Excel range.
<i>new_space_from_module</i> (module[, recursive])	Create a child space from an module.
<i>reload</i> ()	Reload the source module and update the formulas.
<i>remove_bases</i> (*bases)	Remove base spaces.
<i>set_formula</i> (formula)	Set if the parameter function.
<i>to_frame</i> (*args)	Convert the space itself into a Pandas DataFrame object.

## Attributes

<i>all_spaces</i>	A mapping associating names to all(static and dynamic) spaces.
<i>allow_none</i>	Whether a cells can have None as its value.
<i>argvalues</i>	A tuple of space arguments.
<i>bases</i>	List of base classes.
<i>cells</i>	A mapping of cells names to the cells objects in the space.
<i>dynamic_spaces</i>	A mapping associating names to dynamic spaces.
<i>formula</i>	Property to get, set, delete formula.
<i>frame</i>	Alias of <code>to_frame()</code> .
<i>fullname</i>	Dotted name of the object.
<i>model</i>	The model this object belongs to.
<i>name</i>	Name of the object.
<i>parameters</i>	A tuple of parameter strings.
<i>parent</i>	The parent of this object.
<i>properties</i>	
<i>refs</i>	A map associating names to objects accessible by the names.
<i>spaces</i>	A mapping associating names to static spaces.
<i>static_spaces</i>	A mapping associating names to static spaces.

**new\_cells** (*name=None, formula=None*)

Create a cells in the space.

### Parameters

- **name** – If omitted, the model is named automatically `CellsN`, where N is an available number.
- **func** – The function to define the formula of the cells.

**Returns** The new cells.

**add\_bases** (*\*bases*)

Add base spaces.

**remove\_bases** (*\*bases*)

Remove base spaces.

**import\_funcs** (*module*)

Create a cells from a module.

**new\_cells\_from\_module** (*module*)

Create a cells from a module.

Alias to `import_funcs()`.

**reload** ()

Reload the source module and update the formulas.

If the space was created from a module, reload the module and update the formulas of its cells.

If a cell in the space is not created from a function definition in the source module of the space, it is not updated.

If the formula of a cell in the space was created from a function definition in the source module of the space and the definition is missing from the updated module, the formula is cleared and values calculated directly or indirectly depending the cells are cleared.

If the formula of a cell in the space has not been changed before and after reloading the source module, the values held in the cell and relevant cells are retained.

**Returns** This method returns the space itself.

```
new_cells_from_excel(book, range_, sheet=None, names_row=None, param_cols=None,
                      param_order=None, transpose=False, names_col=None,
                      param_rows=None)
```

Create multiple cells from an Excel range.

This method reads values from a range in an Excel file, create cells and populate them with the values in the range. To use this method, `openpyxl` package must be installed.

The Excel file to read data from is specified by `book` parameters. The `range_` can be a range address, such as “\$G4:\$K10”, or a named range. In case a range address is given, `sheet` must also be given.

By default, cells data are interpreted as being laid out side-by-side. `names_row` is a row index (starting from 0) to specify the row that contains the names of cells and parameters. Cells and parameter names must be contained in a single row. `param_cols` accepts a sequence (such as list or tuple) of column indexes (starting from 0) that indicate columns that contain cells arguments.

### 2-dimensional cells definitions

The optional `names_col` and `param_rows` parameters are used, when data for one cells spans more than one column. In such cases, the cells data is 2-dimensional, and there must be parameter row(s) across the columns that contain arguments of the parameters. A sequence of row indexes that indicate parameter rows is passed to `param_rows`. The names of those parameters must be contained in the same rows as parameter values (arguments), and `names_col` is to indicate the column position at which the parameter names are defined.

### Horizontal arrangement

By default, cells data are interpreted as being placed side-by-side, regardless of whether one cells corresponds to a single column or multiple columns. `transpose` parameter is used to alter this orientation, and if it is set to `True`, cells values are interpreted as being placed one above the other. “row(s)” and “col(s)” in the parameter names are interpreted inversely, i.e. all indexes passed to “row(s)” parameters are interpreted as column indexes, and all indexes passed to “col(s)” parameters as row indexes.

### Parameters

- **book** (*str*) – Path to an Excel file.
- **range** (*str*) – Range expression, such as “A1”, “\$G4:\$K10”, or named range “Name-dRange1”.
- **sheet** (*str*) – Sheet name (case ignored).
- **names\_row** (*optional*) – an index number indicating what row contains the names of cells and parameters. Defaults to the top row (0).
- **param\_cols** (*optional*) – a sequence of index numbers indicating parameter columns. Defaults to only the leftmost column ([0]).
- **names\_col** (*optional*) – an index number, starting from 0, indicating what column contains additional parameters.
- **param\_rows** (*optional*) – a sequence of index numbers, starting from 0, indicating rows of additional parameters, in case cells are defined in two dimensions.

- **transpose** (*optional*) – Defaults to `False`. If set to `True`, “row(s)” and “col(s)” in the parameter names are interpreted inversely, i.e. all indexes passed to “row(s)” parameters are interpreted as column indexes, and all indexes passed to “col(s)” parameters as row indexes.
- **param\_order** (*optional*) – a sequence to reorder the parameters. The elements of the sequence are the indexes of `param_cols` elements, and optionally the index of `param_rows` elements shifted by the length of `param_cols`.

**formula**

Property to get, set, delete formula.

**set\_formula** (*formula*)

Set if the parameter function.

**\_baseattrs**

A dict of members expressed in literals

**\_derived\_cells**

A mapping associating names to derived cells.

**\_derived\_spaces**

A mapping associating names to derived spaces.

**\_is\_base** (*other*)

True if the space is a base space of `other`, False otherwise.

**\_is\_defined** ()

True if the space is a defined space, False otherwise.

**\_is\_derived** ()

True if the space is a derived space, False otherwise.

**\_is\_dynamic** ()

True if the space is in a dynamic space, False otherwise.

**\_is\_root** ()

True if this space is a dynamic space, False otherwise.

**\_is\_static** ()

True if the space is a static space, False if dynamic.

**\_is\_sub** (*other*)

True if the space is a sub space of `other`, False otherwise.

**\_self\_cells**

A mapping that associates names to cells defined in the space

**\_self\_spaces**

A mapping associating names to self spaces.

**\_to\_attrdict** (*attrs=None*)

Get extra attributes

**all\_spaces**

A mapping associating names to all(static and dynamic) spaces.

**allow\_none**

Whether a cells can have `None` as its value.

This is a property of `Model`, `Space` and `Cells`. If `allow_none` of a cells is `False`, the cells cannot have `None` as its value. Assigning `None` to the cells or its formula returning `None` raises an `Error`. If `True`, the

cells can have None as their value. If set to None, `allow_none` of its parent is looked up, and the search continues until True or False is found.

**Returns** True if the cells can have None, False if it cannot, or None if a default value from the parent is to be used.

**argvalues**

A tuple of space arguments.

**bases**

List of base classes.

**cells**

A mapping of cells names to the cells objects in the space.

**cur\_space** (*name=None*)

Set the current space to Space *name* and return it.

If called without arguments, the current space is returned. Otherwise, the current space is set to the space named *name* and the space is returned.

**dynamic\_spaces**

A mapping associating names to dynamic spaces.

**frame**

Alias of `to_frame()`.

**fullname**

Dotted name of the object.

Names joined by dots, such as 'Model1.Space1.Cells1', each element in the string is the name of the parent object of the next one joined by a dot.

**has\_params** ()

Check if the parameter function is set.

**import\_module** (*module=None, recursive=False, \*\*params*)

Create a child space from an module.

**Parameters**

- **module** – a module object or name of the module object.
- **recursive** – Not yet implemented.
- **\*\*params** – arguments to pass to `new_space`

**Returns** The new child space created from the module.

**model**

The model this object belongs to.

This is a property of Model, Space and Cells. For models, this property is themselves.

**name**

Name of the object.

**new\_space** (*name=None, bases=None, formula=None, refs=None*)

Create a child space.

**Parameters**

- **name** (*str, optional*) – Name of the space. Defaults to `SpaceN`, where N is a number determined automatically.

- **bases** (*optional*) – A space or a sequence of spaces to be the base space(s) of the created space.
- **formula** (*optional*) – Function to specify the parameters of dynamic child spaces. The signature of this function is used for setting parameters for dynamic child spaces. This function should return a mapping of keyword arguments to be passed to this method when the dynamic child spaces are created.

**Returns** The new child space.

```
new_space_from_excel(book, range_, sheet=None, name=None, names_row=None,
                    param_cols=None, space_param_order=None,
                    cells_param_order=None, transpose=False, names_col=None,
                    param_rows=None)
```

Create a child space from an Excel range.

To use this method, `openpyxl` package must be installed.

#### Parameters

- **book** (*str*) – Path to an Excel file.
- **range** (*str*) – Range expression, such as “A1”, “\$G4:\$K10”, or named range “Name-dRange1”.
- **sheet** (*str*) – Sheet name (case ignored).
- **name** (*str, optional*) – Name of the space. Defaults to `SpaceN`, where `N` is a number determined automatically.
- **names\_row** (*optional*) – an index number indicating what row contains the names of cells and parameters. Defaults to the top row (0).
- **param\_cols** (*optional*) – a sequence of index numbers indicating parameter columns. Defaults to only the leftmost column ([0]).
- **names\_col** (*optional*) – an index number, starting from 0, indicating what column contains additional parameters.
- **param\_rows** (*optional*) – a sequence of index numbers, starting from 0, indicating rows of additional parameters, in case cells are defined in two dimensions.
- **transpose** (*optional*) – Defaults to `False`. If set to `True`, “row(s)” and “col(s)” in the parameter names are interpreted inversely, i.e. all indexes passed to “row(s)” parameters are interpreted as column indexes, and all indexes passed to “col(s)” parameters as row indexes.
- **space\_param\_order** – a sequence to specify space parameters and their orders. The elements of the sequence denote the indexes of `param_cols` elements, and optionally the index of `param_rows` elements shifted by the length of `param_cols`. The elements of this parameter and `cell_param_order` must not overlap.
- **cell\_param\_order** (*optional*) – a sequence to reorder the parameters. The elements of the sequence denote the indexes of `param_cols` elements, and optionally the index of `param_rows` elements shifted by the length of `param_cols`. The elements of this parameter and `cell_space_order` must not overlap.

**Returns** The new child space created from the Excel range.

```
new_space_from_module(module, recursive=False, **params)
```

Create a child space from an module.

Alias to `import_module()`.

**Parameters**

- **module** – a module object or name of the module object.
- **recursive** – Not yet implemented.
- **\*\*params** – arguments to pass to `new_space`

**Returns** The new child space created from the module.

**parameters**

A tuple of parameter strings.

**parent**

The parent of this object. None for models.

The parent object of a cells is a space that contains the cells. The parent object of a space is either a model or another space that contains the space.

**refs**

A map associating names to objects accessible by the names.

**spaces**

A mapping associating names to static spaces.

**static\_spaces**

A mapping associating names to static spaces.

Alias to `spaces()`

**to\_frame(\*args)**

Convert the space itself into a Pandas DataFrame object.

**DynamicSpace**

**class** `modelx.core.space.DynamicSpace`

Bases: `modelx.core.space.BaseSpace`

Dynamically created space.

Dynamic spaces of a parametric space are created by accessing its elements for the first time, through subscription `[]` or call `()` operations on the parametric space.

Dynamic spaces are not editable like static spaces.

**Methods**

<code>cur_space([name])</code>	Set the current space to Space name and return it.
<code>has_params()</code>	Check if the parameter function is set.
<code>to_frame(*args)</code>	Convert the space itself into a Pandas DataFrame object.

**Attributes**

<code>all_spaces</code>	A mapping associating names to all(static and dynamic) spaces.
<code>allow_none</code>	Whether a cells can have None as its value.

Continued on next page

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<i>argvalues</i>	A tuple of space arguments.
<i>bases</i>	List of base classes.
<i>cells</i>	A mapping of cells names to the cells objects in the space.
<i>dynamic_spaces</i>	A mapping associating names to dynamic spaces.
<i>formula</i>	Property to get, set, delete formula.
<i>frame</i>	Alias of <code>to_frame()</code> .
<i>fullname</i>	Dotted name of the object.
<i>model</i>	The model this object belongs to.
<i>name</i>	Name of the object.
<i>parameters</i>	A tuple of parameter strings.
<i>parent</i>	The parent of this object.
<i>properties</i>	
<i>refs</i>	A map associating names to objects accessible by the names.
<i>spaces</i>	A mapping associating names to static spaces.
<i>static_spaces</i>	A mapping associating names to static spaces.

**`_baseattrs`**

A dict of members expressed in literals

**`_derived_cells`**

A mapping associating names to derived cells.

**`_derived_spaces`**

A mapping associating names to derived spaces.

**`_is_base`** (*other*)

True if the space is a base space of *other*, False otherwise.

**`_is_defined`** ()

True if the space is a defined space, False otherwise.

**`_is_derived`** ()

True if the space is a derived space, False otherwise.

**`_is_dynamic`** ()

True if the space is in a dynamic space, False otherwise.

**`_is_root`** ()

True if this space is a dynamic space, False otherwise.

**`_is_static`** ()

True if the space is a static space, False if dynamic.

**`_is_sub`** (*other*)

True if the space is a sub space of *other*, False otherwise.

**`_self_cells`**

A mapping that associates names to cells defined in the space

**`_self_spaces`**

A mapping associating names to self spaces.

**`_to_attrdict`** (*attrs=None*)

Get extra attributes

**`all_spaces`**

A mapping associating names to all(static and dynamic) spaces.

**allow\_none**

Whether a cells can have None as its value.

This is a property of Model, Space and Cells. If `allow_none` of a cells is False, the cells cannot have None as its value. Assigning None to the cells or its formula returning None raises an Error. If True, the cells can have None as their value. If set to None, `allow_none` of its parent is looked up, and the search continues until True or False is found.

**Returns** True if the cells can have None, False if it cannot, or None if a default value from the parent is to be used.

**argvalues**

A tuple of space arguments.

**bases**

List of base classes.

**cells**

A mapping of cells names to the cells objects in the space.

**cur\_space** (*name=None*)

Set the current space to Space *name* and return it.

If called without arguments, the current space is returned. Otherwise, the current space is set to the space named *name* and the space is returned.

**dynamic\_spaces**

A mapping associating names to dynamic spaces.

**formula**

Property to get, set, delete formula.

**frame**

Alias of `to_frame()`.

**fullname**

Dotted name of the object.

Names joined by dots, such as 'Model1.Space1.Cells1', each element in the string is the name of the parent object of the next one joined by a dot.

**has\_params** ()

Check if the parameter function is set.

**model**

The model this object belongs to.

This is a property of Model, Space and Cells. For models, this property is themselves.

**name**

Name of the object.

**parameters**

A tuple of parameter strings.

**parent**

The parent of this object. None for models.

The parent object of a cells is a space that contains the cells. The parent object of a space is either a model or another space that contains the space.

**refs**

A map associating names to objects accessible by the names.

**spaces**

A mapping associating names to static spaces.

**static\_spaces**

A mapping associating names to static spaces.

Alias to `spaces()`

**to\_frame(\*args)**

Convert the space itself into a Pandas DataFrame object.

**Cells**

**class** modelx.core.cells.Cells

Bases: modelx.core.base.Interface, collections.abc.Mapping, collections.abc.Callable

Data container with a formula to calculate its own values.

Cells are created by `new_cells` method or its variant methods of the containing space, or by function definitions with `defcells` decorator.

**Methods**

<code>clear(*args, **kwargs)</code>	Clear all the values.
<code>clear_formula()</code>	Clear the formula.
<code>copy([space, name])</code>	Make a copy of itself and return it.
<code>get(k[,d])</code>	
<code>items()</code>	
<code>keys()</code>	
<code>match(*args, **kwargs)</code>	Returns the best matching args and their value.
<code>node(*args, **kwargs)</code>	Return a <code>CellNode</code> object for the given arguments.
<code>preds(*args, **kwargs)</code>	Return a list of predecessors of a cell.
<code>set_formula(func)</code>	Set formula from a function.
<code>succs(*args, **kwargs)</code>	Return a list of successors of a cell.
<code>to_frame(*args)</code>	Convert the cells itself into a Pandas DataFrame and return it.
<code>to_series(*args)</code>	Convert the cells itself into a Pandas Series and return it.
<code>values()</code>	

**Attributes**

<code>allow_none</code>	Whether a cells can have None as its value.
<code>formula</code>	Property to get, set, delete formula.
<code>frame</code>	Alias of <code>to_frame()</code> .
<code>fullname</code>	Dotted name of the object.
<code>model</code>	The model this object belongs to.
<code>name</code>	Name of the object.
<code>parameters</code>	A tuple of parameter strings.
<code>parent</code>	The parent of this object.
<code>properties</code>	

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<code>series</code>	Alias of <code>to_series()</code> .
<code>value</code>	Get, set, delete the scalar value.

**match** (\*args, \*\*kwargs)

Returns the best matching args and their value.

If the cells returns None for the given arguments, continue to get a value by passing arguments masking the given arguments with Nones. The search of non-None value starts from the given arguments to the all None arguments in the lexicographical order. The masked arguments that returns non-None value first is returned with the value.

**copy** (space=None, name=None)

Make a copy of itself and return it.

**clear** (\*args, \*\*kwargs)

Clear all the values.

**to\_series** (\*args)

Convert the cells itself into a Pandas Series and return it.

**series**

Alias of `to_series()`.

**to\_frame** (\*args)

Convert the cells itself into a Pandas DataFrame and return it.

if no *args* are passed, the returned DataFrame contains as many values as the cells have.

if A sequence of arguments to the cells is passed as *args*, the returned DataFrame contains values only for the specified *args*.

**Parameters** *args* – A sequence or iterable of arguments to the cells.

**Returns** a DataFrame with a column named after the cells, with indexes named after the parameters of the cells.

**frame**

Alias of `to_frame()`.

**formula**

Property to get, set, delete formula.

**parameters**

A tuple of parameter strings.

**set\_formula** (func)

Set formula from a function. Deprecated since version 0.0.5. Use formula property instead.

**clear\_formula** ()

Clear the formula. Deprecated since version 0.0.5. Use formula property instead.

**value**

Get, set, delete the scalar value. The cells must be a scalar cells.

**node** (\*args, \*\*kwargs)

Return a *CellNode* object for the given arguments.

**preds** (\*args, \*\*kwargs)

Return a list of predecessors of a cell.

This method returns a list of *CellNode* objects, whose elements are predecessors of (i.e. referenced in the formula of) the cell specified by the given arguments.

**succs** (*\*args, \*\*kwargs*)

Return a list of successors of a cell.

This method returns a list of `CellNode` objects, whose elements are successors of (i.e. referencing in their formulas) the cell specified by the given arguments.

**\_baseattrs**

A dict of members expressed in literals

**\_to\_attrdict** (*attrs=None*)

Get extra attributes

**allow\_none**

Whether a cells can have `None` as its value.

This is a property of `Model`, `Space` and `Cells`. If `allow_none` of a cells is `False`, the cells cannot have `None` as its value. Assigning `None` to the cells or its formula returning `None` raises an `Error`. If `True`, the cells can have `None` as their value. If set to `None`, `allow_none` of its parent is looked up, and the search continues until `True` or `False` is found.

**Returns** `True` if the cells can have `None`, `False` if it cannot, or `None` if a default value from the parent is to be used.

**fullname**

Dotted name of the object.

Names joined by dots, such as `'Model1.Space1.Cells1'`, each element in the string is the name of the parent object of the next one joined by a dot.

**get** (*k[, d]*) → `D[k]` if `k` in `D`, else `d`. `d` defaults to `None`.

**items** () → a set-like object providing a view on `D`'s items

**keys** () → a set-like object providing a view on `D`'s keys

**model**

The model this object belongs to.

This is a property of `Model`, `Space` and `Cells`. For models, this property is themselves.

**name**

Name of the object.

**parent**

The parent of this object. `None` for models.

The parent object of a cells is a space that contains the cells. The parent object of a space is either a model or another space that contains the space.

**values** () → an object providing a view on `D`'s values

## SpaceView

**class** `modelx.core.space.SpaceView` (*data*)

Bases: `modelx.core.base.BaseView`

A mapping of space names to space objects.

## Methods

<code>__init__(data)</code>	Initialize self.
<code>get(k[,d])</code>	
<code>items()</code>	
<code>keys()</code>	
<code>values()</code>	

**`_baseattrs`**

A dict of members expressed in literals

**`get(k[, d])`** → `D[k]` if `k` in `D`, else `d`. `d` defaults to `None`.

**`items()`** → a set-like object providing a view on `D`'s items

**`keys()`** → a set-like object providing a view on `D`'s keys

**`values()`** → an object providing a view on `D`'s values

**CellsView**

**class** `modelx.core.space.CellsView` (*data*, *keys=None*)

Bases: `modelx.core.base.SelectedView`

A mapping of cells names to cells objects.

`CellsView` objects are returned by `StaticSpace.cells` property. When `StaticSpace.cells` is called without subscription(`[]` operator), the returned `CellsView` contains all the cells in the space.

`CellsView` supports a normal subscription(`[]`) operation with one argument to retrieve a cells object from its name, but it also supports multiple arguments to indicate the names of cells to select, and returns another `CellsView` containing only the selected cells.

For example, if `space` contains 3 cells `foo`, `bar` and `baz`:

```
>> space.cells
{foo,
 bar,
 baz}

>> space.cells['bar', 'baz']
{bar,
 baz}
```

**Methods**

<code>__init__(data[, keys])</code>	Initialize self.
<code>get(k[,d])</code>	
<code>items()</code>	
<code>keys()</code>	
<code>to_frame(*args)</code>	Convert the cells in the view into a DataFrame object.
<code>values()</code>	

**`to_frame(*args)`**

Convert the cells in the view into a DataFrame object.

If `args` is not given, this method returns a DataFrame that has an Index or a MultiIndex depending of the number of cells parameters and columns each of which corresponds to each cells included in the view.

`args` can be given to calculate cells values and limit the DataFrame indexes to the given arguments.

The cells in this view may have different number of parameters, but parameters shared among multiple cells must appear in the same position in all the parameter lists. For example, Having `foo()`, `bar(x)` and `baz(x, y=1)` is okay because the shared parameter `x` is always the first parameter, but this method does not work if the view has `quz(x, z=2, y=1)` cells in addition to the first three cells, because `y` appears in different positions.

**Parameters** `args` (*optional*) – multiple arguments, or an iterator of arguments to the cells.

**`_baseattrs`**

A dict of members expressed in literals

**`get(k[, d])`** → `D[k]` if `k` in `D`, else `d`. `d` defaults to `None`.

**`items()`** → a set-like object providing a view on `D`'s items

**`keys()`** → a set-like object providing a view on `D`'s keys

**`values()`** → an object providing a view on `D`'s values

## CellNode

**class** `modelx.core.cells.CellNode` (*node*)

Bases: `object`

A combination of a cells, its args and its value.

### Methods

<code>__init__(node)</code>	Initialize self.
-----------------------------	------------------

### Attributes

<code>args</code>	Return a tuple of the cells' arguments.
<code>cells</code>	Return the Cells object
<code>has_value</code>	Return <code>True</code> if the cell has a value.
<code>preds</code>	A list of nodes that this node refers to.
<code>succs</code>	A list of nodes that refer to this node.
<code>value</code>	Return the value of the cells.

**`cells`**

Return the Cells object

**`args`**

Return a tuple of the cells' arguments.

**`has_value`**

Return `True` if the cell has a value.

**`value`**

Return the value of the cells.

**`preds`**

A list of nodes that this node refers to.

**succs**

A list of nodes that refer to this node.

**\_baseattrs**

A dict of members expressed in literals

- genindex
- search



## Symbols

- `_baseattrs` (*modelx.core.cells.CellNode* attribute), 75
  - `_baseattrs` (*modelx.core.cells.Cells* attribute), 72
  - `_baseattrs` (*modelx.core.model.Model* attribute), 59
  - `_baseattrs` (*modelx.core.space.CellsView* attribute), 74
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