



# **LIAM2 User Guide**

***Release 0.10.0***

**G. Bryon, G. Dekkers, G. de Menten**

June 15, 2015



<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	About LIAM2 . . . . .	1
1.2	About microsimulation . . . . .	2
1.3	About this guide . . . . .	2
<b>2</b>	<b>Environment</b>	<b>3</b>
2.1	LIAM2 bundle . . . . .	3
2.2	Getting Started . . . . .	3
2.3	Using your own data . . . . .	3
<b>3</b>	<b>Model Definition</b>	<b>5</b>
3.1	Comments . . . . .	5
3.2	General structure . . . . .	5
3.3	import . . . . .	6
3.4	globals . . . . .	6
3.5	entities . . . . .	7
3.6	simulation . . . . .	9
<b>4</b>	<b>Running a model/simulation</b>	<b>13</b>
<b>5</b>	<b>Processes</b>	<b>15</b>
5.1	Expressions . . . . .	15
5.2	Assignments . . . . .	16
5.3	Functions . . . . .	16
5.4	globals . . . . .	19
5.5	Built-in Functions . . . . .	20
5.6	While loops . . . . .	35
5.7	Output . . . . .	36
5.8	Debugging and the interactive console . . . . .	56
<b>6</b>	<b>Links</b>	<b>59</b>
6.1	many2one . . . . .	59
6.2	one2many . . . . .	60
<b>7</b>	<b>Importing other models</b>	<b>63</b>
<b>8</b>	<b>Importing data</b>	<b>67</b>
8.1	data files . . . . .	67
8.2	description file . . . . .	67
8.3	importing the data . . . . .	71
<b>9</b>	<b>Indices and tables</b>	<b>73</b>
<b>10</b>	<b>Appendix</b>	<b>75</b>
10.1	Known issues . . . . .	75
10.2	Code architecture . . . . .	76

10.3	Technical choices . . . . .	79
10.4	Change log . . . . .	79
10.5	Credits . . . . .	98
	<b>Index</b>	<b>99</b>

## INTRODUCTION

### 1.1 About LIAM2

LIAM2 is a tool to develop (different kinds of) *microsimulation* models.

The goal of the project is to let modellers concentrate on what is strictly specific to their model without having to worry about the technical details. This is achieved by providing a generic microsimulation toolbox which is not tied to a particular model. By making it available for free, our hope is to greatly reduce the development costs (in terms of both time and money) of microsimulation models.

The toolbox is made as generic as possible so that it can be used to develop almost any microsimulation model as long as it use cross-sectional ageing, ie all individuals are simulated at the same time for one period, then for the next period, etc.

#### 1.1.1 License

LIAM2 is licensed under the [GNU General Public License \(GPL\) version 3](#). This means you can freely use, copy, modify and redistribute this software provided you follow a few conditions. See the license text for details.

#### 1.1.2 Staying informed

You can get notified of new versions and other LIAM2-related announcements by either using [our website RSS feed](#) or subscribing to the [LIAM2-announce mailing list](#) on Google Groups.

#### 1.1.3 Credits

The software is primarily being developed at the Federal Planning Bureau (Belgium), with testing and funding by CEPS/INSTEAD (Luxembourg) and IGSS (Luxembourg), and funding from the European Commission. See the [credits page](#) for details.

#### 1.1.4 Contact

For any question, suggestion or comment you might have, please send a message to the [LIAM2-users mailing list](#). Please note that, as a spam counter measure, new member posts are moderated. We are doing all we can to let them through as quickly as possible, but since it is a manual process it can take a few hours, or exceptionally a few days. Please be patient in case your post is delayed.

If you **really** do not want your message to be public, you can contact the authors at `liam2 x plan y be` (replace x and y by @ and . respectively) but **we would highly prefer if you used the mailing list instead if you can**.

## 1.2 About microsimulation

Microsimulation is a modelling technique that operates at the level of individual units such as persons, households, vehicles or firms. Each unit has a set of associated attributes – e.g. a person has an associated age, sex, and employment status. In the case of discrete-time dynamic models, a set of rules (intended to represent individual preferences) are applied to these units at each time step, leading to simulated changes in state and possibly behaviour. These rules may be deterministic (probability = 1), such as ageing, or stochastic (probability < 1), such as the chance of dying, marrying, giving birth or moving within a given time period.

The aim of such simulations is to give insight about both the overall aggregate change of some characteristics and, most importantly, the way these changes are distributed in the population that is being modelled. The methodology is often used to design and evaluate public policies that are affected by earlier events and choices as is the case for pensions or education.

## 1.3 About this guide

This guide will help you develop dynamic microsimulation models using LIAM2. Please note that it describes version 0.10 of LIAM2, but both the software package and this manual are work-in-progress, and are therefore subject to change.

## ENVIRONMENT

### 2.1 LIAM2 bundle

The bundle includes:

- The executable for Windows.
- A text editor (Notepad++), pre-configured to work with LIAM2 models.
  - Notepad++ is a free (and open source) text editor that is available at <http://sourceforge.net/projects/notepad-plus/>.
  - We pre-configured it so that you can import csv files and run your models directly from within the editor by simply pressing F5 or F6 respectively. See below for more information.
- The documentation in HTML Help format (.chm). You can find .pdf and .html versions on our website.
- A demonstration model with a synthetic data set of 20,200 persons grouped in 14,700 households.

### 2.2 Getting Started

- Copy the contents of the bundle in a directory on your disk (let us call it *[BUNDLEPATH]*).
- Run the “Notepad++Portable.exe” from the *[BUNDLEPATH]editor* directory.
- Open a model (eg. *[BUNDLEPATH]examples\demo01.yml*)
- Press F6 to run the model. A console window will open within the editor and display the status of the simulation. After the simulation completes, the console window becomes interactive.
- Use this console to explore the results. If you already quit the interactive console and want to explore the results with the interactive console again without (re)simulating the model, you can press F7.
- Alternatively, you can explore the results “graphically” by pressing F9. This will open both the input dataset and the result file (if any) with an hdf5 viewer (ViTables).

### 2.3 Using your own data

- Prepare your data as CSV files. The first row should contain the name of the fields. You need at least two integer columns: “id” and “period” (though they do not necessarily need to be named like that in the csv file).
- Create an import file, as described in the *Importing data* section. You can use *[BUNDLEPATH]examples\demo\_import.yml* as an example.
- Press F5 to convert your CSV files to hdf5.
- Use the newly created data file with your model.





## MODEL DEFINITION

To define the model, we have to describe the different *entities*, their *fields*, the way they interact (*links*) and how they behave over time (*processes*).

LIAM2 model files use a dialect of the YAML format. This format uses the level of indentation and colons (: characters) to differentiate objects from sub objects.

### 3.1 Comments

Another particularity inherited from YAML is the use of the hash character, #, to start comments, which extend to the end of the line. A comment may appear at the start of a line or following whitespace or a complete line of code, but not within an expression. Since comments are only meant to clarify code, they are ignored by LIAM2 and may be omitted if typing in examples.

### 3.2 General structure

A LIAM2 model file has the following general structure:

```
import:      # optional section (can be entirely omitted)
  ...

globals:    # optional section
  ...

entities:
  ...

simulation:
  ...
```

Here is an example of what a trivial model looks like:

```
entities:
  person:
    fields:
      # period and id are implicit
      - age: int

    processes:
      ageing:
        - age: age + 1

simulation:
  processes:
    - person: [ageing]
  input:
```

```
file: input.h5
output:
  file: output.h5
start_period: 2015
periods: 10
```

### 3.3 import

A model file can (optionally) import (an)other model file(s). This can be used to simply split a large model file into smaller files, or (more interestingly) to create simulation variants without having to duplicate the common parts.

For details, see the *Importing other models* section.

### 3.4 globals

*globals* are variables (aka. parameters) that do not relate to any particular *entity* defined in the model. They can be used in expressions in any entity.

LIAM2 currently supports two kinds of globals: tables and multi-dimensional arrays. Both kinds need to be declared in the simulation file, as follow:

```
globals:
  mytable:
    fields:
      - MYINTFIELD: int
      - MYFLOATFIELD: float

  MYARRAY:
    type: float
```

Please see the *globals* usage section for how to use them in you expressions.

Globals can be loaded from either .csv files during the simulation, or from the HDF5 input file, along with the entities data. In the later case, they need to be imported (as explained in the *Importing data* section) before they can be used. If globals need to be loaded from .csv files during the simulation, the path to the files need to be given like

```
globals:
  mytable:
    path: mytable.csv
    fields:
      - MYINTFIELD: int
      - MYFLOATFIELD: float

  MYARRAY:
    path: path\to\myarray.csv
    type: float
```

If no path is specified, the globals are assumed to be in the HDF5 file.

There are globals with a special status: **periodic globals**. Those globals have a different value for each period. *periodic* is thus a reserved word and is always a table, so the “fields” keyword can be omitted for that table.

For example, the retirement age for women in Belgium has been gradually increasing from 61 in 1997 to 65 in 2009. A global variable WEMRA has therefore been included.

```
globals:
  periodic:
```

```
# PERIOD is an implicit column of the periodic table
- WEMRA: float
```

## 3.5 entities

Each entity has a unique identifier and a set of attributes (**fields**). You can use different entities in one model. You can define the interaction between members of the same entity (eg. between partners) or among different entities (eg. a person and its household) using **links**.

The **processes** section describe how the entities behave. The order in which they are declared is not important. In the **simulation** block you define if and when they have to be executed, this allows to simulate processes of different entities in the order you want.

In LIAM2, entities are declared as follows:

```
entities:
  entity-name1:
    fields:      # optional section (can be omitted)
      fields definition

    links:      # optional section (can be omitted)
      links definition

    macros:     # optional section (can be omitted)
      macros definition

    processes:  # optional section (can be omitted)
      processes definition

  entity-name2:
    ...
```

As a reminder, indentation and the use of ":" are important.

### 3.5.1 fields

The fields hold the information of each member in the entity. That information is global in a run of the model. Every process defined in that entity can use and change the value.

LIAM2 handles three types of fields:

- bool: boolean (True or False)
- int: integer
- float: real number

There are two implicit fields that do not have to be defined:

- id: the unique identifier of the item
- period: the current period in the run of the program

*example*

```
entities:
  person:
    fields:
      # period and id are implicit
      - age:      int
      - gender:   bool
      # 1: single, 2: married, 3: cohabitant, 4: divorced, 5: widowed
      - civilstate: int
```

```
- partner_id: int
- earnings: float
```

This example defines the entity person. Each person has an age, gender, civil state and possibly a partner. We use the field `civilstate` to store the marital status which can take one of several predefined values.

Field names must be unique per entity (i.e. several entities may have a field with the same name).

By default, all declared fields are supposed to be present in the input file (because they are *observed* or computed elsewhere and their value can be found in the supplied data set) and the value for all declared fields will be stored for each period in the output file.

However, in practice, there are often some fields which are not present in the input file. They will need to be calculated later by the model, and you need to tell LIAM2 that the field is missing, by using `initialdata: False` in the definition for that field (see the `agegroup` variable in the example below). One can have a field not stored in the output file by using “`output: False`” in its definition. Note that (local) *temporary variables within functions do not need to be declared*. The only case where you want to use `output: False` is when you need a variable that is accessible in several functions but not stored in the output file.

**Warning:** All fields used in `lag()` expressions **must** be in the output file.

*example*

```
entities:
  person:
    fields:
      - age: int
      - agegroup: {type: int, initialdata: False}
      - temporary: {type: int, output: False}
```

### 3.5.2 links

Individuals can be linked with each other or with individuals of other entities, for example, mothers are linked to their children, partners are linked to each other and persons belong to households.

For details, see the [Links](#) section.

### 3.5.3 macros

Macros are a way to make the code easier to read and maintain. They are defined on the entity level. Macros are re-evaluated wherever they appear. An usual convention is to use *capital* letters to define macros.

*example*

```
entities:
  person:
    fields:
      - age: int

    macros:
      ISCHILD: age < 18

    processes:
      test_macros:
        - show("before", ISCHILD)
        - age: age + 1
        - show("after", ISCHILD)

simulation:
  processes:
    - person: [test_macros]
```

The above example does

- `show()`: displays whether each person is a child.
- `age`: the age is changed.
- **`show()`: displays again whether each person is a child. This value is different** than above, even though we did not explicitly assign it a new value.

### 3.5.4 processes

Here you define the processes you will need in the model.

For details, see the *Processes* section.

## 3.6 simulation

The *simulation* block includes the location of the datasets (**input**, **output**), the number of periods and the start period. It sets what processes defined in the **entities** block are simulated (since some can be omitted), and the order in which this is done.

Please note that even though in all our examples periods correspond to years, the interpretation of the period is up to the modeller and can thus be an integer number representing anything (a day, a month, a quarter or anything you can think of). This is an important choice as it will impact the whole model.

Suppose that we have a model that starts in 2002 and has to simulate for 10 periods. Furthermore, suppose that we have two entities: individuals and households. The model starts by some initial processes (defined in the *init* section) that precede the actual prospective simulation of the model, and that only apply to the observed dataset in 2001 (or before). These initial simulations can pertain to the level of the individual or the household. Use the *init* block to calculate variables for the starting period.

The prospective part of the model starts by a number of sub-processes setting the household size and composition. Next, two processes apply on the level of the individual, changing the age and agegroup. Finally, mortality and fertility are simulated. Seeing that this changes the numbers of individuals in households, the process establishing the household size and composition is again used.

*example*

```
simulation:
  init:                                # optional
    - household: [household_composition]
    - person: [agegroup]

  processes:
    - household: [household_composition]
    - person: [
        age, agegroup,
        death, birth
      ]
    - household: [household_composition]

  input:
    path: liam2                          # optional
    file: base.h5

  output:
    path: liam2                          # optional
    file: simulation.h5

  start_period: 2015
  periods: 10
  skip_shows: False                      # optional
  random_seed: 5235                      # optional
  assertions: warn                       # optional
```

```
default_entity: person # optional
logging:          # optional
  timings: True     # optional
  level: functions  # optional
autodump: False   # optional
autodiff: False   # optional
```

### 3.6.1 processes

This block defines which processes are executed and in what order. They will be executed for each period starting from *start\_period* for *periods* times. Since processes are defined on a specific entities (they change the values of items of that entity), you have to specify the entity before each list of process. Note that you can execute the same process more than once during a simulation and that you can alternate between entities in the simulation of a period.

In the example you see that after death and birth, the `household_composition` function is re-executed.

### 3.6.2 init

Every process specified here is only executed in the last period before *start period* (`start_period - 1`). You can use it to calculate (initialise) variables derived from observed data. This section is optional (it can be entirely omitted).

### 3.6.3 input

The initial (observed) data is read from the file specified in the *input* entry.

Specifying the *path* is optional. If it is omitted, it defaults to the directory where the simulation file is located.

The hdf5-file format can be browsed with *vitables* (<http://vitables.org/>) or another hdf5-browser available on the net.

### 3.6.4 output

The simulation result is stored in the file specified in the *output* entry. Only the variables defined at the *entity* level are stored. Temporary (local) variables are not saved. The output file contains values for each period and each field and each item.

Specifying the *path* is optional. If it is omitted, it defaults to the directory where the simulation file is located.

### 3.6.5 start\_period

Defines the first period (integer) to be simulated. It should be consistent (use the same scale/time unit) with the “period” column in the input data.

### 3.6.6 periods

Defines the number of periods (integer) to be simulated.

### 3.6.7 random\_seed

Defines the starting point (integer) of the pseudo-random generator. This section is optional. This can be useful if you want to have several runs of a simulation use the same random numbers.

### 3.6.8 skip\_shows

If set to *True*, makes all show() functions do nothing. This can speed up simulations which include many shows (usually for debugging). Defaults to *False*.

### 3.6.9 assertions

This option can take any of the following values:

**raise** interrupt the simulation if an assertion fails (this is the default).

**warn** display a warning message.

**skip** do not run the assertions at all.

### 3.6.10 default\_entity

If set to the name of an entity, the interactive console will start in that entity.

### 3.6.11 logging

#### level

Sets logging level. If set, it should be one of the three following values (by increasing level of verbosity):

**periods** show only periods.

**functions** show periods and functions (this is the default).

Changed in version 0.10: Renamed from “procedures” to “functions”.

**procedures** Deprecated since version 0.10: Please use “functions” instead.

**processes** show periods, functions and individual processes.

#### timings

If set to *False*, hide all timings from the simulation log, so that two simulation log files are more easily comparable (for example with “diff” tools like WinMerge). Defaults to *True*.

### 3.6.12 autodump

If this option is used, at the end of each function, all (non-scalar) variables changed during the function (including temporaries) will be dumped in an hdf5 file (named “autodump.h5” by default). This option can be used alone for debugging, or in combination with autodiff (in a later run). This option can take either a filename or a boolean (in which case “autodump.h5” is used as the filename). Defaults to *False*.

### 3.6.13 autodiff

If this option is used, at the end of each function, all (non-scalar) variables changed during the function (including temporaries) will be compared with the values stored previously by autodump in another run of the model (or a variant of it). This can be used to precisely compare two versions/variants of a model and see exactly where they start to differ. This option can take either a filename or a boolean (in which case “autodump.h5” is used as the filename). Defaults to *False*.





## RUNNING A MODEL/SIMULATION

- If you are using the bundled editor, simply open the simulation file and press F6.
- If you are using the command line, use:

```
[BUNDLEPATH]\liam2\main run <path_to_simulation_file>
```



## PROCESSES

The processes define how individuals of each entity evolve over time. LIAM2 supports several kinds of processes: *assignments*, which change the value of a variable (predictor) using an expression, *actions* which don't (but have other effects) and *control flow operators* which specify which processes need to be executed. Processes are usually grouped in *functions*.

### 5.1 Expressions

LIAM2 at its core compute expressions. Expressions are any combination of variables, operators, constants, globals and functions which explain how to compute a value.

Expression syntax looks like many other programming languages (>>> denotes an interactive prompt):

```
>>> 1 + 2
3
>>> 1.5 * 2.0 - 0.5 * 5.0
0.5
```

Numeric constants with a fractional part (e.g. 3.0, 1.6) have type float, others (e.g. 1, 2, 20) have type int.

Operations with mixed types (int and float) return floats.

```
>>> 4 - 0.5 * 3
2.5
```

Parentheses (()) can be used for grouping. For example:

```
>>> (2.5 - 0.5) * 4
8.0
```

LIAM2 supports many common operators:

- Arithmetic operators: +, -, \*, /, \*\* (exponent), % (modulo)

---

**Note:** An integer divided by an integer returns a float. For example “1 / 2” will evaluate to 0.5 instead of 0 as in many programming languages. If you are only interested in the integer part of that result (for example, if you know the result has no decimal part), you can use the *trunc* function:

```
>>> trunc(3 / 2)
1
```

- 
- Comparison operators: <, <=, ==, !=, >=, >
  - Boolean operators: and, or, not

---

**Note:** Starting with version 0.6, you do not need to use parentheses when you mix *boolean operators* with other operators.

```
age >= 10 and age < 20
```

is now equivalent to:

```
(age >= 10) and (age < 20)
```

---

## 5.2 Assignments

Assignments compute values for existing individuals. They have the following general format:

```
- variable_name: expression
```

What this means is: compute expression and store the result in the variable named *variable\_name*. The variable that is assigned to (the *endogenous variable*) will often be one of the variables defined in the *fields* block of the entity but, as we will see later, it is not always necessary.

*example*

```
- age: age + 1
```

This process increases the variable *age* of each individual by one, each period.

## 5.3 Functions

### 5.3.1 Declaration

One usually group processes in *functions*. Whenever a function is executed, the processes within the function are executed in the order they were declared. By using functions, one can actually make *building blocks* or modules in the model.

Changed in version 0.10: Functions were previously called “procedures”.

Each function definition starts at a new line with an extra indentation of four spaces compared to the “processes” keyword of the current entity. Within a function, each process should start on a new line, with an extra indentation of four spaces compared to the function name and a -. So, the usual setup to declare a function is:

```
processes:
    function_name:
        - process1
        - process2
```

*example*

```
entities:
    person:
        fields:
            - age: int

        processes:
            ageing:
                - age: age + 1
                - agegroup: trunc(age / 10) * 10

        display:
            - show("agegroup", agegroup)
```

In this example, there are two functions, one with two processes, and one with only one process. If the *ageing* function is executed, then both processes will be executed in turn (*age*, then *agegroup*).

---

**Note:** Function names have to be **unique** for each entity.

---

Within a function, it is possible for several assignment processes to modify the same variable. Like all processes within the function, they will be executed in turn. Splitting an expression into smaller bits overwriting the same variable over and over can make some long expressions much more readable.

*example*

```
processes:
  ageing:
    - age: age + 1
    - agegroup: trunc(age / 10)
    - agegroup: agegroup * 10
```

New in version 0.10.

Since version 0.10, functions can optionally also take arguments and return a value. So the general setup to declare a function is:

```
processes:
  function_name(argument1, argument2, ...):
    - process1
    - process2
    - return value
```

*example*

```
plus(a, b):
  - show("adding", a, "and", b)
  - return a + b
```

**Note:** There are currently two ways to define a function without arguments (with or without the parentheses after the function name). The version without parentheses is going to be deprecated at some point in the future, so you might want to get used to typing the parentheses.

### 5.3.2 Call

To execute a function, it has to be either:

1. specified in the “processes” section of the simulation block of the model.

*example*

```
entities:
  person:
    fields:
      - age: int
    processes:
      ageing:
        - age: age + 1
simulation:
  processes:
    - person: [ageing]
  ...
```

2. called explicitly within an expression. In that case, the format is:

```
function_name()
```

If the function does not return any result (or if the result is not interesting), this comes down to:

```
processes:
  myfunction:
    - anotherfunction()
```

but it can really be used anywhere within an expression (whose result can be stored in a variable like any other expression):

```
- variable_name: expr + function_name() * expr
```

*example*

```
entities:
  person:
    processes:
      other_func:
        - show("in other_func")

      plus(a, b):
        - return a + b

      test_func:
        - show("in test_func")
        - other_func()
        - show("back to test_func")
        # storing the result in a temporary variable
        - three: plus(1, 2)
        - show("1 + 2 is", three)
        # but the function call can happen anywhere within an
        # expression
        - show("(1 + 2) * 2 is", plus(1, 2) * 2)

simulation:
  processes:
    - person: [test_func]
```

### 5.3.3 Local (temporary) variables

All fields declared in the “fields” section of the entity are stored in the output file. Often you need a variable only to store an intermediate result during the computation of another variable.

In LIAM2, you can create a temporary variable at any point in the simulation by simply having an assignment to an undeclared variable. Temporary variables defined/computed within a function are local to that function: they are only valid within that function and their value will be discarded at the end of the function.

*example*

```
person:
  fields:
    # period and id are implicit
    - age: int
    - agegroup: int

  processes:
    ageing:
      - age: age + 1
      - agediv10: trunc(age / 10)
      - agegroup: agediv10 * 10
```

In this example, *agediv10* is a temporary (local) variable. In this particular case, we could have bypassed the temporary variable, but when a model contains very long expressions, it is often more readable to split it using temporary variables. Also if some long expression occurs several times, it is often more efficient to express it (and compute it) only once and store its result in a temporary variable.

If you want to pass variables between functions you have to make them global by defining them in the **fields** section.

**bad example**

```
person:
  fields:
    - age: int
```

```

processes:
  ageing:
    - age: age + 1
    - isold: age >= 150 # isold is a local variable
    - show("isold", isold)

  rejuvenation:
    - age: age - 1
    - backfromoldage: isold and age < 150 # <-- WRONG !
    - show("back from old age", backfromoldage)

```

In this example, *isold* and *backfromoldage* are local variables. They can only be used in the function where they are defined. Because we are trying to use the local variable *isold* in another function in this example, LIAM2 will refuse to run, complaining that *isold* is not defined.

### 5.3.4 Actions

In LIAM2, there are a few builtin functions which do not return any value (but have other effects). We call those *actions*. Since they do not need a variable to store their result, we simply:

```

processes:
  function_name:
    - action_expression
    ...

```

*example*

```

processes:
  death:
    - dead: age > 150
    - remove (dead)

```

## 5.4 globals

Globals can be used in expressions in any entity. LIAM2 currently supports two kinds of globals: tables and multi-dimensional arrays. They both declared (see the *globals* section) before they can be used.

Globals tables come in two variety: those with a **PERIOD** column and those without.

The fields in a globals **table with a PERIOD column** can be used like normal (entity) fields except they need to be prefixed by the name of their table:

```
myvariable: mytable.MYINTFIELD * 10
```

the value for MYINTFIELD is in fact the value MYINTFIELD has for the period currently being evaluated.

There is a special case for the **periodic** table: its fields do not need to be prefixed by “periodic.” (but they can be, if desired).

```

- retirement_age: if(gender, 65, WEMRA)
- workstate: if(age >= retirement_age, 9, workstate)

```

This changes the workstate of the individual to retired (9) if the age is higher than the required retirement age in that year.

Another way to use globals from a table with a **PERIOD** column is to specify explicitly for which period you want them to be evaluated. This is done by using `tablename.FIELDNAME[period_expr]`, where `period_expr` can be any expression yielding a valid period value. Here are a few artificial examples:

```
- women_retirement_age_in_2010: WEMRA[2010]
- women_retirement_age_in_previous_period: WEMRA[period - 1]
# a possibly different value for each woman
- women_retirement_age_when_60: WEMRA[year_of_birth + 60]
```

Globals tables **without a PERIOD column** can **only** be used with the second syntax, and the row index (0 based) must be given explicitly: LIAM2 does not automatically compute it (by subtracting the “base period” from the index).

Globals **arrays** can simply be used like a normal field:

```
myvariable: MYARRAY * 2
```

## 5.5 Built-in Functions

### 5.5.1 conditional function

One of the most used function in LIAM2 is the conditional function. It evaluates a condition and, depending on its value, returns the result of one expression or another. Its general format is:

```
if(condition_expression, expression_if_true, expression_if_false)
```

*example*

```
agegroup: if(age < 50,
            5 * trunc(age / 5),
            10 * trunc(age / 10))
```

**Note:** The *if* function always requires three arguments. If you want to leave a variable unchanged if a condition is not met, use the variable in the *expression\_if\_false*:

```
# retire people (set workstate = 9) when aged 65 or more
workstate: if(age >= 65, 9, workstate)
```

You can nest if-functions. The example below retires men (gender = True) over 64 and women over 61.

```
workstate: if(gender,
            if(age >= 65, 9, workstate),
            if(age >= 62, 9, workstate))
# could also be written like this:
workstate: if(age >= if(gender, 65, 62), 9, workstate)
```

### 5.5.2 mathematical functions

- `log(expr)`: natural logarithm (ln)
- `exp(expr)`: exponential
- `abs(expr)`: absolute value
- `round(expr[, n])`: returns the rounded value of `expr` to specified `n` (number of digits after the decimal point). If `n` is not specified, 0 is used.
- `trunc(expr)`: returns the truncated value (by dropping the decimal part) of `expr` as an integer.
- `clip(x, a, b)`: returns `a` if `x < a`, `x` if `a < x < b`, `b` if `x > b`.
- `min(x, a)`, `max(x, a)`: the minimum or maximum of `x` and `a`.



### 5.5.3 aggregate functions

- **count([condition]):** count individuals

It counts the individuals in the current entity. If a (boolean) condition is given, it only counts the ones satisfying that condition. For example, `count(male and age >= 18)` will produce the number of men in the sample who are eighteen years old or older.

---

**Note:** `count()` can be used without any argument: `count()` will return the total number of individuals in the sample for the current entity.

---

- **sum(expr[, filter=condition][, skip\_na=True]):** sum of an expression

It computes the sum of any expression over all individuals of the current entity. If a **filter** (boolean condition) is given, it only takes into account the individuals satisfying the filter. For example `sum(earnings)` will produce the sum of the earnings of all persons in the sample, while `sum(earnings, age >= 30)` will produce the sum of the earnings of all persons in the sample who are 30 or older. **skip\_na** determines whether missing values (nan) are discarded before the computation or not. It defaults to `True`.

---

**Note:** `sum` and `count` are exactly equivalent if their only argument is a boolean variable (eg. `count(age >= 18) == sum(age >= 18)`).

---

- **avg(expr[, filter=condition][, skip\_na=True]):** average
- **std(expr[, filter=condition][, skip\_na=True]):** standard deviation
- **min(expr[, filter=condition][, skip\_na=True]):** minimum
- **max(expr[, filter=condition][, skip\_na=True]):** maximum
- **median(expr[, filter=condition][, skip\_na=True]):** median
- **percentile(expr, percent[, filter=condition][, skip\_na=True]):** percentile
- **gini(expr[, filter=condition][, skip\_na=True]):** gini
- **all(condition1[, filter=condition2]):** is condition True for all?

Returns True if all individuals who satisfy the optional condition2 also satisfy condition1, False otherwise. Note that `all(condition1, filter=condition2)` is equivalent to `all(condition1 and condition2)`.

- **any(condition1[, filter=condition2]):** is condition True for any?

Returns True if any individual who satisfy the optional condition2 also satisfy condition1, False otherwise. Note that `any(condition1, filter=condition2)` is equivalent to `any(condition1 and condition2)`.

### 5.5.4 link methods

(one2many links)

- `link.count([filter])` - counts the number of related individuals
- **`link.sum(expr[, filter])` - compute the sum of an expression over the related individuals**
- **`link.avg(expr[, filter])` - compute the average of an expression over the related individuals**
- **`link.min(expr[, filter])` - compute the minimum of an expression over the related individuals**
- **`link.max(expr[, filter])` - compute the maximum of an expression over the related individuals**

*example*

```
entities:
  household:
    fields:
      # period and id are implicit
```

```

- nb_persons: {type: int, initialdata: False}

links:
  persons: {type: one2many, target: person, field: household_id}

processes:
  household_composition:
    - nb_persons: persons.count()
    - nb_children: persons.count(age < 18)
    - total_income: persons.sum(income)
    - avg_age: persons.avg(age)

```

### 5.5.5 temporal functions

- `lag(expr[, num_periods][, missing=value])`: value at previous period.

**expr**: any expression.

**num\_periods**: optional argument specifying the number of periods to go back to. This can be either a constant or a scalar expression. Defaults to 1.

**missing**: the value to return for individuals which were not present in the past period. By default, it returns the missing value corresponding to the type of the expression: -1 for an integer expression, nan for a float or False for a boolean.

*example*

```

lag(age) # the age each person had last year, -1 if newborn
lag(age, missing=0) # the age each person had last year, 0 if newborn
avg(lag(age)) # average age that the current population had last year
lag(avg(age)) # average age of the population of last year
lag(age, 2) # the age each person had two years ago (-1 for
# newborns)
lag(lag(age)) # this is equivalent (but slightly less efficient)

```

- `value_for_period(expr, period[, missing=value])`: value at a specific period

**expr**: any expression.

**period**: the period used to evaluate the expression. This can be either a constant or a scalar expression.

**missing**: the value to return for individuals which were not present in the period. By default, it returns the missing value corresponding to the type of the expression: -1 for an integer expression, nan for a float or False for a boolean.

*example*

```
value_for_period(inwork and not male, 2002)
```

- `duration(expr)`: number of consecutive period the expression was True

*examples*

```

duration(inwork and (earnings > 2000))
duration(educationlevel == 4)

```

- `tavg(expr)`: average of an expression since the individual was created

*example*

```
tavg(income)
```

- `tsum(expr)`: sum of an expression since the individual was created

## 5.5.6 random functions

LIAM2 includes support for many random number generator functions. Like for all other functions in LIAM2, all arguments can be expressions (computed at runtime) and arguments with default values can be omitted. All those functions provide the same interface than (and actually internally use) the corresponding functions in `numpy.random`.

*examples*

```
uniform()           # uniform in [0, 1)
normal(loc=0.0, scale=1.0) # standard normal (mean=0, stdev=1)
normal()           # equivalent
normal(scale=std(errsal)) # stdev derived from the "errsal" variable
randint(0, 10)     # random integer between 0 and 10 (excluded)
```

**beta(a, b, size=None)** The Beta distribution over [0, 1]. See `numpy.random.beta` for details.

New in version 0.9.

**binomial(n, p, size=None)** Draw samples from a binomial distribution. See `numpy.random.binomial` for details.

New in version 0.9.

**chisquare(df, size=None)** Draw samples from a chi-square distribution. See `numpy.random.chisquare` for details.

New in version 0.9.

**dirichlet(alpha, size=None)** Draw samples from the Dirichlet distribution. See `numpy.random.dirichlet` for details.

New in version 0.9.

**exponential(scale=1.0, size=None)** Exponential distribution. See `numpy.random.exponential` for details.

New in version 0.9.

**f(dfnum, dfden, size=None)** Draw samples from a F distribution. See `numpy.random.f` for details.

New in version 0.9.

**gamma(shape, scale=1.0, size=None)** Draw samples from a Gamma distribution. See `numpy.random.gamma` for details.

New in version 0.9.

**geometric(p, size=None)** Draw samples from the geometric distribution. See `numpy.random.geometric` for details.

New in version 0.9.

**gumbel(loc=0.0, scale=1.0, size=None)** Gumbel distribution, also known as the Smallest Extreme Value (SEV) distribution. See `numpy.random.gumbel` for details.

New in version 0.8.1.

**hypergeometric(ngood, nbad, nsample, size=None)** Draw samples from a Hypergeometric distribution. See `numpy.random.hypergeometric` for details.

New in version 0.9.

**laplace(loc=0.0, scale=1.0, size=None)** Draw samples from the Laplace or double exponential distribution with specified location (or mean) and scale (decay). See `numpy.random.laplace` for details.

New in version 0.9.

**lognormal(mean=0.0, sigma=1.0, size=None)** Return samples drawn from a log-normal distribution. See `numpy.random.lognormal` for details.

New in version 0.9.

**logseries(p, size=None)** Draw samples from a Logarithmic Series distribution. See [numpy.random.logseries](#) for details.

New in version 0.9.

**multinomial(n, pvals, size=None)** Draw samples from a multinomial distribution. See [numpy.random.multinomial](#) for details.

New in version 0.9.

**multivariate\_normal(mean, cov, size=None)** Draw random samples from a multivariate normal distribution. See [numpy.random.multivariate\\_normal](#) for details.

New in version 0.9.

**negative\_binomial(n, p, size=None)** Draw samples from a negative\_binomial distribution. See [numpy.random.negative\\_binomial](#) for details.

New in version 0.9.

**noncentral\_chisquare(df, nonc, size=None)** Draw samples from a noncentral chi-square distribution. See [numpy.random.noncentral\\_chisquare](#) for details.

New in version 0.9.

**noncentral\_f(dfnum, dfden, nonc, size=None)** Draw samples from the noncentral F distribution. See [numpy.random.noncentral\\_f](#) for details.

New in version 0.9.

**normal(loc=0.0, scale=1.0, size=None)** Draw random samples from a normal (Gaussian) distribution. See [numpy.random.normal](#) for details.

**pareto(a, size=None)** Draw samples from a Pareto II or Lomax distribution with specified shape. See [numpy.random.pareto](#) for details.

New in version 0.9.

**poisson(lam=1.0, size=None)** Draw samples from a Poisson distribution. See [numpy.random.poisson](#) for details.

New in version 0.9.

**power(a, size=None)** Draws samples in [0, 1] from a power distribution with positive exponent  $a - 1$ . See [numpy.random.power](#) for details.

New in version 0.9.

**randint(low, high=None, size=None)** Return random integers between low (inclusive) and high (exclusive). See [numpy.random.randint](#) for details.

**rayleigh(scale=1.0, size=None)** Draw samples from a Rayleigh distribution. See [numpy.random.rayleigh](#) for details.

New in version 0.9.

**standard\_cauchy(size=None)** Standard Cauchy distribution with mode = 0. See [numpy.random.standard\\_cauchy](#) for details.

New in version 0.9.

**standard\_exponential(size=None)** Draw samples from the standard exponential distribution. See [numpy.random.standard\\_exponential](#) for details.

New in version 0.9.

**standard\_gamma(shape, size=None)** Draw samples from a Standard Gamma distribution. See [numpy.random.standard\\_gamma](#) for details.

New in version 0.9.

**standard\_normal(size=None)** Returns samples from a Standard Normal distribution (mean=0, stdev=1). See [numpy.random.standard\\_normal](#) for details.

New in version 0.9.

**standard\_t(df, size=None)** Standard Student's t distribution with df degrees of freedom. See [numpy.random.standard\\_t](#) for details.

New in version 0.9.

**triangular(left, mode, right, size=None)** Draw samples from the triangular distribution. See [numpy.random.triangular](#) for details.

New in version 0.9.

**uniform(low=0.0, high=1.0, size=None)** Draw random samples between low (inclusive) and high (exclusive) from a uniform distribution. See [numpy.random.uniform](#) for details.

**vonmises(mu, kappa, size=None)** Draw samples from a von Mises distribution. See [numpy.random.vonmises](#) for details.

New in version 0.9.

**wald(mean, scale, size=None)** Draw samples from a Wald, or Inverse Gaussian, distribution. See [numpy.random.wald](#) for details.

New in version 0.9.

**weibull(a, size=None)** Weibull distribution. See [numpy.random.weibull](#) for details.

New in version 0.9.

**zipf(a, size=None)** Draw samples from a Zipf distribution. See [numpy.random.zipf](#) for details.

New in version 0.9.

## choice

Monte Carlo or probabilistic simulation is a method for iteratively evaluating a deterministic model using sets of random numbers as inputs. In microsimulation, the technique is used to simulate changes of state dependent variables. Take the simplest example: suppose that we have an exogenous probability of an event happening,  $P(x=1)$ , or not  $P(x=0)$ . Then draw a random number  $u$  from an uniform  $[0,1)$  distribution. If, for individual  $i$ ,  $u_i < P(x=1)$ , then  $x_i=1$ . If not, then  $x_i=0$ . The expected occurrences of  $x$  after, say, 100 runs is then  $P(x=1) * 100$  and the expected value is  $1xP(1)+0xP(0)=P(1)$ . This type of simulation hinges on the confrontation between a random variable and an exogenous probability.

In LIAM2, such a probabilistic simulation is called a **choice** process. Suppose  $i=1..n$  choice options, each with a probability `prob_option_i`. A choice expression then has the following form:

```
choice([option_1, option_2, ..., option_n],
       [prob_option_1, prob_option_2, ..., prob_option_n])
```

Note that both the list of options and their probabilities are between []'s. The options can be of any numeric type.

A simple example of a process using a choice expression is the simulation of the gender of newborns (51% males and 49% females), as such:

```
gender: choice([True, False], [0.51, 0.49])
```

In the current version of LIAM2, it is not possible to combine a choice with alignment.

Here is a more complex example of a process using choice. Suppose we want to simulate the work status (blue collar worker or white collar worker) for all working individuals. We want to assign 1 or 2 to their collar variable based on their sex and level of education (education\_level=2, 3, 4). We could write our process as follow:

```
collar_process:
- no_collar: WORKING and collar == -1
- collar: if(no_collar and (education_level == 2),
            if(gender,
               choice([1, 2], [0.836, 0.164]),
               choice([1, 2], [0.687, 0.313]) ),
            collar)
- collar: if(no_collar and (education_level == 3),
            if(gender,
               choice([1, 2], [0.643, 1 - 0.643]),
               choice([1, 2], [0.313, 1 - 0.313]) ),
            collar)
- collar: if(no_collar and (education_level == 4),
            if(gender,
               choice([1, 2], [0.082, 1 - 0.082]),
               choice([1, 2], [0.039, 1 - 0.039]) ),
            collar)
```

The function *collar\_process* has collar as the key endogenous variable and has four sub-processes.

The first sub-process defines a local variable *no\_collar*, which will be used to select those that the function should apply to. These are all the workers that do not have a value for collar.

The next three sub-processes simulate the actual collar variable. If one meets the above *no\_collar* filter and has the lowest level of education (2), then one has a probability of about 83.6% (men) and 68.7% (women) of being a blue collar worker. If one has “education\_level” equal to 3, the probability of being a blue collar worker is lower (64.3% for men and 31.3% for women), etc.

## 5.5.7 Regressions

### logit\_score

The logit of a number *p* between 0 and 1 is given by the formula:

```
logit(p) = log(p / (1 - p))
```

Its inverse, the logistic function has the interesting property that it can convert any real number into a probability.

```
logistic(a) = 1 / (1 + exp(-a))
```

The *logit\_score* function is a logistic with a random part:

```
logit_score(a) = logistic(a - logit(u))
```

where *u* is a random number from an uniform distribution [0, 1).

*logit\_score* is very useful in behavioural equations. A behavioural equation starts by creating a score that reflects the risk *p*\**i* of an event occurring. A typical usage is as follow:

```
- score_variable: if(condition_1,
                    logit_score(logit_expr_1),
                    if(condition_2,
                       logit_score(logit_expr_2),
                       -1))
```

However, the nested structure can make things less readable if you have many different conditions. In that case, one would prefer the following longer form:

```
process_name:
  # initialise the score to -1
  - score_variable: -1

  # first condition
```

```

- score_variable: if(condition_1,
                    logit_score(logit_expr_1),
                    score_variable)
# second condition
- score_variable: if(condition_2,
                    logit_score(logit_expr_2),
                    score_variable)

# ... other conditions ...

```

In a first sub-process, a variable *score\_variable* is set equal to -1, because this makes it highly unlikely that the event will happen to those not included in the conditions for which the logit is applied.

Next, subject to conditions *condition\_1* and *condition\_2*, this score (risk) is simulated on the basis of estimated logits. Note that by specifying the endogenous variable *score\_variable* without any transformation in the “else” conditions of the if functions makes sure that the score variable is not manipulated by a sub-process it does not pertain to.

When the score is known, it can be either used as-is:

```
- event_happened: uniform() < score_variable
```

or in combination with an alignment (see below).

## align

Now that we have computed a score (risk) for an event happening, we might want to use alignment so the number of events occurring per category matches a proportion defined externally.

There are different ways to choose which individuals are taken. The methodology used for now by LIAM2 is called “alignment by sorting”, that is, for each category, the N individuals with the highest scores are selected.

The score computation is not done internally by the align() function, but is rather computed by an expression given by the modeller. One will usually use logit\_score() to compute it, but it can be computed in any other way a modeller choose.

---

**Note:** It is usually a good idea to include a random component (like in logit\_score) in the score expression because otherwise the individuals with the smaller scores will never be selected.

---

To know more about the alignment process reading “Evaluating Alignment Methods in Dynamic Microsimulation Models”, by Li and O’Donoghue is advised.

An alignment expression takes the following general form:

```

align(score,
      proportions
      [, filter=conditions]
      [, take=conditions]
      [, leave=conditions]
      [, expressions=expressions]
      [, possible_values=pvalues]
      [, frac_need="uniform"|"round"|"cutoff"])

```

For example, it could look like:

```

- unemp: align(unemp_score,
              'al_p_unemployed_m.csv',
              filter=not ISINWORK and (age > 15) and (age < 65),
              take=ISUNEMPLOYED,
              leave=ISSTUDENT or ISRETIRED)

```

Now let us examine each argument in turn:

- **score:** it must be an expression (or a simple variable) returning a numerical value. It will be used to rank individuals. One will usually use `logit_score()` to compute the score, but it can be computed in any other way a modeller choose. Note that the score is not modified in any way within the `align()` function, so if one wants a random factor, it should be added manually (or through the use of a function like `logit_score` which includes one).
- **proportions:** the target proportions for each category. This argument can take many forms. The most common one will probably be a string holding the name of a file containing the alignment data (like in the example above) but it can be any of the following:
  - a single scalar, for aligning with a constant proportion.
  - a list of scalars, for aligning with constant proportions per category.
  - an expression returning a single scalar.
  - an expression returning an n-dimensional array. expressions and possible values will be retrieved from that array, so you can simply use:

```
align(score_expr, array_expr)
```

- a list of expressions returning scalars [`expr1`, `expr2`].
- a string treated as a filename. That file should be in the “array” format described in the *Importing data* section. In that case, the proportions, expressions (column names) and possible values are read from that file. The “fname” argument which used to be the way to define this is still supported for backward compatibility.

There is no technical restriction on names for files containing alignment data but, by convention, they usually use the following pattern: start with the prefix *al\_* followed by the name of the endogenous variable and a suffix *\_m* or *\_f*, depending on gender.

- **filter:** an expression specifying which individuals to take into account for the alignment. Note that if the `align()` function is used inside an *if()* expression, its filter is adjusted accordingly (“anded” with the filter of the *if()* expression). For example:

```
- aligned: if(condition,
              align(score_expr1, 'filename1.csv'),
              align(score_expr2, 'filename2.csv'))
```

is equivalent to:

```
- aligned1: align(score_expr1, 'filename1.csv', filter=condition)
- aligned2: align(score_expr2, 'filename2.csv', filter=not condition)
- aligned: if(condition, aligned1, aligned2)
```

- **take:** an expression specifying individuals which should always be selected, regardless of their score. This argument should be used with care as those individuals will be selected unconditionally, even if that means overflowing the number of individuals desired to satisfy the alignment.

Suppose that the alignment specifies that 10 individuals should experience a certain event, and that there are 3 individuals who meet the conditions specified in the *take*. Then these 3 individuals will be selected a priori (irrespective of their score) and the alignment process will select the remaining 7 candidates from the rest of the sample.

A “softer” alternative can be easily achieved by setting a very high score for individuals to be taken first.

- **leave:** an expression specifying individuals which should never be selected, regardless of their score. This argument should be used with care as those individuals will *never* be selected, even if that cause the target number of individuals for some categories to not be reached.

A “softer” alternative can be easily achieved by setting a very low score for individuals to be taken last.

---

**Note:** Note that even if the score for an individual is -1 (or any other negative number), it *can* still be selected by the alignment expression. This happens when there are not enough candidates (selected by the filter) to meet the alignment needs.

---



- **expressions:** specify the expressions used to partition the individuals into the different alignment categories. If proportions is a file name, the column names declared in the file are used by default, but they can be overridden using this argument. For example:

```
align(0.0, 'al_p_dead.csv', expressions=[gender, age + 1])
```

- **possible\_values:** specify the different values for each of the expressions in the expressions argument that should be evaluated. The combination of the different lists of possible values will form all the alignment categories. For example:

```
align(0.0,
      proportions=[0.1, 0.2, 0.3, 0.4],
      expressions=[gender, age < 50],
      possible_values=[[False, True], [False, True]])
```

- **frac\_need:** control how “fractional needs” are handled. This argument can take any of three values: “uniform” (default), “cutoff” or “round”.
  - “uniform” draws a random number (u) from an uniform distribution and adds one individual if  $u < \text{fractional\_need}$ . “uniform” is the default behavior.
  - “round” simply rounds needs to the nearest integer. In other words, one individual is added for a category if the fractional need for that category is  $\geq 0.5$ .
  - “cutoff” tries to match the total need as closely as possible (at the expense of a slight loss of precision for individual categories) by searching for the “cutoff point” that yields:

```
count(frac_need >= cutoff) == sum(frac_need)
```

In practice alignment data is often separate for men and women. In that case, one will usually use the following form:

```
- variable: if(condition,
              if(gender,
                 align(score_expr, 'filename_m.csv'),
                 align(score_expr, 'filename_f.csv')),
              False)
```

Since LIAM2 supports alignment with any number of dimensions, one could also merge both data files in a single file with one more dimension and use a single align() expression:

```
- variable: if(condition,
              align(score_expr, 'filename_m_and_f.csv'),
              False)
# or even
- variable: align(score_expr, 'filename_m_and_f.csv', filter=condition)
```

The example below describes the process of getting (or keeping) a job:

```
inwork:
- work_score: -1
# men
- work_score: if(ISMALE and ACTIVEAGE and ISINWORK,
                 logit_score(-0.196599 * age + 0.0086552 * age **2 - 0.000988 * age **3
                             + 0.1892796 * ISMARRIED + 3.554612),
                 work_score)
- work_score: if(ISMALE and ACTIVEAGE and (ISUNEMPLOYED or ISOTHERINACTIVE),
                 logit_score(0.9780908 * age - 0.0261765 * age **2 + 0.000199 * age **3
                             - 12.39108),
                 work_score)
# women
- work_score: if(ISFEMALE and ACTIVEAGE and ISINWORK,
                 logit_score(-0.2740483 * age + 0.0109883 * age **2 - 0.0001159 * age **3
                             - 0.0906834 * ISMARRIED + 3.648706),
                 work_score)
```

```

- work_score: if(ISFEMALE and ACTIVEAGE and (ISUNEMPLOYED or ISOTHERINACTIVE),
    logit_score(0.8217638 * age - 0.0219761 * age **2 + 0.000166 * age **3
    - 0.5590975 * ISMARRIED - 10.48043),
    work_score)

- work: if(ACTIVEAGE,
    if(ISMALE,
        align(work_score, 'al_p_inwork_m.csv',
            leave=ISSTUDENT or ISRETIRED),
        align(work_score, 'al_p_inwork_f.csv',
            leave=ISSTUDENT or ISRETIRED)),
    False)

```

The first sub process illustrates a “*soft leave*” by setting the score variable *work\_score* to -1. This makes sure that the a priori selection probability is very low (but not zero, as in the case of *leave* conditions) for those who satisfy the filter of the alignment but for which a score is not explicitly specified the subsequent processes.

Next come four *if* conditions, separating the various behavioural equations to the sub-sample they pertain to. The first two conditions pertain to men and respectively describe the probability of keeping a job and getting a job. The next two conditions describe the same transitions but for women.

The last sub-process describes the alignment process itself. Alignment is applied to individuals between the age of 15 and 65. The input-files of the alignment process are ‘al\_p\_inwork\_m.csv’ and ‘al\_p\_inwork\_f.csv’. The alignment process uses as input the scores simulated previously, and the information in the alignment files and sets the boolean variable *work*. No “take” or “leave” conditions are used in this case.

## align\_abs

`align_abs` is equivalent to `align()`, except that it aligns to absolute numbers instead of proportions. It also supports a few additional arguments to work on a **linked entity**.

The general form of `align_abs` is :

```

align_abs(score,
    need,
    [filter=conditions,]
    [take=conditions,]
    [leave=conditions,]
    [expressions=expressions,]
    [possible_values=pvalues,]
    [frac_need="uniform"|"round"|"cutoff",]
    [link=link_name,]
    [secondary_axis=column_name,]
    [errors="default"|"carry"])

```

In addition to all the arguments supported by `align()`, `align_abs()` also supports an optional “link” argument, which makes it work on a linked entity.

Here is a description of the arguments specific to `align_abs`:

- **link**: must be the name of a one2many link. When the link argument is used, the groups (given by the alignment file or in the *expressions* argument) are evaluated on the linked entity and the needs are expressed in terms of that linked entity. When the link argument is in effect, `align_abs` uses the “Chenard” algorithm.

This can be used, for example, to take as many *households* as necessary trying to get as close as possible to a particular distribution of *persons*.

- **secondary\_axis**: name of an axis which will influence `rel_need` when the subtotal for that axis is exceeded. See `total_by_sex` in Chenard. *secondary\_axis* can only be used in combination with the link argument and it *must* be one of the alignment columns.
- **errors**: if set to ‘carry’, the error for a period (difference between the number of individuals aligned and the target for each category) is stored and added to the target for the next period. In the current version of LIAM2, *errors* can only be used in combination with the *link* argument.

*example*

```

test_align_link:
  # this is a function defined at the level of households
  - num_persons: persons.count()
  - total_population: sum(num_persons)

  # MIG_PERCENT is a simple float periodic global
  - num_migrants: total_population * MIG_PERCENT

  # MIG is a 3d array: age - gender - period but we want only the
  # 2d array for this period.
  # currently, we need to manually compute the index (0-based)
  # for the current period in the array. We know the first
  # period in our array is 2000, so the index for the current
  # period is: "period - 2000"
  # period is the last dimension of the array and we do not
  # want to modify other dimensions, so we use ":" for those
  # dimensions.
  - mig_period: MIG[:, :, period - 2000]

  # Distribute total desired migrants, by age and gender
  - need: num_migrants * mig_period

  # households have a 50% chance to be candidate for immigration
  - is_candidate: uniform() < 0.5

  # apply alignment, using the number of persons in each household
  # as a score, so that households with more persons are tried first
  # as this gives better results.
  - aligned: align_abs(num_persons, need,
                      filter=is_candidate,
                      link=persons, secondary_axis=gender,
                      errors='carry')

```

**logit\_regr**

logit\_regr is a shortcut form to call logit\_score and “evaluate whether the event happened” in a single function. Thus, the function returns a boolean: True for individuals which are selected, False for all others. Its general form is:

```

- aligned: logit_regr(expression,
                    [filter=conditions,]
                    [align=proportions])

```

The *align* argument supports all the same formats than the *proportions* argument of align(): filename, percentage, list of values, ...

Evaluation whether the event happens is done differently whether the align argument is used or not. If alignment is used, logit\_regr is equivalent to:

```

- aligned: align(logit_score(expression), proportions, filter=conditions)

```

Without align argument, the condition for the event occurring is  $p_i > 0.5$ , which means that in this form, logit\_regr is equivalent to:

```

- aligned: if(conditions, logit_score(expression) > 0.5, False)

```

*example*

```

- to_give_birth: logit_regr(0.0,
                          filter=FEMALE and (age >= 15) and (age <= 50),
                          align='al_p_birth.csv')

```

## other regressions

- Continuous (expr + normal(0, 1) \* mult + error\_var): `cont_regr(expr[, filter=None, mult=0.0, error_var=None])`
- Clipped continuous (always positive): `clip_regr(expr[, filter=None, mult=0.0, error_var=None])`
- Log continuous (exponential of continuous): `log_regr(expr[, filter=None, mult=0.0, error_var=None])`

## 5.5.8 Matching functions

The goal of matching functions is to match individuals from a set with individuals from another set, for example to select spouses for marriage. There are many different algorithms to do so. LIAM2 currently implements two: **matching** takes the highest scoring individual in set 2 for each individual in set 1, while **rank\_matching** sorts both sets by their own ordering expression and match individuals with the same rank.

### matching

For each individual in set 1 following the order given by the *orderby* argument, the function computes the score of all (unmatched) individuals in set 2 and takes the highest scoring one. The function returns the id of the matched individual for each individual which was actually matched, -1 for others. If the two sets are of different sizes, the surplus of the largest set is ignored.

*generic setup*

```
matching(set1filter=boolean_expr,
         set2filter=boolean_expr,
         score=coef1 * field1 + coef2 * other.field2 + ...,
         orderby=expr,                    # expression or 'EDtM'
         [pool_size=int,]                 # None by default
         [algo="onebyone"|"byvalue"])    # "onebyone" by default
```

Arguments:

- **set1filter** and **set2filter** specify the boolean filters which provide the two sets to match.
- **score** is an expression to assign a value to each individual of set 2 (given a particular individual in set 1). In the score expression the fields of the set 1 individual can be used normally while the fields of its possible partners (from set 2) can be used by prefixing them by “**other**”.
- **orderby** defines the order in which the individuals of the first set are matched. It can be either an expression or the ‘EDtM’ string. If it is an expression, individuals in set 1 will be sorted by its decreasing values. If set to ‘EDtM’ (Euclidean Distance to the Mean), individuals will be sorted by decreasing distance to an hypothetical “mean individual” measured on all the variables (of set 1) used in the score expression<sup>1</sup>. In short, “unusual individuals” will be matched first.
- The optional **pool\_size** argument specifies the size of the subset of set 2 to use as candidates. If used, it should be a positive integer. In that case, the best match for each individual of set 1 will be searched for in a random subset of size *pool\_size*, instead of in all unmatched individuals in set 2. This may be closer to actual marriage where people do not meet every single potential partner. When the remaining number of candidates in set 2 is lower than *pool\_size*, the match is looked for among all remaining candidates.

New in version 0.9.

- The optional **algo** argument specifies the algorithm to use. It can be set to either “onebyone” or “byvalue”.
  - “onebyone” is the current default and should give the same result than with LIAM2 versions < 0.9.
  - “byvalue” groups individuals by their value for all the variables involved in both the score and orderby expressions, and match groups together. Depending on whether all individuals in each set have many different combinations of values or not, this is usually much faster than matching each individual in

<sup>1</sup>  $\sum((\text{variable} - \text{mean}(\text{variable}))^2 / \text{var}(\text{variable}))$ .

turn. It is thus **highly encouraged** to use this option if possible. It will become the default value in a future version. This algorithm also scales better ( $O(N1g*N2g)$  instead of  $O(N1*N2)$  where  $N1g$  and  $N2g$  are the number of combination of values in each set and  $N1$  and  $N2$  are the number of individuals in each set).

**Note:** the “byvalue” algorithm is only available if the C extensions are installed.

**Warning:** The results of the two algorithms are **NOT** exactly the same, hence the switch cannot be done lightly from one to another if comparing simulation results with those of an earlier version of LIAM2 (< 0.9) is of importance.

New in version 0.9.

*example*

```
marriage:
- to_couple: not in_couple and age >= 18 and age <= 90
- avg_age_males_to_couple: avg(age, filter=to_couple and MALE)
- difficult_match: if(to_couple and FEMALE,
                    abs(age - avg_age_males_to_couple),
                    nan)
- partner_id: if(to_couple,
                matching(set1filter=FEMALE, set2filter=MALE,
                        orderby=difficult_match,
                        score=- 0.4893 * other.age
                          + 0.0131 * other.age ** 2
                          - 0.0001 * other.age ** 3
                          + 0.0467 * (other.age - age)
                          - 0.0189 * (other.age - age) ** 2
                          + 0.0003 * (other.age - age) ** 3
                          - 0.9087 * (other.work and not work)
                          - 1.3286 * (not other.work and work)
                          - 0.6549 * (other.work and work)),
                partner_id)
```

The code above shows an application. First, we decided that all persons between 18 and 90 years old who are not part of a couple are candidate for marriage. Next, for each candidate women, the variable *difficult\_match* is the difference between her age and the average age of candidate men.

In a third step, for each candidate woman in turn (following the order set by *difficult\_match*), all candidate men which are still available are assigned a score and the man with the highest score is matched with that woman. This score depends on his age, his difference in age with the woman and the work status of the potential partners.

## rank\_matching

New in version 0.9.

rank\_matching works in three steps :

1. Set 1 is sorted by decreasing orderby1
2. Set 2 is sorted by decreasing orderby2
3. Individuals in the nth rank (position) in each list are matched together.

The function returns the id of the matched individual for each individual which was actually matched, -1 for others. If the two sets are of different sizes, the surplus of the largest set is ignored.

*generic setup*

```
rank_matching(set1filter=boolean_expr,
             set2filter=boolean_expr,
             orderby1=expression, orderby2=expression)
```

## 5.5.9 Lifecycle functions

### new

**new** creates new individuals. It can create individuals of the same entity (eg. a women gives birth) or another entity (eg. a *person*'s marriage creates a new *household*). The function returns the id of the newly created individuals.

*generic format*

```
new('entity_name'[, filter=expr][, number=value]
    *set initial values of a selection of variables*)
```

The first argument specifies the entity in which the individuals will be created (eg person, household, ...).

Then, one should use one of either the *filter* or the *number* argument.

- **filter** specifies which individuals of the current entity will serve as the origin for the new individuals (for persons, that would translate to who is giving birth, but the function can of course be used for any kind of entity).
- **number** specifies how many individuals need to be created. In this version, those new individuals do not have an “origin”, so they can copy value from it.

Any subsequent argument specifies values for fields of the new individuals. Any field which is not specified there will receive the missing value corresponding to the type of the field ('nan' for floats, -1 for integers and False for booleans). Those extra arguments can be given constants, but also any expression (possibly using links, random functions, ...). Those expressions are evaluated in the context of the origin individuals. For example, you could write “mother\_age = age”, which would set the field “mother\_age” on the new children to the age of their mother.

*example 1*

```
birth:
- to_give_birth: logit_regr(0.0,
                          filter=not gender and
                              (age >= 15) and (age <= 50),
                          align='al_p_birth.csv')
- new('person', filter=to_give_birth,
      mother_id = id,
      father_id = partner.id,
      household_id = household_id,
      partner_id = -1,
      age = 0,
      civilstate = SINGLE,
      gender=choice([True, False], [0.51, 0.49]) )
```

The first sub-process (*to\_give\_birth*) is a logit regression over women (not gender) between 15 and 50 which returns a boolean value whether that person should give birth or not. The logit itself does not have a deterministic part (0.0), which means that all women that meet the above condition are equally likely to give birth (they are selected randomly). This process is also aligned on the data in ‘al\_p\_birth.csv’.

In the above case, a new person is created for each time a woman is selected to give birth. Secondly, a number of links are established: the value for the *mother\_id* field of the child is set to the id-number of his/her mother, the child’s father is set to the partner of the mother, the child receives the household number of his/her mother, ... Finally some variables of the child are set to specific initial values: the most important of these is its gender, which is the result of a simple choice process.

**new** can create individuals of different entities; the below function *get\_a\_life* makes sure that all those who are single when they are 24 year old, leave their parents’ household for their own household. The region of this new household is created randomly through a choice-process.

*example 2*

```
get_a_life:
- household_id: if(ISSINGLE and age == 24,
                  new('household',
```

```

region_id=choice([0, 1, 2, 3],
                 [0.1, 0.2, 0.3, 0.4])),
household_id)

```

## clone

**clone** is very similar to **new** but is intended for cases where most or all variables describing the new individual should be copied from his/its parent/origin instead of being set to “missing”. With clone, you cannot specify what kind of entity you want to create, as it is always the same as the origin item. However, similarly to **new**, **clone** also allows fields to be specified manually by any expression evaluated on the parent/origin.

Put differently, a **new** with no fields mentioned will result in a new item of which the initial values of the fields are all set to missing and have to be filled through simulation; on the contrary, a **clone** with no fields mentioned will result in a new item that is an exact copy of the origin except for its id number which is always set automatically.

### example

```

make_twins:
- clone(filter=new_born and is_twin,
        gender=choice([True, False], [0.51, 0.49]))

```

## remove

**remove** removes items from an entity dataset. With this command you can remove obsolete items (eg. dead persons, empty households) thereby ensuring they are not simulated anymore. This will also save some memory and, in some cases, improve simulation speed.

The function below simulates whether an individual survives or not, and what happens in the latter case.

```

dead_function:
# decide who dies
- dead: if(gender,
           logit_regr(0.0, align='al_p_dead_m.csv'),
           logit_regr(0.0, align='al_p_dead_f.csv'))
# change the civilstate of the surviving partner
- civilstate: if(partner.dead, 5, civilstate)
# break the link to the dead partner
- partner_id: if(partner.dead, -1, partner_id)
# remove the dead
- remove(dead)

```

The first sub-process *dead* simulates whether an individual is ‘scheduled for death’, using again only a logistic stochastic variable and the age-gender-specific alignment process. Next some links are updated for the surviving partner. The sub-process *civilstate* puts the variable of that name equal to 5 (which means that one is a widow(er) for those individuals whose partner has been scheduled for death. Also, in that case, the partner identification code is erased. All other processes describing the heritage process should be included here. Finally, the *remove* command is called to removes the *dead* from the simulation dataset.

## 5.6 While loops

New in version 0.10.

### generic format

```

- while scalar_condition:
-   the_code_to_repeat
-   ...

```

**Warning:** the condition must be a scalar expression, that is it must have a single value for all individuals. In other words, the number of iterations is always the same for all individuals. See examples below.

*example 1*

```
count_to_5:
- i: 1
- while i <= 5:
  - show(i)
  - i: i + 1
```

Now let us suppose one wants to repeat a computation until some condition is met per individual. One could intuitively write it like below.

**bad example**

```
wrong_repeat_while_below_1:
- score: age / max(age)
- while score < 1: # <-- this line is WRONG !
  - score: score + 0.1
- show(score)
```

However, that would result in this error:

```
ValueError: The truth value of an array with more than one element is
ambiguous. Use a.any() or a.all()
```

The solution is to follow the advice in the error message and use `any()` in this case.

*example 2*

```
repeat_while_below_1:
- score: age / max(age)
- while any(score < 1):
  - score: score + 0.1
- show(score)
```

This will repeat the code until all individuals have reached the target **but** individuals who reached it early will continue to be updated, and it might not be what is needed. If that is the case, one has to **explicitly** only update the individuals which are not “done” yet.

*example 3*

```
repeat_while_below_1:
- score: age / max(age)
- while any(score < 1):
  - score: if(score < 1, score + 0.1, score)
- show(score)
```

## 5.7 Output

LIAM2 produces simulation output in three ways. First of all, by default, the simulated datasets are stored in hdf5 format. These can be accessed at the end of the run. You can use several tools to inspect the data.

You can display information during the simulation (in the console log) using the `show` function. You can write that same information to csv files using the `csv` function. You can produce tabular data by using the `dump` or `groupby` functions.

In the interactive console, you can use any of those output functions to inspect the data interactively.



### 5.7.1 show

*show* evaluates expressions and prints the result to the console log. Note that, in the *interactive console*, *show* is implicit on all commands, so you do not need to use it. *show* has the following signature:

```
show(expr1[, expr2, expr3, ...])
```

*example 1*

```
show(count(age >= 18))
show(count(not dead), avg(age, filter=not dead))
```

The first process will print out the number of persons of age 18 and older in the dataset. The second one displays the number of living people and their average age.

*example 2*

```
show("Count:", count(),
     "Average age:", avg(age),
     "Age std dev:", std(age))
```

gives

```
Count: 19944 Average age: 42.7496991576 Age std dev: 21.9815913417
```

Note that you can use the special character “\n” to display the rest of the result on the next line.

*example 3*

```
show("Count:", count(),
     "\nAverage age:", avg(age),
     "\nAge std dev:", std(age))
```

gives

```
Count: 19944
Average age: 42.7496991576
Age std dev: 21.9815913417
```

### 5.7.2 qshow

*qshow* evaluates expressions and prints their results to the console log alongside the “textual form” of the expressions. If several expressions are given, they are each printed on a separate line. *qshow* usage is exactly the same than *show*.

*example*

```
qshow(count(), avg(age), std(age))
```

will give:

```
count(): 19944
avg(age): 42.7496991576
std(a=age): 21.9815913417
```

### 5.7.3 csv

The *csv* function writes values to csv files.

```
csv(expr1[, expr2, expr3, ...,
     [suffix='file_suffix'][, fname='filename'][, mode='w']])
```

'suffix', 'fname' and 'mode' are optional arguments. By default (if neither 'fname' nor 'suffix' is used), the name of the csv file is generated using the following pattern: "{entity}\_{period}.csv".

*example*

```
csv(avg(income))
```

will create one file for each simulated period. Assuming, start\_period is 2002 and periods is 2, it will create two files: "person\_2002.csv" and "person\_2003.csv" with the average income of the population for period 2002 and 2003 respectively.

Arguments:

- 'suffix' allows to customize the name of the files easily. When it is used, the files are named using the following pattern: "{entity}\_{period}\_{suffix}.csv".

*example*

```
csv(avg(income), suffix='income')
```

would create "person\_2002\_income.csv" and "person\_2003\_income.csv".

- 'fname' allows defining the exact file name or pattern to use. You can optionally use the '{entity}' and '{period}' key words to customize the name.

*example*

```
csv(avg(income), fname='income{period}.csv')
```

would create "income2002.csv" and "income2003.csv".

- 'mode' allows appending (mode='a') to a csv file instead of overwriting it (mode='w' by default). This allows you, for example, to store the value of some expression for all periods in the same file (instead of one file per period by default).

*example*

```
csv(period, avg(income), fname='avg_income.csv', mode='a')
```

---

**Note:** Unless you erase/overwrite the file one way or another between two runs of a simulation, you will append the data of the current simulation to that of the previous one. One way to do overwrite the file automatically at the start of a simulation is to have a function in the init section without mode='a'.

---

If you want that file to start empty, you can do so this way:

```
csv(fname='avg_income.csv')
```

If you want some headers in your file, you could write them at that point:

```
csv('period', 'average income', fname='avg_income.csv')
```

When you use the csv() function in combination with (at least one) table expressions (see dump and groupby functions below), the results are appended below each other.

```
csv(table_expr1, 'and here goes another table', table_expr2,
     fname='tables.csv')
```

Will produce a file with a layout like this:

```
| table 1 value at row 1, col 1 | col 2 | ... | col N |
|                               |     |   |     |
|                               |     |   |     |
|           row N, col 1 | col 2 | ... | col N |
| and here goes another table |     |   |     |
| table 2 value at row 1, col 1 | ... | col N |
|                               |     |   |     |
|                               |     |   |     |
|           row N, col 1 | ... | col N |
```

You can also output several rows with a single command by enclosing values between brackets:

```
csv([row1value1, ..., row1valueN],
    ...
    [rowNvalue1, ..., rowNvalueN],
    fname='several_rows.csv')
```

*example*

```
csv(['this is', 'a header'],
    ['with', 'several lines'],
    fname='person_age_aggregates.csv')
```

Will produce a file with a layout like this:

```
| this is | a header      |
| with    | several lines |
```

## 5.7.4 dump

**dump** produces a table with the expressions given as argument evaluated over many (possibly all) individuals of the dataset.

*general format*

```
dump([expr1, expr2, ...,
      filter=filterexpression, missing=value, header=True])
```

If no expression is given, *all* fields of the current entity will be dumped (including temporary variables available at that point), otherwise, each expression will be evaluated on the objects which satisfy the filter and produce a table.

The ‘filter’ argument allows to evaluate the expressions only on the individuals which satisfy the filter. Defaults to None (evaluate on all individuals).

The ‘missing’ argument can be used to transform ‘nan’ values to another value. Defaults to None (no transformation).

The ‘header’ argument determine whether column names should be in the dump or not. Defaults to True.

*example*

```
show(dump(age, partner.age, gender, filter=id < 10))
```

gives

```
id | age | partner.age | gender
0  | 27  |      -1    | False
1  | 86  |      71    | False
2  | 16  |      -1    |  True
3  | 19  |      -1    | False
4  | 27  |      21    | False
5  | 89  |      92    |  True
6  | 59  |      61    |  True
7  | 65  |      29    | False
8  | 38  |      35    |  True
9  | 48  |      52    |  True
```

## 5.7.5 groupby

**groupby** (aka *pivot table*): group all individuals by their value for the given expressions, and optionally compute an expression for each group (using the *expr* argument). If no expression is given, it will compute the number of individuals in that group. A *filter* can be specified to limit the individuals taken into account.

*general format*

```
groupby(expr1[, expr2, expr3, ...]
        [, expr=expression]
        [, filter=filterexpression]
        [, percent=True],
        [, pvalues=possible_values])
```

*example*

```
show(groupby(trunc(age / 10), gender))
```

*gives*

trunc((age / 10))	gender		
	False	True	total
0	818	803	1621
1	800	800	1600
2	1199	1197	2396
3	1598	1598	3196
4	1697	1696	3393
5	1496	1491	2987
6	1191	1182	2373
7	684	671	1355
8	369	357	726
9	150	147	297
total	10002	9942	19944

*example*

```
show(groupby(inwork, gender))
```

*gives*

inwork	gender		
	False	True	total
False	6170	5587	11757
True	3832	4355	8187
total	10002	9942	19944

*example*

```
show(groupby(inwork, gender, percent=True))
```

*gives*

inwork	gender		
	False	True	total
False	30.94	28.01	58.95
True	19.21	21.84	41.05
total	50.15	49.85	100.00

*example*

```
groupby(workstate, gender, expr=avg(age))
```

gives the average age by workstate and gender

workstate	gender		
	False	True	total
1	41.29	40.53	40.88
2	40.28	44.51	41.88
3	8.32	7.70	8.02
4	72.48	72.27	72.38
5	42.35	46.56	43.48
total	42.67	42.38	42.53

As of version 0.6, `groupby` can also be used in larger expressions. This can be used for example to compute alignment targets on the fly:

```
# see note below about expr=count(condition) vs filter=condition
- men_by_age: groupby(age, expr=count(gender))
- men_prop_by_age: men_by_age / groupby(age)
- aligned: align(proportions=men_prop_by_age)
```

Note that there is a subtle difference between using “`filter=condition`” and “`expr=count(condition)`”. The former will not take the filtered individuals into account at all, while the later will take them into account but not count them. This can make a difference on the output if there are some empty categories, and this can be important when using the result of a `groupby` inside a larger expression (as above) because it can only work with arrays of the same size. Compare :

```
groupby(civilstate, filter=age > 80)
```

civilstate	1	3	4	total
	542	150	85	777

with

```
groupby(civilstate, expr=count(age > 80))
```

civilstate	1	2	3	4	total
	542	0	150	85	777

The `expr` argument will usually be used with an aggregate function, but it also supports normal expressions, in which case the values for each individual will be displayed in a list. This feature should only be used with care and usually in combination with a strong `filter` to avoid producing extremely large tables which would take forever to display.

```
groupby(agegroup_civilstate, gender, expr=id, filter=id < 20)
```

agegroup_civilstate	gender		total
	False	True	
0	[0 1 4 6]	[2 3 5 7]	[0 1 4 6 2 3 5 7]
5	[8 10 12]	[9 11 13]	[8 10 12 9 11 13]
10	[14 16 18]	[15 17 19]	[14 16 18 15 17 19]
total	[0 1 4 6 8 10 12 14 16 18]	[2 3 5 7 9 11 13 15 17]	[0 1 4 6 8 10 12 14 16 18 2 3 5 7 9 11 13 15 17 19]

or

```
groupby(civilstate, gender, expr=age, filter=id > 100 and id < 110)
```

civilstate	gender		total
	False	True	
1	[46 47]	[46 47 47]	[46 47 46 47 47]
2	[47]	[45 46]	[47 45 46]
4	[46]	[]	[46]
total	[46 47 47 46]	[46 47 47 45 46]	[46 47 47 46 46 47 47 45 46]

## 5.7.6 charts

New in version 0.8.

LIAM2 has some charting capabilities, courtesy of `matplotlib`. They are available both during a simulation and in the interactive console. Each of the following functions is designed around the function of the same name in

matplotlib. Even though we have tried to stay as close as possible to their API, their implementation in LIAM2 has a few differences, in particular we added a few arguments which are available in most functions.

- *fname*: name of the file to save the chart to. The file format is automatically deduced from the file extension. You can optionally use the ‘{entity}’ and ‘{period}’ key words to customize the name. You can save the same chart to several formats at once by using ‘&’ in the extension. For example: `plot(expr, fname='plot03.png&pdf')` will write the chart to both `plot03.png` and `plot03.pdf`. If the *fname* argument is not used, a window will open to view and interact with the figure using a navigation toolbar. See [matplotlib navigation toolbar documentation](#) for more details.

---

**Note:** Keyboard shortcuts mentioned on that page currently do not work.

---

- *suffix*: a more concise alternative to set the name of the file the chart will be saved to. When it is used, the files are named using the following pattern: `{entity}_{period}_{suffix}.png`. For example:

```
bar(expr, suffix='income')
```

would create “`person_2002_income.png`”, “`person_2003_income.png`”, etc.

- *colors*: a list of the colors to be used for the chart. See [matplotlib colors documentation](#) for the different ways you can specify colors. For example:

```
bar(expr, colors=['r', 'g', 'b'])
```

will make a bar chart with red, green and blue bars.

---

**Note:** `boxplot()` does not support the *colors* argument.

---

- *grid* (False/True): determine whether to display a grid (in addition to axes ticks). It defaults to *True* for `bar()` and `plot()` and to *False* for `boxplot()` and `stackplot()`.

---

**Note:** `pie()` does not support the *grid* argument.

---

- *maxticks*: limit the number of axes ticks. It defaults to 20 for all charts except `bar3d` where it defaults to 10.

---

**Note:** `pie()` does not support the *maxticks* argument.

---

## bar charts

New in version 0.8.

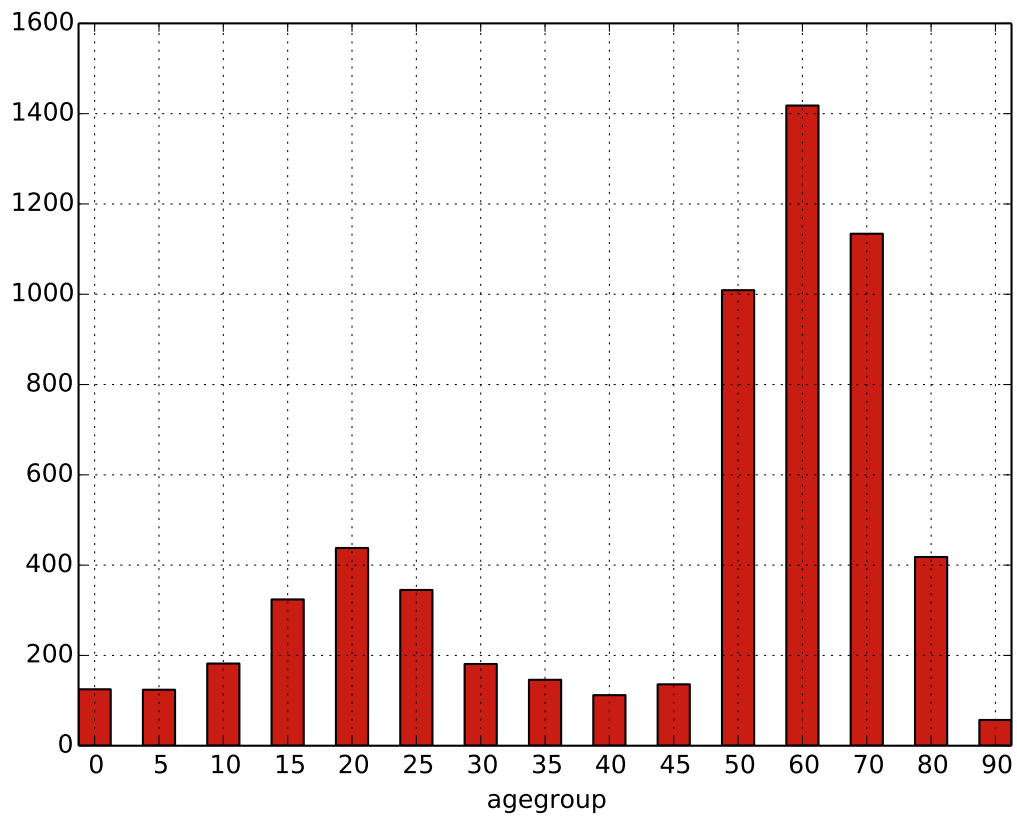
**bar** can be used to draw bar charts. It uses `matplotlib.pyplot.bar` and inherits all of its keyword arguments. There are 3 ways to use it:

```
bar(1d_expr, ...)  
bar(1d_expr1, 1d_expr2, ...)  
bar(2d_expr, ...)
```

In the first two *1d\_expr* is (an expression returning) a one-dimensional array (for example an entity field or a groupby expression with only one dimension). For example:

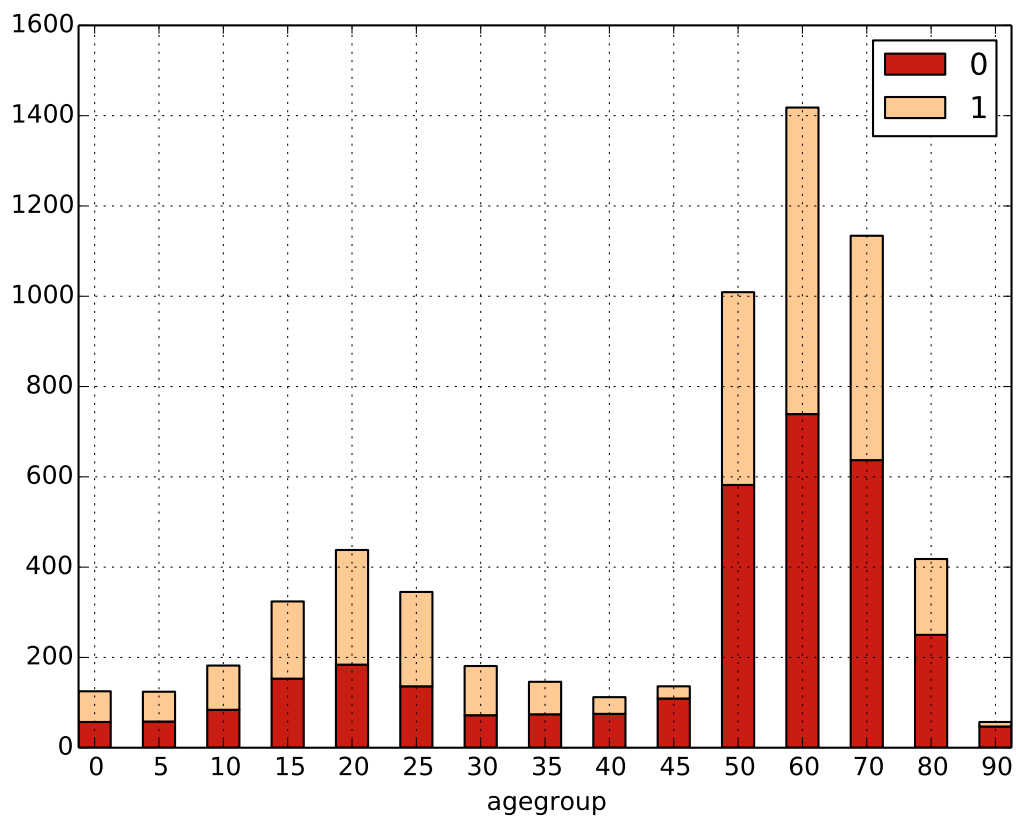
```
bar(groupby(agegroup))
```

would produce:



If one passes several arrays/expressions, they will be stacked on each other.

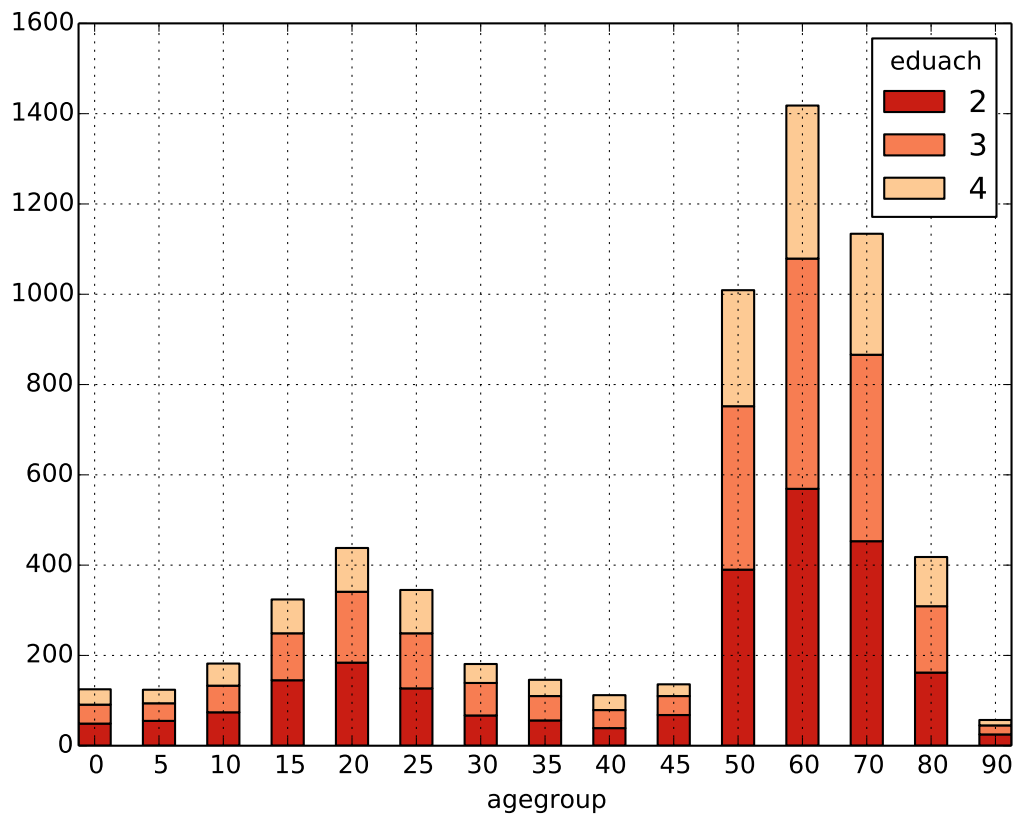
```
bar(groupby(agegroup, filter=not gender),  
    groupby(agegroup, filter=gender))
```



Alternatively, one can pass (an expression returning) a two-dimensional array, in which case, the first dimension will be “stacked”: for each possible value of the first dimension, there will be a bar “part” with a different color.

```
- bar(groupby(eduach, agegroup))
```





## plot

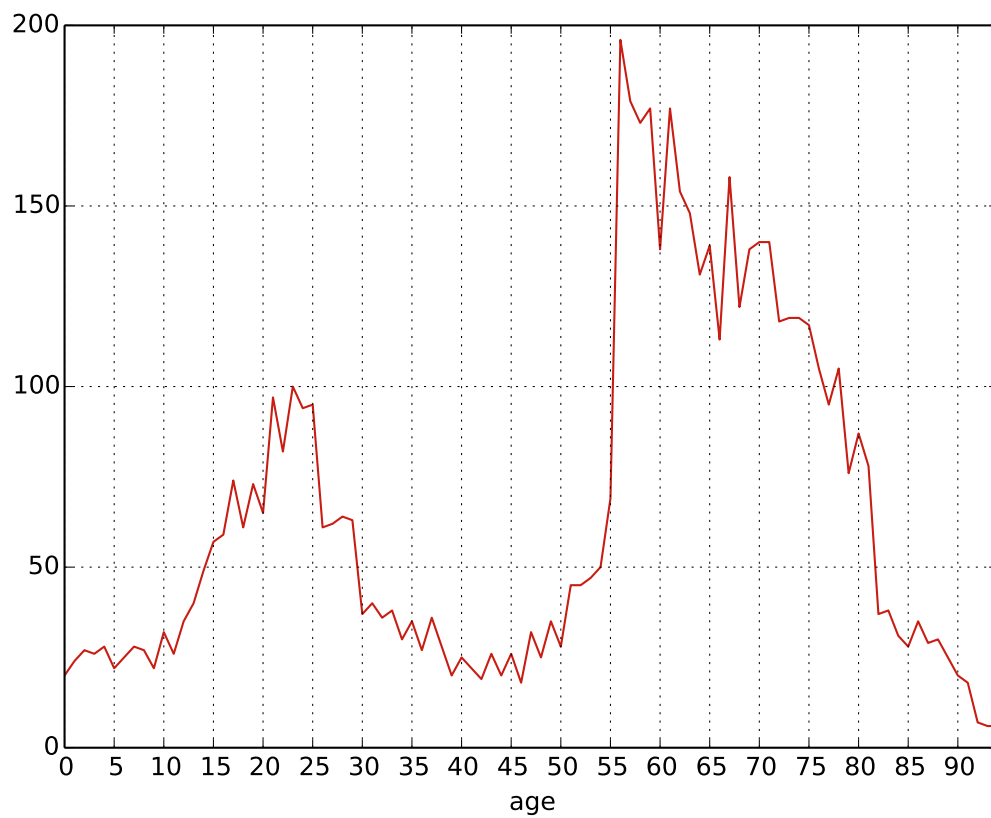
New in version 0.8.

**plot** can be used to draw (line) plots. It uses `matplotlib.pyplot.plot` and inherits all of its keyword arguments. There are 4 ways to use it:

```
plot(1d_expr, ...)
plot(1d_expr1, 1d_expr2, ...)
plot(2d_expr, ...)
plot(1d_expr1, style_str1, 1d_expr2, style_str2, ...)
```

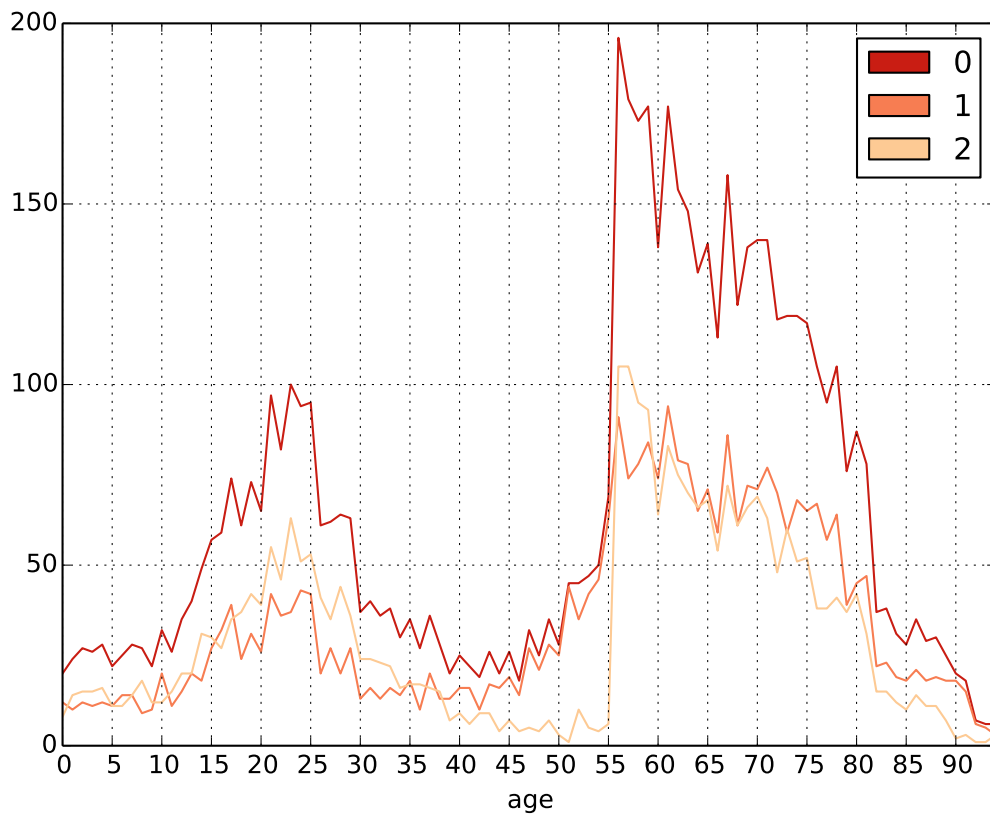
In the first two *1d\_expr* is (an expression returning) a one-dimensional array (for example an entity field or a groupby expression with only one dimension). For example:

```
plot(groupby(age))
```



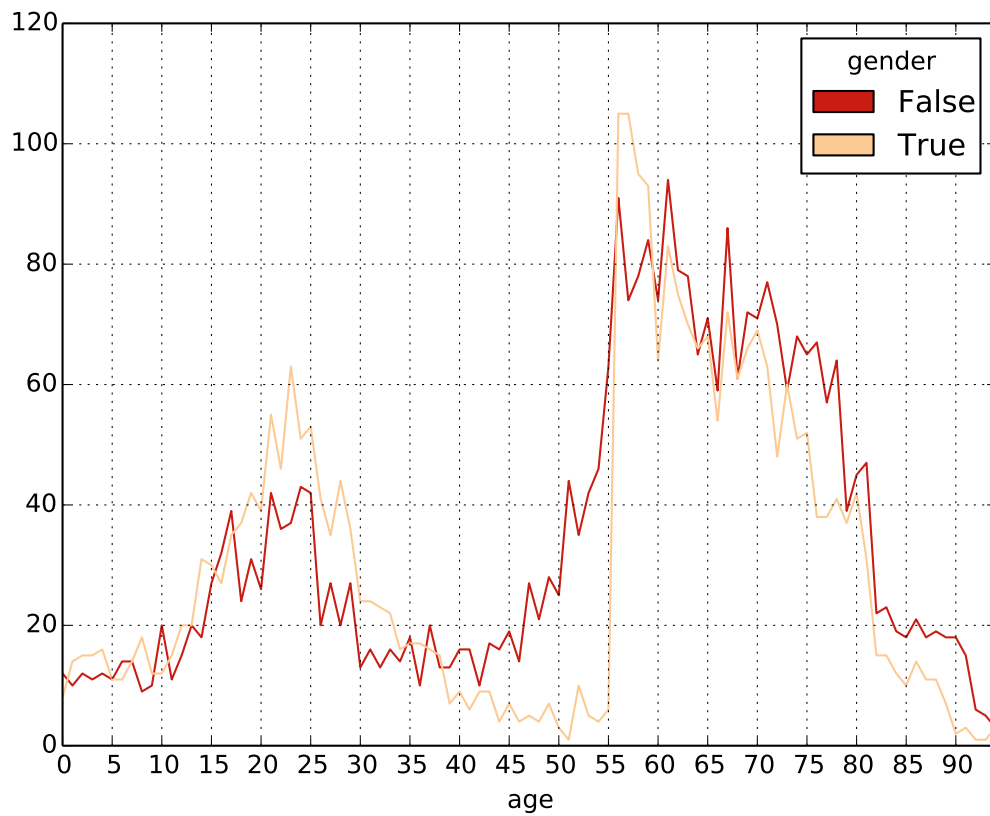
If one passes several expressions, each will be plotted as a different line.

```
plot(groupby(age),  
      groupby(age, filter=not gender),  
      groupby(age, filter=gender))
```



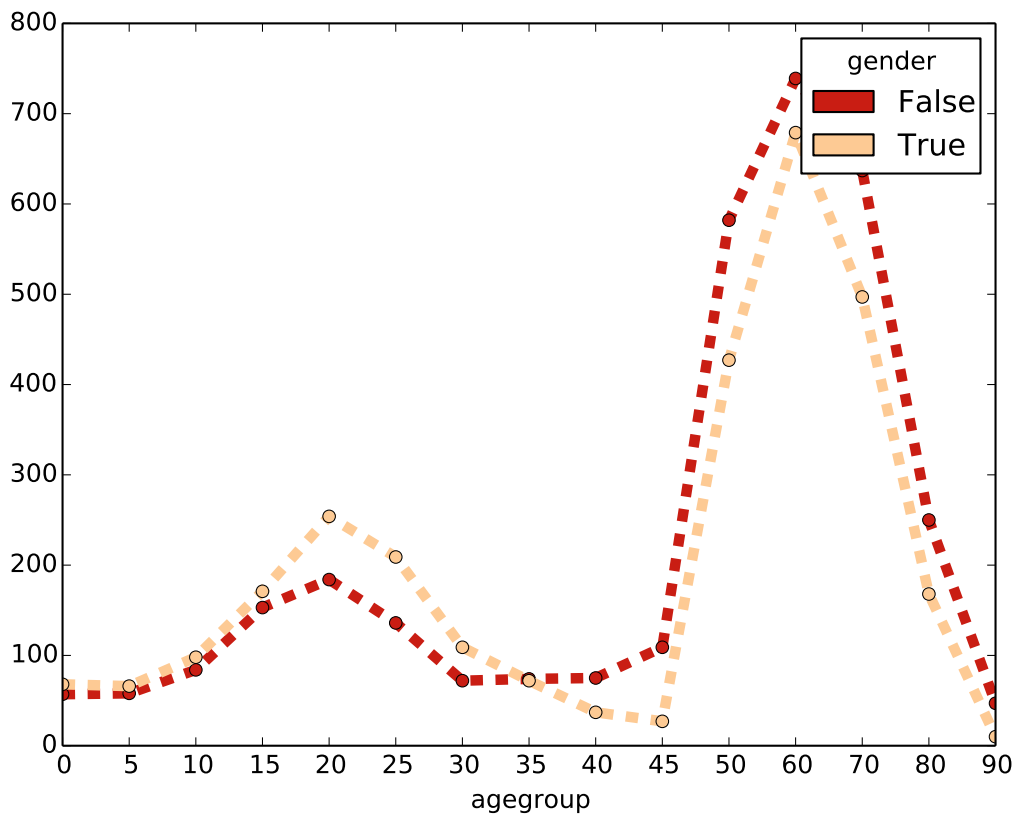
The third option is to pass (an expression returning) a two-dimensional array (`plot(2d_expr, ...)`) in which case, there will be one line for each possible value of the first dimension and the second dimension will be plotted along the x axis. For example:

```
plot(groupby(gender, age))
```



and, using a few of the many possible options to customize the appearance:

```
plot(groupby(gender, agegroup),  
      grid=False, linestyle='dashed', marker='o', linewidth=5)
```

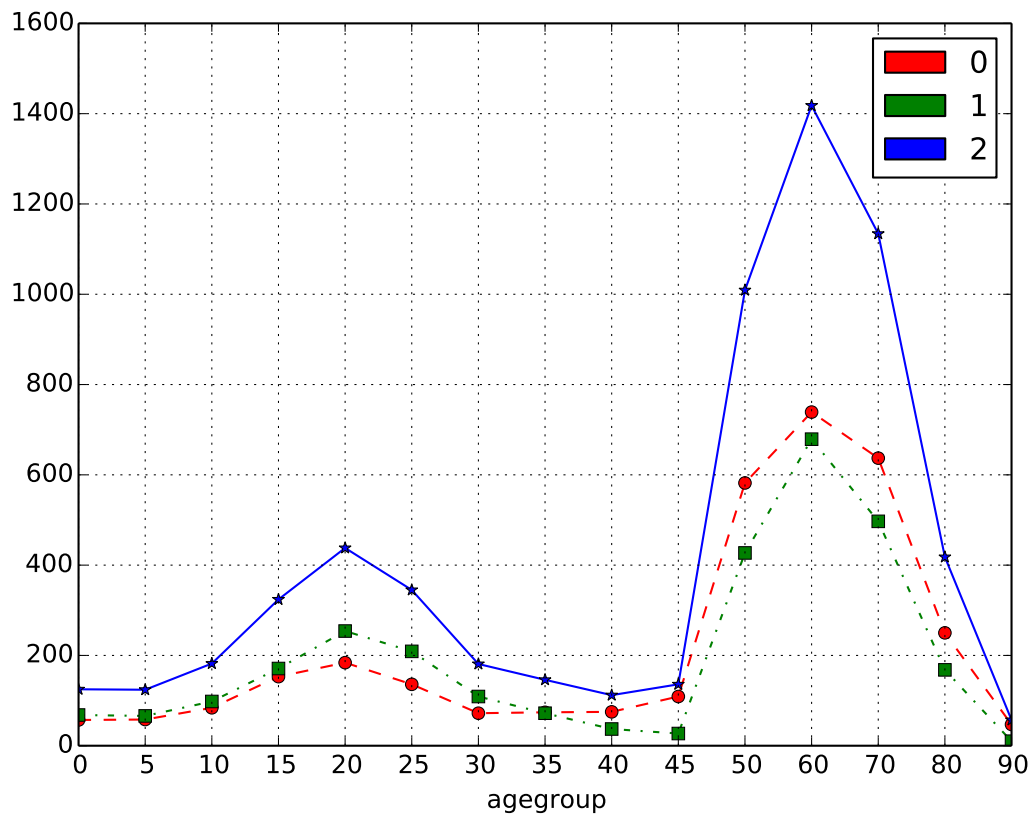


And the fourth and last option is to alternate expressions returning one-dimensional arrays with *styles strings* (`plot(1d_expr1, style_str1, 1d_expr2, style_str2, ...)`) which allows each line/array to be plotted with a different style. See [plot documentation](#) for a description of possible styles strings.

**Note:** Styles including a color (as explained in the matplotlib documentation – eg ‘bo’) are **not** supported by our implementation. Colors should rather be set using the *colors* argument (as explained above and shown in the example below).

Example:

```
plot(groupby(agegroup, expr=count(not gender)), 'o--',
      groupby(agegroup, expr=count(gender)), 's-.',
      groupby(agegroup), '*-'
      colors=['r', 'g', 'b'])
```



## stackplot

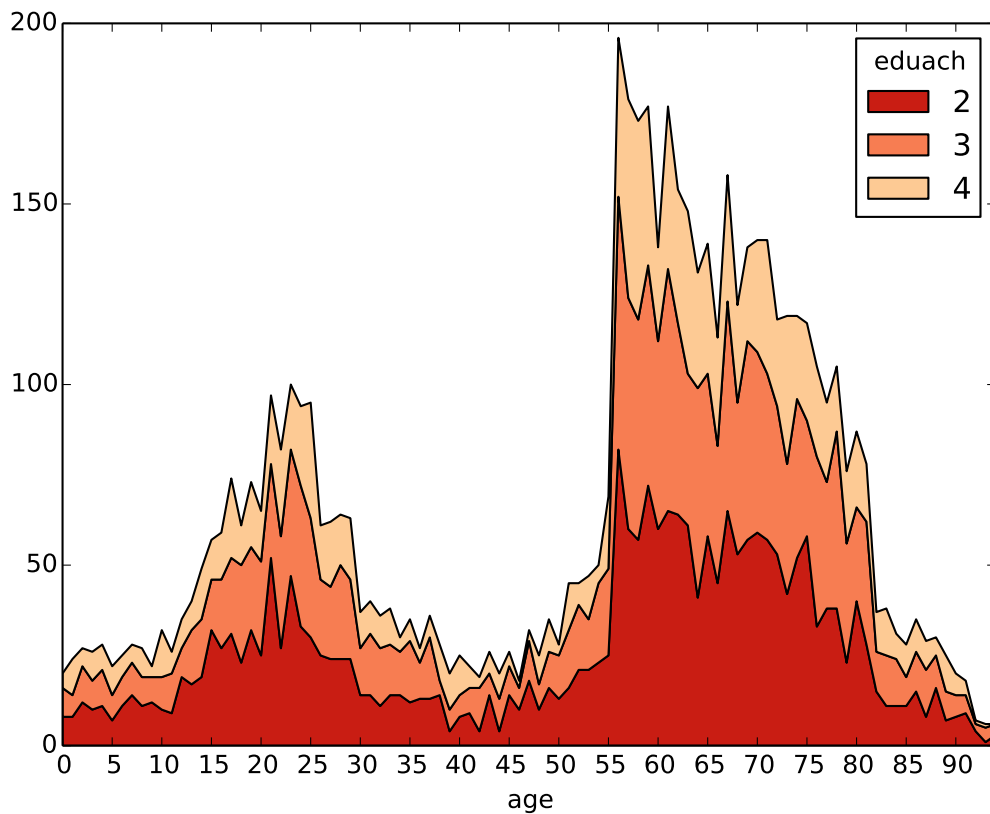
New in version 0.8.

**stackplot** can be used to draw stacked (line) plots. It uses `matplotlib.pyplot.stackplot` and inherits all of its keyword arguments. There are two ways to use it:

```
stackplot(1d_expr1, 1d_expr2, ...)
stackplot(2d_expr, ...)
```

Example:

```
stackplot(groupby(eduach, age))
```



## pie charts

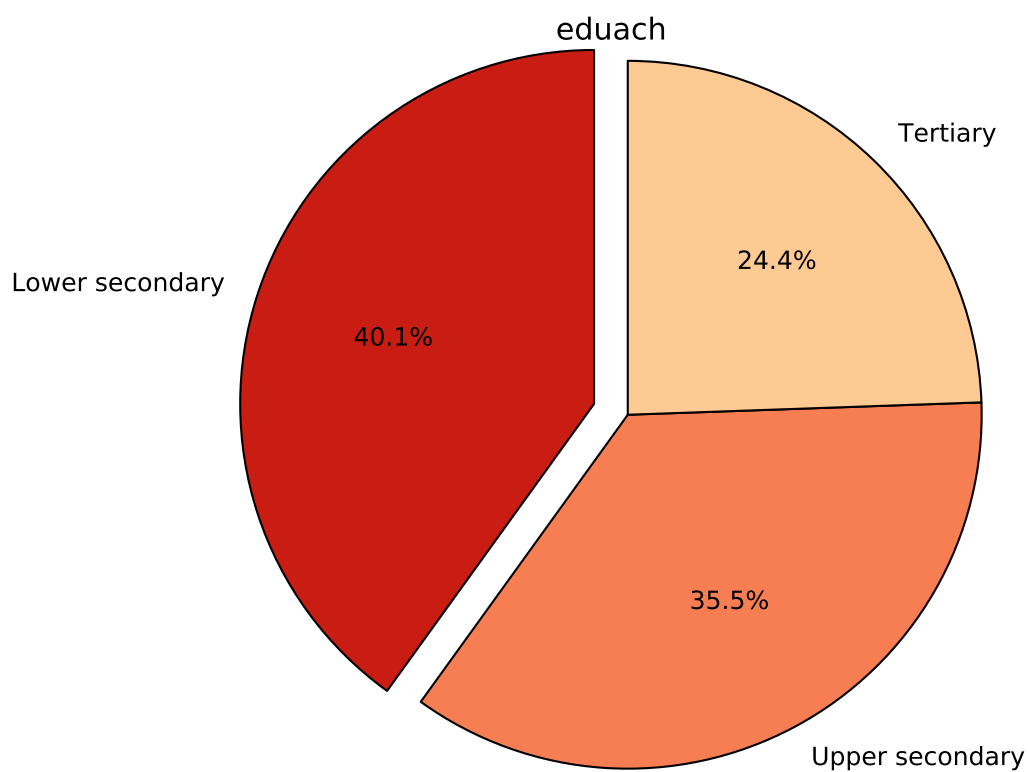
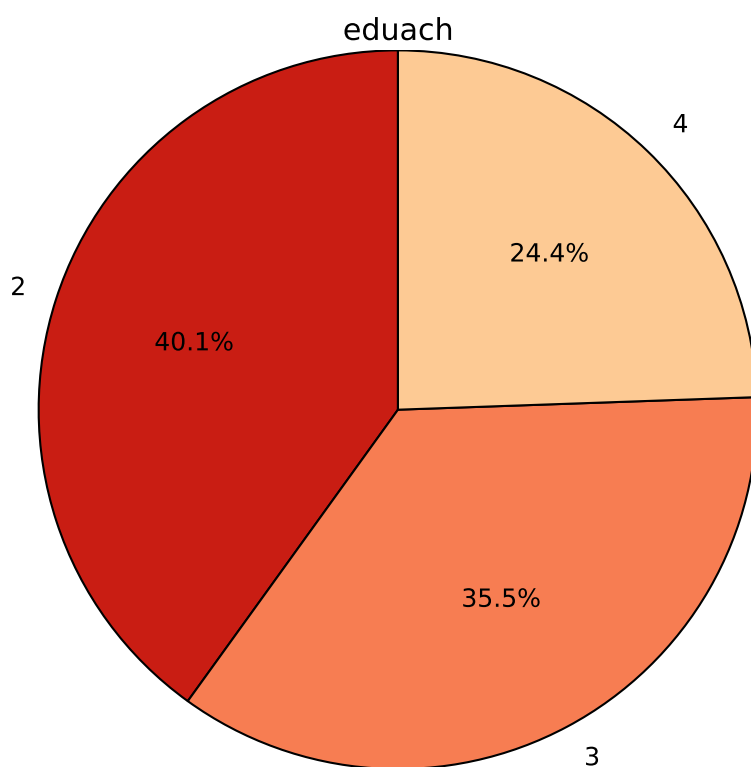
New in version 0.8.

**pie** can be used to draw pie charts. It uses `matplotlib.pyplot.pie` and inherits all of its keyword arguments. It should be used like this:

```
pie(1d_expr1, ...)
```

Where *1d\_expr* is (an expression returning) a one-dimensional array (for example an entity field or a groupby expression with only one dimension). Examples:

```
pie(groupby(eduach))
pie(groupby(eduach),
    explode=[0.1, 0, 0],
    labels=['Lower secondary', 'Upper secondary', 'Tertiary'])
```





## scatter plots

New in version 0.8.

**scatter** can be used to draw scatter plots. It uses `matplotlib.pyplot.scatter` and inherits all of its keyword arguments. It should be used like this:

```
scatter(x_expr, y_expr, ...)
```

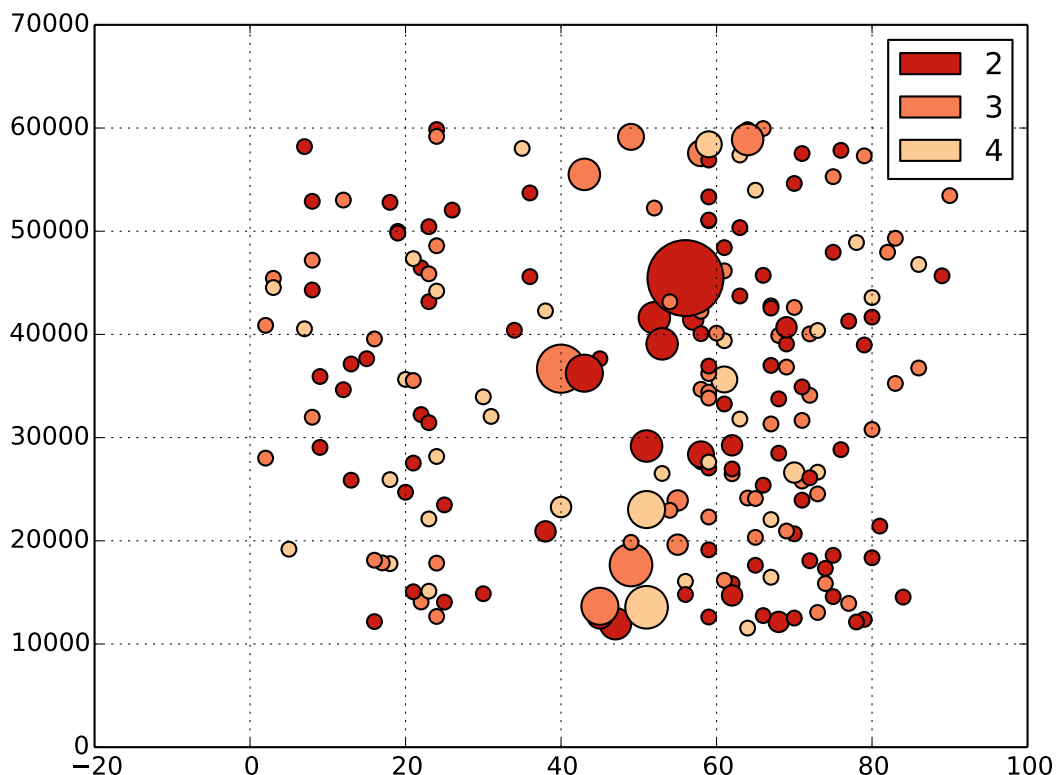
Where both `x_expr` and `y_expr` are (expressions returning) one-dimensional arrays (for example an entity field or a groupby expression with only one dimension).

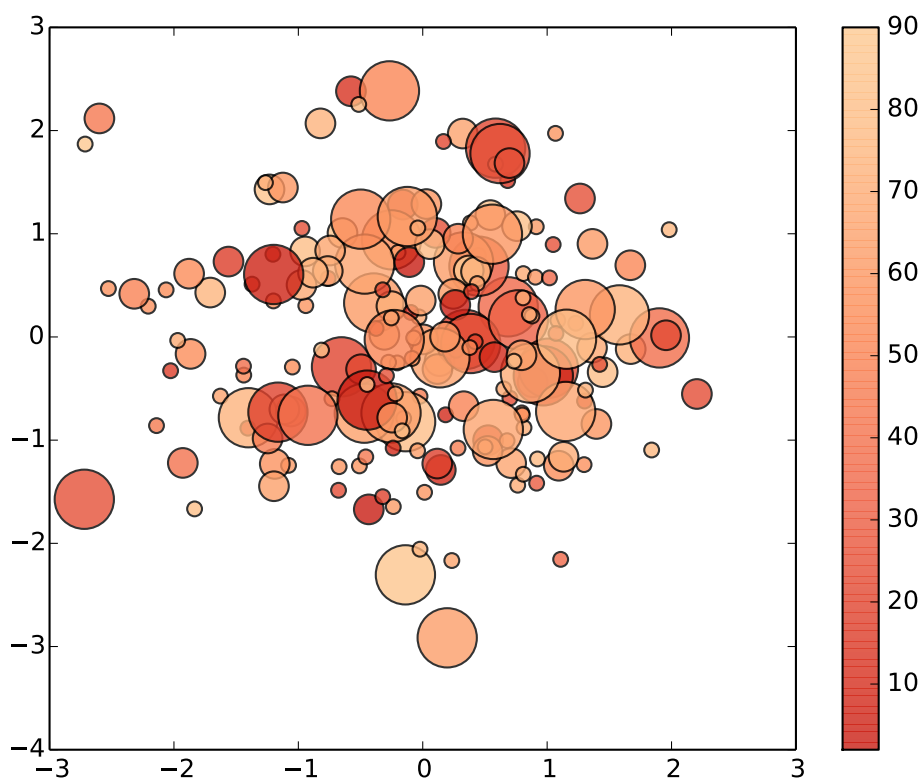
Optional keyword arguments include (among others, see above link):

- **c**: to set the color of each circle. A color will be assigned for each different value of this argument.
- **s**: to set the surface of each circle (mutually exclusive with the `r` argument).
- **r**: to set the radius of each circle ( $r=expr$  is equivalent to  $s=\pi * expr ** 2$ ). It is mutually exclusive with the `s` argument. The `r` argument is specific to `liam2`.

Examples:

```
- salary: 10000 + uniform() * 50000
- area: 3.1415 * (4 + 1.5 * children.count()) ** 2
- scatter(age, salary, c=eduach, s=area, alpha=0.5s, grid=True)
- scatter(normal(), normal(), c=age, r=2 ** eduach)
```





## boxplot

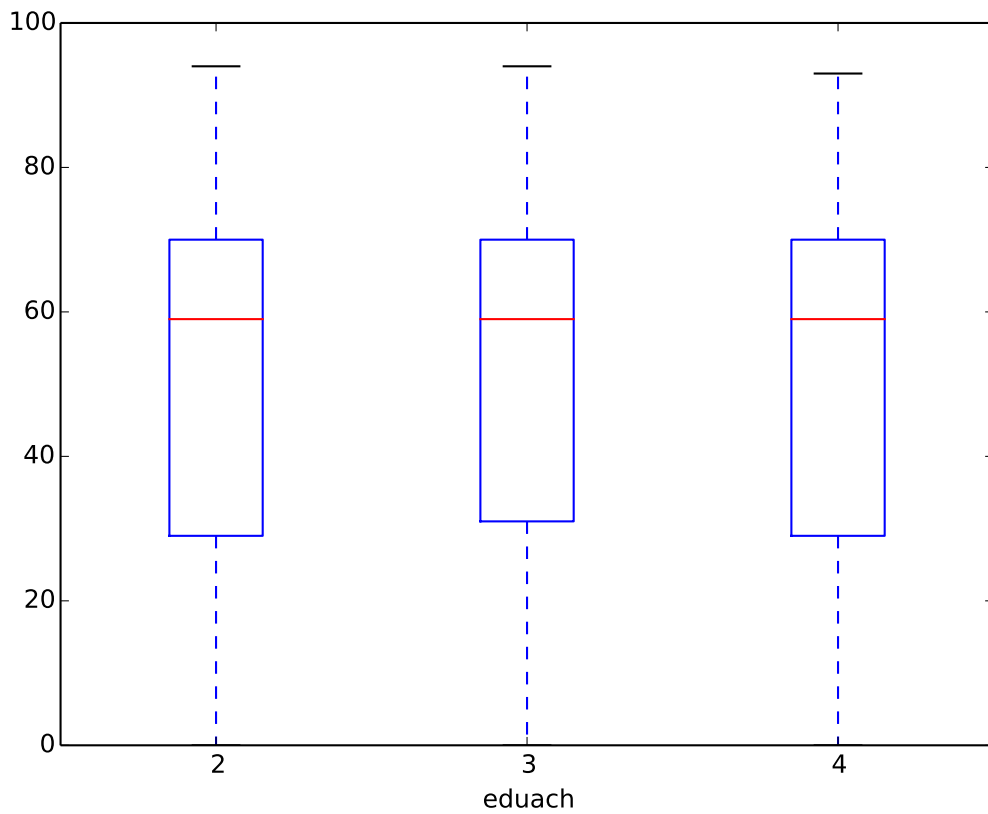
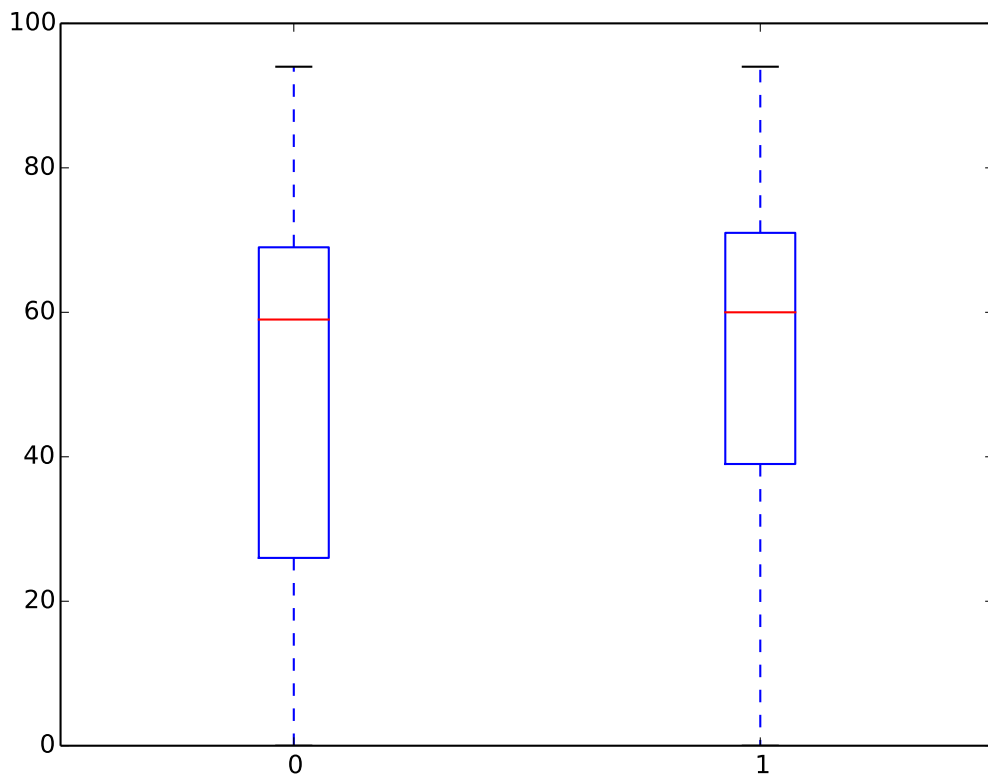
New in version 0.8.

**boxplot** can be used to draw **box plots**. It uses `matplotlib.pyplot.boxplot` and inherits all of its keyword arguments. There are two ways to use it:

```
boxplot(1d_expr1, 1d_expr2, ...)  
boxplot(2d_expr, ...)
```

Examples:

```
- boxplot(age[gender], age[not gender])  
- boxplot(groupby(educach, expr=age, filter=educach != -1))
```



## 5.8 Debugging and the interactive console

LIAM2 features an interactive console which allows you to interactively explore the state of the memory either during or after a simulation completed.

You can reach it in two ways. You can either pass “-i” as the last argument when running the executable, in which case the interactive console will launch after the whole simulation is over. The alternative is to use breakpoints in your simulation to interrupt the simulation at a specific point (see below).

Type “help” in the console for the list of available commands. In addition to those commands, you can type any expression that is allowed in the simulation file and have the result directly. Show is implicit for all operations.

*examples*

```
>>> avg(age)
53.7131819615

>>> groupby(trunc(age / 20), gender, expr=count(inwork))

trunc(age / 20) | gender |      |
                | False | True | total
0 |      14 |   18 |    32
1 |     317 |  496 |   813
2 |     318 |  258 |   576
3 |      40 |  102 |   142
4 |       0 |    0 |     0
5 |       0 |    0 |     0
total |     689 |  874 |  1563
```

### 5.8.1 breakpoint

**breakpoint:** temporarily stops execution of the simulation and launch the interactive console. There are two additional commands available in the interactive console when you reach it through a breakpoint: “step” to execute (only) the next process and “resume” to resume normal execution.

*general format*

```
breakpoint([period])
```

the “period” argument is optional and if given, will make the breakpoint interrupt the simulation only for that period.

*example*

```
marriage:
- in_couple: MARRIED or COHAB
- breakpoint(2002)
- ...
```

### 5.8.2 assertions

Assertions can be used to check that your model really produce the results it should produce. The behavior when an assertion fails is determined by the *assertions* simulation option.

- `assertTrue(expr)`: evaluates the expression and check its result is True.
- `assertFalse(expr)`: evaluates the expression and check its result is False.
- `assertEqual(expr1, expr2)`: evaluates both expressions and check their results are equal.
- `assertNaNEqual(expr1, expr2)`: evaluates both expressions and check their results are equal, even in the presence of nans (because normally `nan != nan`).

- `assertEquiv(expr1, expr2)`: evaluates both expressions and check their results are equal tolerating a difference in shape (though they must be compatible).
- `assertIsClose(expr1, expr2)`: evaluates both expressions and check their results are almost equal.



## LINKS

Individuals can be linked with each other or with individuals of other entities, for example, mothers are linked to their children, partners are linked to each other and persons belong to households.

A typical link declaration has the following form:

```
name: {type: <type>, target: <entity>, field: <name of link field>}
```

LIAM2 uses **integer fields** to establish the link between entities. Those integer fields contain the id-number of the linked individual.

For link fields, -1 is a special value meaning the link points to nothing (eg. a person has no partner). Other negative values **should never be used** (whatever the reason) for link fields.

LIAM2 allows two types of links: *many2one* and *one2many*.

### 6.1 many2one

A **many2one link** links an individual of the entity to **one** other individual in the same (eg. a person to his/her mother) or another entity (eg. a person to its household).

This allows the modeller to use information stored in the linked entities.

```
entities:
  person:
    fields:
      - age: int
      - income: float
      - mother_id: int
      - father_id: int
      - partner_id: int

    links:
      mother: {type: many2one, target: person, field: mother_id}
      father: {type: many2one, target: person, field: father_id}
      partner: {type: many2one, target: person, field: partner_id}

    processes:
      age: age + 1
      mother_age: mother.age
      parents_income: mother.income + father.income
```

To access a field of a linked individual (possibly of the same entity), you use:

```
link_name.field_name
```

For example, the *mother\_age* process uses the ‘mother’ link to assign the age of the mother to the *mother\_age* field. If an individual’s link does not point to anything (eg. a person has no known mother), trying to use the link would yield the missing value (eg. for orphans, *mother.age* is -1 and *parents\_income* is *nan*).

As another example, the process below sets a variable *to\_separate* to *True* if the variable *separate* is *True* for either the individual or his/her partner.

```
- to_separate: separate or partner.separate
```

Note that it is perfectly valid to chain links as, for example, in:

```
grand_parents_income: mother.mother.income + mother.father.income +  
                      father.mother.income + father.father.income
```

Another option to get values in the linked individual is to use the form:

```
link_name.get(expr)
```

this syntax is a bit more verbose in the simple case, but is much more powerful as it allows to evaluate (almost) any expression on the linked individual.

For example, if you want to get the average age of both parents of the mother of each individual, you can do it so:

```
mother.get((mother.age + father.age) / 2)
```

## 6.2 one2many

A **one2many link** links an individual of the entity to at least one other individual in the same (eg. a person to his/her children) or another entity (a household to its members).

```
entities:  
  household:  
    links:  
      persons: {type: one2many, target: person, field: household_id}  
  
  person:  
    fields:  
      - age: int  
      - income: float  
      - household_id : int  
  
    links:  
      household: {type: many2one, target: household, field: household_id}
```

- *persons* is the link from the household to its members.
- *household* is the link from a person to his/her household.

To access the information stored in the linked individuals through a one2many link, you have to use *aggregate methods* on the link:

```
link_name.method_name([arguments])
```

For example:

```
persons.avg(age)
```

one2many links support the following methods: *count()*, *sum()*, *avg()*, *min()* and *max()*. See [link methods](#) for details.

*example*

```
entities:  
  household:  
    fields:  
      - num_children: int  
  
  links:
```



```

# link from a household to its members
persons: {type: one2many, target: person, field: household_id}

processes:
  num_children: persons.count (age <= 17)

person:
  fields:
    - age: int
    - household_id: int

  links:
    # link form a person to his/her household
    household: {type: many2one, target: household,
                field: household_id}

processes:
  num_kids_in_hh: household.num_children

```

The `num_children` process, once called will compute the number of persons aged 17 or less in each household and store the result in the `num_children` field (of the **household**). Afterwards, that variable can be used like any other variable, for example through a `many2one` link, like in the `num_kids_in_hh` process. This process computes for each **person**, the number of children in the household of that person.

Note that the variable `num_kids_in_hh` could also have been simulated by just one process, on the “person” level, by using:

```
- num_kids_in_hh: household.get(persons.count (age <= 17))
```



## IMPORTING OTHER MODELS

A model file can (optionally) import (an)other model file(s). An import directive can take two forms:

```
import: path\filename.yml
```

or

```
import:
  - path1\filename1.yml
  - path2\filename2.yml
```

Each file in the import section will be merged with the current file in the order it appears. Merging means that fields, links, macros and processes from the imported file are added to the ones of the current file. If there is a conflict (something with the same name is defined for the same entity in both files), the “current” file (the model importing the other model) takes priority. This means one can override entity processes defined in imported files, or add fields to an entity defined in the imported model.

Note that both the importing model and the imported model need not be complete/valid models (they do not need to include all required (sub)sections), as long as the combined model is valid. See the examples below.

*example (common.yml)*

```
entities:
  person:
    fields:
      - age: int
      - agegroup: {type: int, initialdata: False}

    processes:
      ageing:
        - age: age + 1
        - agegroup: trunc(age / 10)

simulation:
  processes:
    - person: [ageing]

  # we do not specify output so this model is not valid in itself
  input:
    file: input.h5

  start_period: 2015
  periods: 2
```

*example (variant1.yml)*

```
import: common.yml

entities:
  person:
    processes:
```

```

# override the ageing process
ageing:
  - age: age + 1
  - agegroup: if(age < 50,
                 5 * trunc(age / 5),
                 10 * trunc(age / 10))

simulation:
  # provide the required "output" section which is missing in common.yml
  output:
    file: variant1.h5

```

*example (variant2.yml)*

```

import: common.yml

entities:
  person:
    fields:
      - severe_illness: {type: bool, initialdata: False}

    processes:
      # adding new processes
      illness:
        - severe_illness: uniform() < 0.001

      death:
        - dead: logit_regr(0.5 * severe_illness,
                          align='al_p_dead.csv')
        - show('Avg age of death', avg(age, filter=dead))
        - remove(dead)

simulation:
  # since we have new processes, we have to override the *entire* process
  # list, as LIAM2 would not know where to insert the new processes
  # otherwise.
  processes:
    - person: [ageing, illness, death]

  output:
    file: variant2.h5

```

Imported models can themselves import other models, as for example in variant3.yml.

*example (variant3.yml)*

```

import: variant2.yml

entities:
  person:
    processes:
      # use the "alternate" ageing function
      ageing:
        - age: age + 1
        - agegroup: if(age < 50,
                       5 * trunc(age / 5),
                       10 * trunc(age / 10))

```

This last example could also be achieved by importing both variant1.yml and variant2.yml. Notice that the order of imports is important, since it determines the result of conflicts between variants. For example in variant4.yml below, the process list will be the one from variant2 and the output will go in variant2.h5.

*example (variant4.yml)*

```
import:  
  - variant1.yml  
  - variant2.yml
```



## IMPORTING DATA

### 8.1 data files

As of now, you can only import CSV files. LIAM2 currently supports two kinds of data files: tables and multi-dimensional arrays.

**table** files are used for entities data and optionally for globals. They should have one column per field and their first row should contain the name of the fields. These names should not contain any special character (accents, etc.).

For entities data, you need at least two *integer* columns: “id” and “period” (though they do not necessarily need to be named like that in the csv file).

**array** files are used for other external data (alignment data for example). They are arrays of any number of dimensions of a single homogeneous type. The first row should contain the dimension names (one dimension by cell). The second row should contain the possible values for the last dimension. Each subsequent row should start by the values for the first dimensions then the actual data.

*example*

gender	work	civilstate				
		1	2	3	4	
False	False	5313	1912	695	1222	
False	True	432	232	51	87	
True	False	4701	2185	1164	1079	
True	True	369	155	101	116	

This is the same format that `groupby()` generates except for totals.

### 8.2 description file

To import CSV files, you need to create a description file. Those description files have the following general format:

```
output: <path_of_hdf5_file>.csv

# compression is optional. compression type can be 'zlib', 'bzip2' or 'lzo'
# level is a digit from 1 to 9 and is optional (defaults to 5).
# Examples of valid compression strings are: zlib, lzo-1, bzip2-9.
# You should experiment to see which compression scheme (if any) offers the
# best trade-off for your dataset.
compression: <type>-<level>

# globals are entirely optional
globals:
  periodic:
    path: <path_of_file>.csv
    # if the csv file is transposed (each field is on a row instead of
```

```

# a column and the field names are in the first column, instead of
# the first row), you can use "transpose: True". You do not need to
# specify anything if the file is not transposed.
transposed: True

# fields are optional (if not specified, all fields are imported)
fields:
  # PERIOD is implicit
  - <field1_name>: <field1_type>
  - <field2_name>: <field2_type>
  - ...

other_table:
  # same options than for periodic: path, fields, transpose, ...

other_array:
  path: <path_of_file>.csv
  type: <field_type>

entities:
  <entity1_name>:
    path: <path_to_entity1_data>.csv

    # defaults to False if not present
    transposed: True

    # if you want to manually select the fields to be used, and/or
    # specify their types, you can do so in the following section.
    # If you want to use all the fields present in the csv file, you
    # can simply omit this section. The field types will be
    # automatically detected.
    fields:
      # period and id are implicit
      - <field1_name>: <field1_type>
      - <field2_name>: <field2_type>
      - ...

    # if you want to keep your csv files intact but use different
    # names in your simulation than in the csv files, you can specify
    # name changes here.
    oldnames:
      <fieldX_newname>: <fieldX_oldname>
      <fieldY_newname>: <fieldY_oldname>
      ...

    # another option to specify name changes (takes precedence over
    # oldnames in case of conflicts).
    newnames:
      <fieldX_oldname>: <fieldX_newname>
      <fieldY_oldname>: <fieldY_newname>
      ...

# if you want to merge several files, use this format:
files:
  - <path>\<to>\<file1>.<ext>:
    # any option (renamings, ...) specified here will override
    # the corresponding options defined at the level of the
    # entity
    transposed: True|False
    newnames:
      <fieldX_oldname>: <fieldX_newname>
      <fieldY_oldname>: <fieldY_newname>

```



```

# if you don't have any specific option for a file, use "{}"
- <path>\<to>\<file2>.<ext>: {}
- ...

# OR, if all the files use the global options (the options defined
# at the level of the entity):
files:
- <path>\<to>\<file1>.<ext>
- <path>\<to>\<file2>.<ext>
- ...

# if you want to fill missing values for some fields (this only
# works when "files" is used).
interpolate:
  <fieldX_name>: previous_value

# if you want to invert the value of some boolean fields
# (True -> False and False -> True), add them to the "invert" list
# below.
invert: [list, of, boolean, fields, to, invert]

<entity2_name>:
  ...

```

Most elements of this description file are optional. The only required elements are “output” and “entities”. If an element is not specified, it uses the following default value:

- if *path* is omitted, it defaults to a file named after the entity in the same directory than the description file (ie *local\_path\name\_of\_the\_entity.csv*).
- if the *fields* section is omitted, all columns of the csv file will be imported and their type will be detected automatically.
- if *compression* is omitted, the output will not be compressed.

Note that if an “entity section” is entirely empty, you need to use the special code: “{}”.

#### *simplest example*

```

output: simplest.h5

entities:
  household: {}
  person: {}

```

This will try to load all the fields of the household and person entities in “*household.csv*” and “*person.csv*” in the same directory than the description file.

#### *simple example*

```

output: simple.h5

globals:
  periodic:
    path: input\globals.csv

entities:
  household:
    path: input\household.csv

  person:
    path: input\person.csv

```

This will try to load all the fields of the household and person entities in “*household.csv*” and “*person.csv*” in the “input” sub-directory of the directory where the description file is.

*example 3*

```
output: example3.h5

globals:
  periodic:
    path: input\globals_transposed.csv
    transposed: True

entities:
  household:
    path: input\household.csv

  person:
    path: input\person.csv
    fields:
      - age:          int
      - gender:       bool
      - workstate:   int
      - civilstate:  int
      - partner_id:  int

  oldnames:
    gender: male
```

This will load all the fields of the household entity in “*household.csv*” and load from “*person.csv*” only the fields listed above. The data will be converted (if necessary) to the type declared. In this case, *person.csv* should contain at least the following columns (not necessarily in this order): *period*, *id*, *age*, *male*, *workstate*, *civilstate*, *partner\_id*.

If the fields of an entity are scattered in several files, you can use the “*files*” key to list them, as in this fourth example :

```
output: example4.h5

entities:
  person:
    fields:
      - age:          int
      - gender:       bool
      - workstate:   int
      - civilstate:  int

  # renamings applying to all files of this entity
  newnames:
    time: period

  files:
    - param\p_age.csv:
      # additional renamings for this file only
      newnames:
        value: age
    - param\p_workstate.csv:
      newnames:
        value: workstate
  # person.csv should have at least 4 columns:
  # period, id, age and gender
  - param\person.csv:
    newnames:
      # we override the "global" renaming
      period: period

  interpolate:
    workstate: previous_value
```

```
civilstate: previous_value
```

But this can become tedious if you have a lot of files to import and they all have the same column names. If the name of the field can be extracted from the name of the file, you can automate the process like this:

*example 5*

```
output: example5.h5

entities:
  person:
    fields:
      - age: int
      - work: bool

    newnames:
      time: period
      # {basename} evaluates to the name of the file without
      # extension. In the examples below, that would be
      # 'p_age' and 'p_work'. We then use the "replace" method
      # on the string we got, to get rid of 'p_'.
      value: eval('{basename}'.replace('p_', ''))

    files:
      - param\p_age.csv
      - param\p_work.csv

    interpolate:
      work: previous_value
```

## 8.3 importing the data

Once you have your data as CSV files and created a description file, you can import your data.

- If you are using the bundled editor, simply open the description file and press F5.
- If you are using the command line, use:

```
[BUNDLEPATH]\liam2\main import <path_to_description_file>
```



## INDICES AND TABLES

- `genindex`
- `search`



## 10.1 Known issues

### 10.1.1 Contextual filter is inconsistent

First, what is a contextual filter? It is the name we gave to the feature which propagates the filter of an *if* function to the “True” side of the function, and the opposite filter to the “False” side. So, for example, in:

```
- aligned: if(gender, align(0.0, 'al_p_dead_m.csv')
              align(0.0, 'al_p_dead_f.csv'))
```

the “gender” filter is automatically propagated to the align functions. Which means, the above code is exactly equivalent to:

```
- aligned_m: align(0.0, 'al_p_dead_m.csv', filter=gender)
- aligned_f: align(0.0, 'al_p_dead_f.csv', filter=not gender)
- aligned: if(gender, aligned_m, aligned_f)
```

One might wonder what happens if an explicit filter is used in addition to the contextual filter? Both filters are combined (using “and”), as for example:

```
- aligned: if(gender, align(0.0, 'al_p_dead_m.csv', filter=age > 10)
              align(0.0, 'al_p_dead_f.csv'))
```

which is in fact evaluated as:

```
- aligned_m: align(0.0, 'al_p_dead_m.csv', filter=gender and age > 10)
- aligned_f: align(0.0, 'al_p_dead_f.csv', filter=not gender)
- aligned: if(gender, aligned_m, aligned_f)
```

### What is the inconsistency anyway?

This contextual filter propagation is implemented for `new()`, `align()`, `logit_regr()`, `matching()` and **some** (but not all) aggregate functions. Specifically, it is implemented for `sum` and `gini`, but not for other aggregate functions (`count`, `avg`, `min`, `max`, `std`, `median` and `percentile`). This situation needs to be changed, but I am unsure in which way: implementing it for all aggregate functions or not contextual filter for any aggregate function (or any function at all)?

While this features feels natural for `new`, `align` and `logit_regr`, it feels out of place for aggregate functions because it means we work at both the individual level and at the “aggregate” levels in the same expression, or, in more technical terms, we work with both vectors and scalars, and it might be confusing: do users realize they are assigning a value for each individual, even if that is only one of two values?

In an expression like the following:

```
- age_sum: if(gender, sum(age), sum(age))
```

do users realize they are assigning a different value for both branches? When I see an expression like this, I think: “it returns the same value whether the condition is True or not, let’s simplify it by removing the condition”:

```
- age_sum: sum(age)
```

which will not have the same result.

Another (smaller) point, is that implementing this contextual filter feature means one cannot “escape” the filter of an if function, so for example:

```
- difficult_match: if(to_marry and not gender,
                    abs(age - avg(age, filter=to_marry and gender)),
                    nan)
```

would not work, and would need to be rewritten as:

```
- avg_age_men: avg(age, filter=to_marry and gender)
- difficult_match: if(to_marry and not gender,
                    abs(age - avg_age_men),
                    nan)
```

I would greatly appreciate more input on the subject, so *please* make your voice heard if you have an opinion about this, [on the -dev mailing list].

### 10.1.2 31 *different* variables per expression

Within a single expression, one may only use 31 *different* variables. There is a simple workaround though: split your expression in several pieces, each one using less than 31 variables. Example:

```
- result: a1 + a2 + ... + a31 + a32 + a33
```

could be rewritten as:

```
- tmp: a1 + a2 + ... + a31
- result: tmp + a32 + a33
```

## 10.2 Code architecture

This document is meant for people who want to know more about the internals of LIAM2, for example to add or modify some functionality. One should already be familiar with how the program is used (on the user side).

### 10.2.1 Concepts

Here is a brief description of the most important concepts to understand the code of LIAM2, as well as where those concepts are implemented.

#### Simulation

file: simulation.py

The *Simulation* class takes care of loading the simulation file (it delegates much of the work to entities), prepares the data source and simulates each period in turn (runs each process in turn).

#### Entity

file: entities.py

The *Entity* class stores all there is to know about each entity: fields, links, processes and data. It serves as a glue class between everything data, processes, ...



## Process

file: process.py

The *Process* class stores users processes. The most common kind of process is the *Assignment* which computes the value of an expression and optionally stores the result in a variable.

Another very common process is the *Function* (previously known as procedures) which runs a list of processes in order, and optionally takes arguments and return a value.

## Expressions

file: expr.py (and many others)

Expressions are the meat of the code. The *Expr* class is the base class for all expressions in LIAM2. It defines all the basic operators on expressions (arithmetic, logical, comparison), but it should not be inherited from directly.

file: exprbases.py

LIAM2 provides many different bases classes to inherit from when implementing a new function:

- NumexprFunction: base class for functions which are implemented as-is in numexpr. eg. abs, log, exp
- CompoundExpression: base class for expressions which can be expressed in terms of other “liam2” expressions. eg. min, max, zeroclip
- EvaluableExpression: base class for all other expressions (those that do not exist in numexpr and cannot be expressed in terms of other liam2 expressions). These expressions need to be pre-evaluated and stored in a (hidden) temporary variable before being fed to numexpr, and this is what EvaluableExpression does. One should only inherit from this class directly if none of the below subclasses applies.
  1. NumpyFunction: subclass for functions which are implemented as is in Numpy. Should not be used directly.
    - NumpyCreateArray: subclass for functions which create arrays out of nothing (usually random functions).
    - NumpyChangeArray: subclass for functions which take an array as input and give another array as output (eg clip, round).
    - NumpyAggregate: subclass for aggregate functions. eg. count, min, max, std, median.
  2. FunctionExpr: subclass for functions. eg. trunc, lag, duration, ...
    - FilteredExpression: subclass for functions which have a filter argument and need to support contextual filters. eg. align, sum, avg, gini.

LIAM2 current expressions are implemented in the following files:

**actions.py** actions are expressions which do not have any result (that can be stored in variables), but have side-effects. Examples include: csv(), show(), remove(), breakpoint()

**alignment.py** handles align() and align\_abs() functions

**align\_link.py** the core algorithm (an implementation of Chenard’s) for align\_abs(link=)

**exprmisc.py** all expressions which are not defined in another file.

**groupby.py** handles groupby()

**links.py** contains all link-related code:

- the *Link* class stores the definition of links
- the *LinkGet* class handles ManyToOne links
- one class for each method of OneToMany links: *Count*, *Sum*, *Avg*, *Min* and *Max*.

**matching.py** handles the matching functions: matching() and rank\_matching()

**regressions.py** handles all the regression functions: `logit_score`, `logit_regr`, `cont_regr`, `clip_regr`, `log_regr`

**tfunc.py** handles all time-related functions: `value_for_period`, `lag`, `duration`, `tavg` and `tsum`

## Context

file: `context.py`

A context is a data structure used to keep track of “contextual” information: what is the “current” entity, what is the “current” period, what is the “current” dataset. The context is passed around to the evaluation functions/methods.

A context must present a simple dictionary interface (key: value). There are a few keys with special meanings:

**period** should be the period currently being evaluated

**\_\_len\_\_** if present, should be an int representing the number of rows in the context

**\_\_entity\_\_** current entity

**\_\_globals\_\_** if present, should be a dictionary of global tables (`'periodic'`, ...)

The kind of context which is most used is the *EntityContext* which provides a context interface to an Entity.

## 10.2.2 Other files

### Main code

**config.py** Stores some global configuration variables

**console.py** Handles the interactive console

**cpartition.pyx** Cython source to speed up our partitioning function (`group_indices_nd`) which is used in `groupby` and alignment.

**cpartition.c** generated from `cpartition.pyx` using Cython

**cpartition.pyd** `cpartition.c` compiled

**cutils.pyx** Cython source to speed up some commonly used utility functions.

**cutils.c** generated from `cutils.pyx` using Cython

**cutils.pyd** `cutils.c` compiled

**data.py** handles loading, indexing, checking, merging, copying or modifying (adding or removing fields) tables (or subsets of them). It tries to provide a uniform interface from different data sources but it is a work in progress.

**exprtools.py** parsing code for expressions

**importer.py** code to import csv files in our own hdf5 “subformat” by reading an “import file” (in yaml).

**khash.h** Generic hash table from Klib, used in `cpartition.pyx` see <https://github.com/attractivechaos/klib>

**main.py** The main script. It reads command line arguments and calls the corresponding code (`run`, `import`, `explore`) in `simulation.py` (`run/explore`) or `importer.py` (`import`)

**partition.py** handles partitioning objects depending on the possible values of their columns.

**utils.py** miscellaneous support functions

### standalone scripts

**diff\_h5.py** diff two liam2 files

**dropfields\_h5.py** copy a subset of a liam2 file (excluding specified columns)

**filter\_h5.py** copy a subset of a liam2 file (all rows matching specified condition)

**merge\_h5.py** merge two liam2 files

### **build scripts**

**build\_exe.py** generic script to make executables (for standalones scripts)

**setup.py** compile cython extensions to pyd and make an .exe for the main liam2 executable (using cx\_Freeze)

## **10.3 Technical choices**

### **10.3.1 Python**

We use the Python language (<http://www.python.org/>) for the development of LIAM2.

Python runs on Windows, Linux/Unix, Mac OS X, and has been ported to the Java and .NET virtual machines.

Python is free to use, even for commercial products, because of its OSI-approved open source license.

### **10.3.2 HDF5**

We store the used data in an hdf5-format (<http://www.hdfgroup.org>).

HDF5 is a data model, library, and file format for storing and managing data. It supports an unlimited variety of data types, and is designed for flexible and efficient I/O and for high volume and complex data. HDF5 is portable and is extensible, allowing applications to evolve in their use of HDF5. The HDF5 Technology suite includes tools and applications for managing, manipulating, viewing, and analyzing data in the HDF5 format.

HDF is open-source and the software is distributed at no cost. Potential users can evaluate HDF without any financial investment. Projects that adopt HDF are assured that the technology they rely on to manage their data is not dependent upon a proprietary format and binary-only software that a company may dramatically increase the price of, or decide to stop supporting altogether.

This allows us to handle important data sets.

### **10.3.3 YAML**

The definition of the data and the model is done in the YAML-language (<http://www.yaml.org>).

YAML: YAML Ain't Markup Language

What It Is: YAML is a human friendly data serialization standard for all programming languages.

## **10.4 Change log**

### **10.4.1 Version 0.10**

Released on 2015-06-15.

## New features

- implemented support for calling *user-defined functions* (previously called procedures) from within user code, optionally passing arguments to them and retrieving their return value. As a consequence of this, every mention of “procedures” in the documentation has been replaced by “functions”, including the name of the “procedures” logging level which is now deprecated. Closes [issue 152](#).
- implemented *while loops* (closes [issue 151](#)).
- added support for *not storing some fields in the output file* (closes [issue 58](#)).
- added support for using the “inf” (infinite) constant.

## Miscellaneous improvements

- improved our error handling code to display the (part of the) line where the error occurred in more cases and to not strip the traceback (error.log) of some important information in the cases where the line was already displayed.
- configured the bundle editor (Notepad++) to display some warning and error lines in red in the console log. Additionally, when the error message contains a filename and/or a line number (this is currently too rare unfortunately), it is now click-able (to jump directly at the file/line).
- defining a process outside of a function has been deprecated because it is ambiguous. For example, this code will now trigger a warning and will be an error in a future version:

```
entities:
  person:
    fields:
      agegroup: int
    processes:
      agegroup: 10 * trunc(age / 10)
simulation:
  processes:
    - person: [agegroup]
```

It should be replaced by (or possibly moved into another existing function):

```
entities:
  person:
    fields:
      agegroup: int
    processes:
      compute_agegroup:
        - agegroup: 10 * trunc(age / 10)
simulation:
  processes:
    - person: [compute_agegroup]
```

If this construct was used to have a temporary field (ie the field was not declared in the fields section) accessible from several functions, like

```
entities:
  person:
    processes:
      tempfield: 0

      func1:
        tempfield: count()

      func2:
        otherfield: tempfield + 1
```

One should now declare that field with *output: False* instead.

```

entities:
  person:
    fields:
      tempfield: {type: int, initialdata: False, output: False}

    processes:
      func1:
        tempfield: count()

      func2:
        otherfield: tempfield + 1

```

This closes [issue 124](#).

- made `bcolz` optional (which is only useful for interpolating the dataset during import). Thanks to Mahdi Ben Jelloul ([pull request 161](#)).
- allow simulations with no processes section (but an init section).
- reworked a few sections of the documentation.
- trying to set a value to an unknown variable in `new/clone` produces a warning instead of being silently ignored (or even crashing with `-debug`)

## Fixes

- fixed end-of-simulation stats when simulating 0 periods (closes [issue 158](#)).
- allow overriding (detected) field types of period and id fields in import (closes [issue 154](#)).
- fixed autodump (broken in 0.9). Note that it is currently incompatible with while loops and recursive (user-defined) functions.

## 10.4.2 Version 0.9.1.1

Released on 2015-04-14.

### Fixes

- fixed version number (release 0.9.1 reports itself as 0.9).
- fixed various small problems with the release script.
- made the 32b version use the exact same versions of third-party packages as the 64b version.

## 10.4.3 Version 0.9.1

Released on 2015-03-31.

### Fixes

- Alignment under and overflows are displayed again, even when `debug` is not set (closes [issue 155](#)).
- Always load all declared entities even if there is no process executed for them (but produce a warning in that case). This used to cause a problem if an entity had no process but was used through links (closes [issue 89](#)).
- Fixed dump when the filter is `False` (a scalar), for example in `dump(filter=period == 2100)` (closes [issue 142](#)).

- Fixed the declared return type of many random distributions, which caused a problem if they were used with a filter or within an `if()` expression. This change also fixed `cont_regr` when both `mult` and `filter` arguments are used (closes [issue 153](#)).

## 10.4.4 Version 0.9

Released on 2015-02-03.

### New features

- added support for most of the random number generators provided by Numpy which were not already supported by LIAM2: `beta`, `chisquare`, `dirichlet`, `exponential`, `f`, `gamma`, `geometric`, `hypergeometric`, `laplace`, `lognormal`, `multivariate_normal`, `noncentral_chisquare`, `noncentral_f`, `pareto`, `power`, `rayleigh`, `standard_cauchy`, `standard_exponential`, `standard_gamma`, `standard_normal`, `standard_t`, `triangular`, `vonnises`, `wald`, `weibull`, `zipf`, `binomial`, `logseries`, `negative_binomial`, `poisson` and `multinomial` (see the [random functions](#) section for details). Closes [issue 137](#).
- added the `rank_matching()` function as an alternative method to match two sets of individuals. Based on [pull request 136](#) from Alexis Eidelman.
- added an optional “algo” argument to the `matching()` function, which can be set to either “onebyone” or “byvalue”.
  - “onebyone” is the current default and should give the same result as previous versions.
  - “byvalue” groups individuals by their value for all the variables involved in both the score and orderby expressions, and match groups together. Depending on whether all individuals have different combination of values or not, this can be much faster than matching each individual in turn. It is highly encouraged to use this option as it is much faster in most cases and it scales better ( $O(N1g*N2g)$  instead of  $O(N1*N2)$  where  $N1g$  and  $N2g$  are the number of combination of values in each set and  $N1$  and  $N2$  are the number of individuals in each set). However, the results are **NOT** exactly the same than in previous versions, even though they are both correct. This means that simulation results will be harder to compare against simulation results obtained using previous versions. This will be the new default value for version 0.10. Please also note that this new option is only available if the C extensions are installed. In our test models on actual data, this version ran from 50% faster to 3x faster.

This code is based on the `optimized_matching` work from [pull request 144](#) by Alexis Eidelman.

- added the possibility to automatically generate an order in `matching()` by using the special value ‘EDtM’ for its `orderby` argument. Based on [pull request 136](#) from Alexis Eidelman.
- added an optional ‘pool\_size’ argument to `matching()`. If used, the best match for an individual is looked for in a random subset of size `pool_size`. Based on [pull request 136](#) from Alexis Eidelman.

### Miscellaneous improvements

- updated bundled dependencies to their latest version. The numpy upgrade to version 1.9 brings some performance improvements in various areas (our test simulation runs approximately 15% faster overall).
- large internal refactoring
  - it is now easier to define new functions (there is much less code to write).
  - all arguments to all functions can now be expressions. Closes [issue 5](#).
  - cleaner variable scopes. Eliminates a whole class of potential problems when using two fields with the same name but a different entity (via a link) in the same expression. Closes [issue 41](#).
- cache some internal structure so that it is not recomputed over and over, which improves overall performance by a few percents in some cases, especially when computing many “small” expressions as is often the case in one-by-one `matching()` (which improved in our tests by 10-20%).

- `remove()` can now be called without filter argument (it removes all individuals)
- better and more consistent error messages when calling functions with incorrect arguments (too few, too many, ...)
- use `input/path` as the base directory for loading `.csv` globals (those using an explicit “path”) instead of using the directory of the HDF input file.
- nicer string representation of some expressions (this only affects `qshow` and `groupby`).
- the `-versions` command-line argument now also shows versions for optional dependencies (if present).
- improved many tests, especially the ones for `matching()`.

## Fixes

- fixed the “view” command (to launch ViTables – via F9 for example) in the 64 bit bundle. This was a regression in 0.8.2. Closes [issue 147](#).
- fixed computing most expressions involving arrays with more than one dimension. It only worked if all the arrays involved were based on the same “source” array (which was the case in our tests).
- `assertEqual` fails gracefully when comparing two arrays with different shapes.
- fixed global fields colliding with fields with the same name from other (global) tables.
- fixed expressions like:

```
if(filter_expr, align(..., array[scalar], ...), False)
```

and made all `if(expr, GLOBAL[scalar_value], ...)` expressions faster in the process.

- fixed a rare problem with some expressions using scalars returned by aggregate functions.

## 10.4.5 Version 0.8.2

Released on 2014-10-02.

### New features

- allow loading globals from `csv` files directly, instead of having them in the input HDF file. One can mix both approaches (have some globals in the “input” HDF file while other globals in `.csv` files). This makes it more practical in case you have a relatively stable input dataset for entities, but need to change the globals often, or have several variants with different globals. See the [globals](#) section for details. This closes [issue 30](#).
- added a new simulation option category: “logging”. This is the new home for the existing “timings” option, and for a new “level” option, which allows to sets the verbosity of logging to one of *periods*, *procedures* (this is the default) or *processes* (which corresponds to the behavior in earlier versions).

### Miscellaneous improvements

- decreased memory usage for models with many periods. It used to keep the index of individuals of past periods forever in memory, which had approximately the same effect than adding one column for each period. Since it is only useful when going back in time more than one period, it now flushes it to disk for periods  $< \text{period} - 1$ . This change has two consequences: it will decrease memory use for models with many periods but will slow down models going back in time more than one period. This closes [issue 130](#).
- the “top times” at the end of the simulation now also include the % of total.
- after each period, a very rough estimate of the remaining time for the simulation is displayed (closes [issue 127](#) in combination with the `logging/level` option).

- updated all dependencies provided in the bundle.
- improved the release script.

### Fixes

- Using links or other “non-simple” variables in the score expression of the matching() function was a lot slower and memory-hungry than necessary because some “system temporary variables” kept accumulating. It is still a lot slower than it should though, see [issue 128](#).

## 10.4.6 Version 0.8.1

Released on 2014-03-19.

### New features

- added the gumbel() function to draw random numbers from the Gumbel distribution (also known as the Smallest Extreme Value (SEV) distribution). Thanks to Gijs Dekkers for the patch.

### Fixes

- fixed a performance regression in 0.8 when using very large negative numbers as indices for a global (eg MINR[bad\_index] where bad\_index contains several -2147483648 values). Closes [issue 121](#).
- fixed the (debug) interactive console to not produce a useless warning if a global temporary was run before entering the console (regression in 0.8). Closes [issue 120](#).
- added missing documentation for assertFalse and assertNaNEqual.

## 10.4.7 Version 0.8

Released on 2014-02-05.

### New features

- added a few functions to create charts (courtesy of [matplotlib](#)): bar, plot, pie, stackplot, boxplot and scatter. As with all other functions in liam2, they are available both during a simulation and in the interactive console. The charts can either be visualized directly or saved to a file. See the [charts section](#) for details.
- added a “view” command line option to LIAM2 to open ViTables (an hdf5 viewer) as well as a corresponding menu entry and keyboard shortcut (F9) in Notepad++. It is meant to be used when editing a *model* file, and it will open both the input dataset and the result file (if any).
- document boolean aggregate functions: all() and any() which were added in 0.7 but were not yet documented.
- added *assertFalse* assert function.

### Miscellaneous improvements

- improved the first few demonstration models quite a bit. A recommended read for all users.
- added precisions in the documentation of align() based on Alexis Eidelman suggestions.
- made a few more error messages a bit more useful by displaying the line where the error occurred.
- sped up global[array\_expr].



- give a hint to use `assertNaNEqual` when it would make a failing `assertEqual` pass.
- implemented `global[slice_expr]` (eg. `MINR[period: period+2]`). When the slice bounds are arrays (different for each individual) and the slice length is not constant (not the same for all individuals), it returns a special array with an extremely limited set of supported operations: only aggregates on `axis=1` are implemented.
- include the documentation only in HTML Help format (.chm) in the bundle. .pdf and “normal” html are still available as separate downloads on the website.
- removed the predictor keyword support (it now raises an exception instead of a warning).
- adapted the release script since our move to git and converted it to Python.

## Fixes

- fixed the “syntax upgrade” script by removing a special case for `grpmin` and `grpmax` as it was in fact not needed and caused problems when the expression being aggregated contained parentheses.

## 10.4.8 Version 0.7

Released on 2013-06-18.

### New features

- implemented imports so that simulation files can be split and reused. This can be used to simply split a large model file into smaller files, or (more interestingly) to create simulation variants without having to duplicate the common parts. This feature was inspired by some code from Alexis Eidelman. For details see the *Importing other models* section.
- added new logit and logistic functions. They were previously used internally but not available to modellers.
- added two new debugging features: `autodump` and `autodiff`. `autodump` will dump all (non-scalar) variables (including temporaries) at the end of each procedure in a separate hdf5 file. It can be used stand-alone for debugging, or in combination with `autodiff`. `Autodiff` will gather all variables at the end of each procedure and compare them with the values stored previously by `autodump` in another run of the model (or a variant of it). This can be used to precisely compare two versions/variants of a model and see exactly where they start to differ.
- added new assert functions:
  - `assertIsClose` to check that two results are “almost” equal tolerating small value differences (for example due to rounding differences).
  - `assertEquiv` to check that two results are equal tolerating differences in shape (though they must be compatible).
  - `assertNaNEqual` to check that two arrays are equal even in the presence of nans (because normally `nan != nan`).
- added a new “timings” option to hide timings from the simulation log, so that two simulation logs are more easily comparable (for example with “diff” tools like WinMerge).
- added a menu entry in notepad++ to run a simulation in “debug mode”.

### Miscellaneous improvements

- improved the performance and memory usage by changing the internal memory layout. Most operations are now faster. `new()`, `remove()`, “merging data” (for retrospective simulations) and writing data at the end of each period are now slower. In our model, this translates to a peak memory usage 20% smaller and a 35% overall speed increase. However, if your model has a low processes/variables ratio, it may very well be slower overall with this version. If it is your case, please contact us.

- changed the syntax for all aggregate functions: `grpxxx(...)` should now be `xxx(...)`. For example, `grpsum(age)` should now be: `sum(age)`. The old syntax is still valid but it is deprecated (it will be removed in a later version). A special note for `grpmin()` and `grpmax()` which becomes `min()` and `max()` respectively even though those functions already existed. The meaning is deduced from the number of “non-keyword” arguments:

**min(expr1, expr2)** minimum between `expr1` and `expr2` (for each individual)

**min(expr)** (aggregate) minimum value of “`expr`” over all individuals

**min(expr1, filter=expr2)** (aggregate) minimum value of “`expr`” over individuals satisfying the filter

A tool to automatically upgrade models to the new syntax is provided. In notepad++, you should use the **LIAM2: upgrade model** command in the **Macro** menu.

You can also run it via the command line:

```
main upgrade model.yml [output.yml]
```

see `main upgrade -help` for details.

- changed the syntax for all one2many link functions: `xxxlink(link_name, ...)` should now be `link_name.xxx(...)`. For example, `countlink(persons)` should now be: `persons.count()`. The old syntax is still valid but it is deprecated (it will be removed in a later version). As for aggregate functions, one can upgrade its models automatically with the “upgrade” command.
- the “period” argument of `value_for_period` can now be a *scalar* expression (it must have the same value for all individuals).
- when the output directory does not exist, LIAM2 will now try to create it.
- when debug mode is on, print the position in the random sequence before and after operations which use random numbers.
- entities are loaded/stored for each period in alphabetical order instead of randomly. This has no influence on the results but produces nicer log files.
- deprecated the “predictor” keyword. If you need several processes to write to the same variable, you should use procedures instead.

## Fixes

- using invalid indexes in “global arrays” do not crash anymore if they are properly enclosed in an `if()` expression. For example if you have an array “`by_age`” with values for indices from 0 to 99, the following code will now work as expected:

```
if(age < 50, by_age[age + 50], 0.5)
```

Periodic globals are unaffected (they always return “missing” when out of bounds).

- fixed link expressions which span 3 (or more) *different* entities.
- fixed using `show()` on a scalar created by summing a “global array”.
- fixed the progress bar of `matching()` when the number of individuals is different in the two sets.

## 10.4.9 Version 0.6.2

Released on 2013-05-21.

## Fixes

- fixed storing a copy of a (declared) field (without any modification) in a temporary “backup” variable. The temporary variable was not a copy but an alias to the same data, so if the field was modified afterwards, the temporary variable was also modified implicitly.

As an example, the following code failed before the fix:

```
# age is a field
- backup: age
# modify age (this also modified backup!)
- age: age + 1
# failed because "backup" was equal to "age"
- assertEquals(age, backup + 1)
```

This only affected assignment of “pure” fields, not expressions nor temporary variables, for example, the following code worked fine (because backup stores an expression, not a simple field):

```
- backup: age * 1
- age: age + 1
- assertEquals(age, backup + 1)
```

and this code worked too (because temp is a temporary variable, not a field):

```
- temp: age + 1
- backup: temp
- temp: temp + 1
- assertEquals(temp, backup + 1)
```

### 10.4.10 Version 0.6.1

Released on 2013-03-27.

#### Miscellaneous improvements

- when importing an nd-array skip cells with only spaces in addition to empty cells.

## Fixes

- fixed using non-scalar values (eg fields) as indices of n-dimensional arrays, and generally made indexing n-dimensional arrays more robust.
- fixed choice which did not refuse to run when the sum of probability is != 1 and the “error” is > 1e-6, as it should. This was the case in past versions but the test was accidentally removed in version 0.5.
- fixed choice to warn when the sum of probabilities is > 1 (and the error is <= 1e-6). Previously, it only warned if the sum was < 1.

### 10.4.11 Version 0.6

Released on 2013-03-15.

#### New features

- globals handling has been vastly improved:

- *multiple tables*: one can now define several tables in globals and not only the “periodic” table.

These should be imported in the import file and declared in the simulation file in the exact same way that periodic globals are.

Their usage within a simulation is a bit different though: whereas periodic global variables can be used without prefixing, others globals need to be prefixed with the name of their table. For example, if one has declared a global table named “othertable”:

```
othertable:
  fields:
    - INTFIELD: int
    - FLOATFIELD: float
```

its fields can be used like this:

```
my_variable: othertable.INTFIELD * 10
```

These other global tables need not contain a PERIOD column. When using such a table, LIAM2 will not automatically subtract the “base period” from the index, which means that to access a particular row, you have to use its row index (0 based).

- *n-dimensional globals*: in addition to tables, globals can now be n-dimensional arrays. The file format for those should be the same than alignment files. They should be declared like this:

```
MYARRAY: {type: float}
```

- globals can now be used in all situations instead of only in simple expressions and only for the “current” period. Namely, it makes globals available in: link functions, temporal functions (lag, value\_for\_period, ...), matching(), new() and in (all the different flavours of) the interactive console.
- alignment has been vastly improved:
  - *align\_abs* is a new function with the same arguments than align which can be used to align to absolute numbers per category, instead of proportions. Combined with other improvements in this release, this allows maximum flexibility for computing alignment targets on the fly (see below).
  - *align on a linked entity* (a.k.a immigration): additionally to the arguments of align, align\_abs has also an optional “link” argument, which makes it work on the linked entities. The link argument must a one2many link. For example, it can be used to take as many *household\*s as necessary trying to get as close as possible to a particular distribution of \*persons*. When the link argument is in effect, the function uses the “Chenard” algorithm.

In this form, align\_abs also supports two extra arguments:

- \* *secondary\_axis*: name of an axis which will influence rel\_need when the subtotal for that axis is exceeded. See total\_by\_sex in Chenard. secondary\_axis must be one of the alignment columns.
- \* *errors*: if set to ‘carry’, the error for a period (difference between the number of individuals aligned and the target for each category) is stored and added to the target for the next period.
- renamed the “probabilities” argument of align to “proportions”
- the “proportions” argument of align() is now much more versatile, as all the following are now accepted:
  - \* a single scalar, for aligning with a constant proportion.
  - \* a list of scalars, for aligning with constant proportions per category. (this used to be the only supported format for this argument)
  - \* an expression returning a single scalar.
  - \* an expression returning an n-dimensional array. expressions and possible\_values will be retrieved from that array, so you can simply use:

```
align(score, array_expr)
```

- \* a list of expressions returning scalars [expr1, expr2].
  - \* a string (in which case, it is treated as a filename). The “fname” argument is still provided for backward compatibility.
- added an optional “frac\_need” argument to align() to control how “fractional needs” are handled. It can take any of three values: “uniform” (default), “cutoff” or “round”.
- \* “uniform” draws a random number (u) from an uniform distribution and adds one individual if  $u < \text{frac\_need}$ . “uniform” is the default behavior.
  - \* “round” simply rounds needs to the nearest integer. In other words, one individual is added for a category if the fractional need for that category is  $\geq 0.5$ .
  - \* “cutoff” tries to match the total need as closely as possible (at the expense of a slight loss of precision for individual categories) by searching for the “cutoff point” that yields:

```
count(frac_need >= cutoff) == sum(frac_need)
```

- changed the order of align() arguments: proportions is now the second argument, instead of filter, which means you can omit the “fname” or “proportions” keywords and write something like:

```
align(score, 'my_csv_file.csv')
```

- made align() (and by extension logit\_regr) always return False for individuals outside the filter, instead of trying to modify the target variable only where the filter is True. That feature seemed like a good idea on paper but had a very confusing side-effect: the result was different when it was stored in an existing variable than in a new temporary variable.
- it is no longer possible to use expressions in alignment files. If you need to align on an expression (instead of a simple variable), you should specify the expression in the alignment function. eg:

```
align(0.0, fname='al_p_dead.csv', expressions=[gender, age + 1])
```

- the result of a groupby can be used in expressions. This can be used, for example, to compute alignment targets on the fly.
- implemented explore on data files (.h5), so that one can, for example, explore the input dataset.
- added skip\_na (defaults to True) argument to all aggregate functions to specify whether or not missing values (nan for float expressions, -1 for integer expressions) should be ignored.
- macros can now be used in the interactive console.
- added “globals” command in the interactive console to list the available globals.
- added qshow() command to show an expression “textual form” in addition to its value. Example:

```
qshow(grpavg(age))
```

will display:

```
grpavg(age) : 38.5277057298
```

- added optional “pvalues” argument to groupby() to manually provide the “axis” values to compute the expression on, instead of having groupby compute the combination of all the unique values present in the dataset for each column.

## Miscellaneous improvements for users

- improved the documentation, in part thanks to the corrections and suggestions from Alexis Eidelman.
- added a “known issues” section to the documentation.
- grpmin and grpmax ignore missing values (nan and -1) by default like other aggregate functions.
- grpavg ignore -1 values for integer expressions like other aggregate functions.

- made the operator precedence for “and”, “or” and “not” more sensible, which means that, for example:

```
age > 10 and age < 20
```

is now equivalent to:

```
(age > 10) and (age < 20)
```

instead of raising an error.

- many2one links are now ~30% faster for large datasets.
- during import, when a column is entirely empty and its type is not specified manually, assume a float column instead of failing to import.
- allow “id” and “period” columns to be defined explicitly (even though they are still implicit by default).
- allow “period” in any dimension in alignment files, not only in the last one.
- disabled all warnings for x/0 and 0/0. This is not an ideal situation, but it is still an improvement because they appeared in LIAM2 code and not in user code and as such confused users more than anything.
- the “num\_periods” argument of lag: lag(age, num\_periods) can now be a *scalar* expression (it must have the same value for all individuals).
- changed output format of groupby to match input format for alignments.
- added Warning in grpgini when all values (for the filter) are zeros.
- when an unrecoverable error happens, save the technical error log to the output directory (for run and explore commands) instead of the directory from where liam2 was run and display on the console where the file has been saved.
- better error message when an input file has inconsistent row lengths.
- better error message when using a one2many function in a groupby expression.

### Miscellaneous improvements for developers

- added a “code architecture” section to the documentation.
- python tracebacks can be re-activated by setting the DEBUG environment variable to True.
- added a script to automate much of the release process.
- added source files for creating liam2 bundle (ie add our custom version of notepad++ to the source distribution).
- updated INSTALL file, and include sections on how to build the documentation and the C extensions.
- added many tests, fixed a few existing ones and generally greatly improved our test suite.

### Fixes

- fixed “transposed” option on import. The number of lines to copy was computed on the untransposed data which meant too few data points were copied if the number columns was greater than the number of lines and it crashed if it was smaller.
- fixed all aggregate functions (except grpcount and grpsum) with a filter argument equal to a simple variable (eg filter=gender) in the presence of “missing” (nan) values in the expression being aggregated: the filter variable was modified.
- fixed duration() on a simple variable (eg duration(work)): the variable was modified by the function.
- fixed a nasty bug which made that each variable that needed to be read on disk (lag of more than one period, duration, value\_for\_period, ...) was read 2 or 3 times instead of just once, greatly slowing down the function.

- fixed accessing columns for the next-to-last period in the interactive console after a simulation: it was either giving bad results or returning an error.
- fixed all aggregate functions (except `grpcount`, `grpsum` and `grpavg` which worked) on boolean expressions. This is actually only (remotely) useful for `grpgini` and `grpstd`.
- fixed `groupby` with both `filter` and `expr` arguments.
- fixed `groupby(expr=scalar)`.
- fixed `sumlink(link, scalar)`.
- fixed `new(number=...)`.
- fixed non-aligned regressions with a filter (it was ignored).
- fixed the editor shortcuts (to launch `liam2`) to work when the directory containing the model contains spaces.
- fixed handling of comments in the first cell of a row in alignments files (the entire row is ignored now).
- fixed “textual form” of choice expressions when bins or choices are dynamic.
- fixed using `numpy 1.7`

### Experimental new features

- implemented optional periodicity for simulation processes.

### 10.4.12 Version 0.5.1

Released on 2012-11-28.

### Miscellaneous improvements

- if there is only one entity defined in a model (like in `demo01.yml`) and the interactive console is launched, start directly in that entity, instead of requiring the user to set it manually.
- improved introduction comments in demo models.
- display whether C extensions are used or not in `-versions`.
- use `default_entity` in demos (from `demo03` onward).
- do not display python version in normal execution but only in `-versions`.
- use `cx_freeze` instead of `py2exe` to build executables for Windows so that we can use the same script to build executables across platforms and tweaked further our build script to minimise the executable size.
- compressed as many files as possible in the 32 bit Windows bundle with UPX to make the archive yet smaller (UPX does not support 64 bit executables yet).
- improved our build system to automate much of the release process.

### Fixes

- fixed the “`explore`” command.
- fixed integer fields on 64 bit platforms other than Windows.
- fixed `demo06`: `WEMRA` is an int now.
- fixed `demo01` introduction comment (bad file name).

### 10.4.13 Version 0.5

Released on 2012-10-25.

#### New features

- added a way to import several files for the same entity. A few comments are in order:
  - Each file can have different data points. eg if you have historical data for some fields data going back to 1950 for some individuals, and other fields going back to only 2000, the import mechanism will merge those data sets.
  - It can also optionally fill missing data points. Currently it only supports filling with the “previous value” (the value the individual had (if any) for that field in a previous period). In the future, we will add more ways to fill those by interpolating existing data. Note that *currently* only data points which are entirely missing are filled, not those which are set to the special value corresponding to “missing” for the field type (i.e. False for booleans, -1 for integers and “nan” for floats). This will probably change in the future.
  - As a consequence of this new feature, it is now possible to import liam1 files using the “normal” import file syntax.
- added an optional “default\_entity” key to the “simulation” block of simulation files, so that the interactive console starts directly in that entity.
- added function to compute the Nth percentile: `grppercentile(expr, percent[, filter])`.
- implemented an optional filter argument for many functions. The behaviour is different depending on the kind of function:
  - for functions that change an existing variable (`clip()` and `round()`), the value for filtered individuals is not modified.
  - for functions which create a new variable (`uniform()`, `normal()` and `randint()`), the value for filtered individuals is the missing value corresponding with the type of the column (-1 for `randint()`, nan for `uniform()` and `normal()`).
  - for aggregate functions (`grpmin()`, `grpmax()`, `grpstd()`, `grpmedian()` and `grppercentile()`), the aggregate is computed over the individuals who satisfy the filter.
- added new functions for testing: `assertTrue` and `assertEqual`:
  - `assertTrue(expr)` evaluates its expression argument and check that it is True.
  - `assertEqual(expr1, expr2)` evaluates its two expressions and check that they are equal.
- The behaviour when an assertion fails is configurable through the “assertions” option in the “simulation” block. This option can take three values:
  - “raise”: interrupt the simulation (this is the default).
  - “warn”: display a warning message.
  - “skip”: do not run the assertion at all.
- added commands to the console:
  - `entities`: prints the list of available entities.
  - `periods`: prints the list of available periods for the current entity.
- added new command line arguments to override paths specified in the simulation file:
  - `-input-path`: override the input path
  - `-input-file`: override the input file
  - `-output-path`: override the output path



- `-output-file`: override the output file
- added `-versions` command line argument to display versions of all the libraries used.

### Miscellaneous improvements

- performance optimisations:
  - fields which are used in lag expressions are cached (stored in memory) to avoid fetching them from disk. This considerably speeds up lag expressions at the expense of a bit more memory used.
  - implemented a few internal functions in Cython to get C-level performance. This considerably speeds up alignment and groupby expressions, especially when the number of “alignment categories” (the number of possible combinations of values for the variables used to partition) is high. The downside is that if someone wants to recreate liam2 binaries from the source code and benefit from this optimisation (there is a pure-python fallback), he needs to have cython and a C compiler installed.
  - other minor optimisations to groupby and alignments with take or leave filters.
  - slightly sped up initial data loading for very large datasets with a lot of historical data.
- `choices()` arguments (options and probabilities) now accept expressions (ie. they can be computed at run time).
- improved the interactive console:
  - made the interactive console start in the last simulated period by default.
  - changed the behaviour of the “entity” command without argument to print the current entity.
  - the “period” command can now be called without argument to print the current period.
- added more explicit checks for bad input:
  - check for duplicate headers in alignment files.
  - check all arguments to `groupby()` are valid instead of only the first one.
  - check for invalid keyword arguments to `dump()`.
  - check for invalid keyword arguments to `csv()`.
  - check the type of arguments to `choice()`.
  - validate globals at load time to make sure the declared globals are actually present in the dataset.
- disallow strings for the score expression in the `matching()` function.
- improved the test coverage: There is still a long way for full test coverage, but the changes in this version is already a first step in the right direction:
  - automated many tests by using the new assertions functions.
  - added more tests.
- only copy declared globals to the output file, and do not create a “globals” node at all if there is no declared global.
- manually close input and output files when an error happens during initialisation, so that the user only sees the real error message.
- globals can be entirely missing from the input file if they are not used in the simulation file.
- made the usual code clean-ups.

## Fixes

- fixed typo in the code outputting durations (“hourss” instead of “hours”).
- fixed a bug which prevented to define constants without quoting them in some cases.
- fixed a crash when all groups were empty in a `groupby(xxx, expr=grpcount(), percent=True)`.
- fixed aggregate functions (`grpmin`, `grpmax`, `grpstd`, `grpmedian` and `grppercentile`) to accept a scalar as argument (even though it is not very useful to do that).
- fixed a bug which prevented to use a simulation output file as input in some cases.

### 10.4.14 Version 0.4.1

Released on 2011-12-02.

#### Miscellaneous improvements

- validate both import and simulation files, i.e. detect bad structure and invalid and missing keywords.
- improved error messages (both during import and the simulation), by stripping any information that is not useful to the user. For some messages, we only have a line number and column left, this is not ideal but should be better than before. The technical details are written to a file (`error.log`) instead.
- improved “incoherent alignment data” error message when loading an alignment file by changing the wording and adding the path of the file with the error.
- reorganised bundle files so that there is no confusion between directories for Notepad++ and those of `liam2`.
- tweaked Notepad++ configuration:
  - added explore command as F7
  - removed more unnecessary features.

## Fixes

- disallowed using one2many links like many2one (it was never intended this way and produced wrong results).
- fixed `groupby` with a scalar expression (it does not make much sense, but it is better to return the result than to fail).
- re-enabled the code to show the expressions containing errors where possible (in addition to the error message). This was accidentally removed in a previous version.
- fixed usage to include the ‘explore’ command.

### 10.4.15 Version 0.4

Released on 2011-11-25.

#### New features

- added `grpgini` function.
- added `grpmedian` function.
- implemented filter argument in `grpsum()`.

- implemented N-dimensional alignment (alignment can be done on more than two variables/dimensions in the same file).
- added keyword arguments to csv():
  - ‘fname’ to allow defining the exact name of the csv file.
  - ‘mode’ to allow appending to a csv file instead of overwriting it.
- reworked csv() function to support several arguments, like show. It also supports non-table arguments.
- added ‘skip\_shows’ simulation option, to make all show() functions do nothing.
- allowed expressions in addition to variable names in alignment files.
- added keyword arguments to dump():
  - ‘missing’ to convert nans into the given value.
  - ‘header’ to determine whether column names should be in the dump or not.
- improved import functionality:
  - compression is now configurable.
  - any csv file can be transposed, not just globals.
  - globals fields can be selected, renamed and inverted like in normal entities.
- added “explore” command to the main executable, to launch the interactive console on a completed simulation without re-simulating it.

### Miscellaneous improvements

- expressions do not need to be quoted anymore.
- reverted init to old semantic: it happens in “start\_period - 1”, so that lag(variable\_set\_in\_init) works even for the first period.
- purge all local variables after each process to lower memory usage.
- allowed the result of new() to not be stored in a variable.
- allowed using temporary variables in matching() function.
- using a string for matching expressions is deprecated.
- added a tolerance of 1e-6 to the sum of choice’s probabilities to be equal 1.0
- added explicit message about alignment over and underflows.
- nicer display for small (< 5ms) and large (>= 1 hour) timings.
- improved error message on missing parenthesis around operands of boolean operators.
- improved error message on duplicate fields.
- improved error message when a variable which is not computed yet is used.
- added more information to the console log:
  - number of individuals at the start and end of each period.
  - more stats at the end of the simulation.
- excluded unused components in the executable to make it smaller.

## Fixes

- fixed `logit_regr`(align=float).
- fixed `grpavg`(bool, filter=cond).
- fixed `groupby`(a, b, c, expr=grpsum(d), percent=True).
- fixed having several `grpavg` with a filter argument in the same expression.
- fixed calling the main executable without argument (simply display usage).
- fixed `dump` with (some kind of) aggregate values in combination with a filter.
- fixed void data source.

## 10.4.16 Version 0.3

Released on 2011-06-29.

### New features

- added ability to import csv files directly with the main executable.

### Miscellaneous improvements

- made periodic globals optional.
- improved a few sections of the documentation.

## Fixes

- fixed non-assignment “actions” in interactive console (`csv`, `remove`, ...).
- fixed `error_var` argument to `cont_regr`, `clip_regr` and `log_regr`.

## 10.4.17 Version 0.2.1

Released on 2011-06-20.

### Miscellaneous improvements

- simplified and cleaned up the demonstration models.
- improved the error message when a link points to an unknown entity.
- the evaluator creates fewer internal temporary variables in some cases.

## Fixes

- added `log` and `exp` to the list of available functions (they were already implemented but not usable because of that).
- fixed `log_regr`, `cont_regr` and `clip_regr` which were comparing their result with 0.5 (like `logit_regr` when there is no alignment).
- fixed `new()` function, which created individuals correctly but in some cases returned values which did not correspond to the ids of the newly created individuals, due to a bug in `numpy`.

## 10.4.18 Version 0.2

Released on 2011-06-07.

### New features

- added support for retrospective simulation (ie simulating periods for which we already have some data): at the start of each simulated period, if there is any data in the input file for that period, it is “merged” with the result of the last simulated period. If there is any conflict, the data in the input file has priority.
- added “clone” function which creates new individuals by copying all fields from their “origin” individuals, except for the fields which are given a value manually.
- added breakpoint function, which launches the interactive console during a simulation. Two more console commands are available in that mode:
  - “s(tep)” to execute the next process
  - “r(esume)” to resume normal execution

The breakpoint function takes an optional period argument so that it triggers only for that specific period.

- added “tsum” function, which sums an expression over the whole lifetime of individuals. It returns an integer when summing integer or boolean expressions, and a float for float expressions.
- implemented using the value of a periodic global at a specific period. That period can be either a constant (eg “MINR[2005]”) or an expression (eg “MINR[period - 10]” or “MINR[year\_of\_birth + 20]”)
- added “trunc” function which takes a float expression and returns an int (dropping everything after the decimal point)

### Miscellaneous improvements

- made integer division (int / int) return floats. eg  $1/2 = 0.5$  instead of 0.
- processes which do not return any value (csv and show) do not need to be named anymore when they are inside of a procedure.
- the array used to run the first period is constructed by merging the individuals present in all previous periods.
- print timing for sub-processes in procedures. This is quite verbose but makes debugging performance problems/regressions easier.
- made error messages more understandable in some cases.
- manually flush the “console” output every time we write to it, not only within the interactive console, as some environments (namely when using the notepad++ bundle) do not flush the buffer themselves.
- disable compression of the output/simulation file, as it hurts performance quite a bit (the simulation time can be increased by more than 60%). Previously, it was using the same compression settings as the input file.
- allowed align() to work on a constant. eg:

```
align(0.0, fname='al_p_dead_m.csv')
```

- made the “tagv” function work with boolean and float expressions in addition to integer expressions
- allowed links to be used in expression given in the “new” function to initialise the fields of the new individuals.
- using “\_\_parent\_\_” in the new() function is no longer necessary.
- made the “init” section optional (it was never intended to be mandatory).
- added progress bar for copying table.

- optimised some parts for speed, making the whole simulation roughly as fast as 0.1 even though more work is done.

### Fixes

- fixed “tavg” function:
  - the result was wrong because the number of values (used in the division) was one less than it should.
  - it yielded “random” values when some individuals were present in a past period, but not in the current period.
- fixed “duration” function:
  - it crashed when a past period contained no individuals.
  - it yielded “random” values when some individuals were present in a past period, but not in the current period.
- fixed “many2one” links returning seemingly random values instead of “missing” when they were pointing to an individual which was not present anymore (usually because the individual was dead).
- fixed min/max functions.
- fields which are not given an explicit value in new() are initialised to missing, instead of 0.
- the result of the new() function (which returns the id of the newly created individuals) is now -1 (instead of 0) for parents which are not in the filter.
- fixed some expressions crashing when used within a lag.
- fixed the progress bar to display correctly even when there are only very few iterations.

### 10.4.19 Version 0.1

First semi-public release, released on 2011-02-24.

## 10.5 Credits

LIAM2 is the result of ongoing collaboration between individual researchers from the Federal Planning Bureau (FPB) in Belgium, CEPS/INSTEAD and the General Inspectorate of Social Security (Inspection Générale de la Sécurité Sociale, IGSS) in Luxembourg.

The software package is primarily being developed at the Federal Planning Bureau by Gaëtan de Menten and Geert Bryon. Testing and model development is done by Raphaël Desmet and Gijs Dekkers (FPB), Philippe Liégeois and Frédéric Berger (CEPS/INSTEAD) and Raymond Wagener (IGSS). Finally, Cathal O’Donoghue shared the source code of the first version of LIAM, which the FPB used in the AIM project (Dekkers et al., 2010).

LIAM2 was initially the result of the MiDaL project (December 2009 - November 2011), “Towards the development of a dynamic Microsimulation toolbox « LIAM-II » and the complementary implementation of administrative Data needed for dynamic microsimulation of pensions in Luxembourg”. The general objective of the project was to “develop an advanced analysis tool that allows Luxembourg and other countries at answering policy-related questions about pensions and social transfers in the longer term through microsimulation models. The project received funding from both the European Community Programme for Employment and Social Solidarity - PROGRESS (2007-2013), under the Grant VS/2009/0569, and the General Inspectorate for Social Security (IGSS) of Luxembourg.

The PROGRESS programme was created by the European Commission to financially support the implementation of the objectives of the European Union in the employment, social affairs and equal opportunities areas. For more information, see: <http://ec.europa.eu/progress>

- abs, 20
- aggregate functions, 20
- align, 27
- align\_abs, 30
- alignment, 26
- all, 21
- any, 21
- assertEqual, 56
- assertions, 56
- assertTrue, 56
- avg, 21
  
- bar, 42
- bar charts, 42
- beta, 23
- binomial, 23
- boxplot, 54
- breakpoint, 56
- builtin functions, 20
- bundle, 2
  
- charts, 41
- chisquare, 23
- choice, 25
- clip, 20
- clone, 35
- comments, 5
- conditional function, 20
- count, 21
- csv, 37
  
- debugging, 55
- dirichlet, 23
- dump, 39
- duration, 22
  
- entities, 7
- exp, 20
- exponential, 23
- expressions, 15
  
- f, 23
- fields, 7
- function call, 17
- function declaration, 16
- gamma, 23
- geometric, 23
- gini, 21
- globals declaration, 6
- globals usage, 19
- groupby, 39
- gumbel, 22, 23
  
- hdf5, 79
- hypergeometric, 23
  
- if, 20
- importing data, 65
- importing models, 61
- interactive console, 55
  
- known issues, 75
  
- lag, 22
- laplace, 23
- leave, 27
- lifecycle functions, 33
- link methods, 21
- link.avg, 21
- link.count, 21
- link.max, 21
- link.min, 21
- link.sum, 21
- links, 57
- log, 20
- logit, 26
- logit\_regr, 31
- logit\_score, 26
- lognormal, 23
- logseries, 23
  
- macros, 8
- many2one, 59
- matching, 32
- matching functions, 32
- mathematical functions, 20
- max, 20, 21
- median, 21
- min, 20, 21
- multinomial, 24
- multivariate\_normal, 24
  
- negative\_binomial, 24
- new, 34
- noncentral\_chisquare, 24

noncentral\_f, 24  
normal, 22, 24  
notepad++, 2

one2many, 60

pareto, 24  
percentile, 21  
pie, 51  
pie charts, 51  
plot, 45  
poisson, 24  
power, 24  
processes, 13  
python, 79

qshow, 37

randint, 22, 24  
random, 22  
rank\_matching, 33  
rayleigh, 24  
remove, 35  
round, 20

scatter, 52  
scatter plots, 52  
show, 36  
stackplot, 50  
standard\_cauchy, 24  
standard\_exponential, 24  
standard\_gamma, 24  
standard\_normal, 24  
standard\_t, 25  
std, 21  
sum, 21

take, 27  
tavg, 22  
temporal functions, 22  
triangular, 25  
trunc, 20  
tsum, 22

uniform, 22, 25

value\_for\_period, 22  
vonmises, 25

wald, 25  
weibull, 25  
while, 35

yaml, 79

zipf, 25