
Agent-Based Computational Economics Documentation

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Contents

1	Introduction	3
1.1	Design	3
1.2	Download and Installation	7
1.3	Interactive jupyter notebook Tutorial	8
1.4	Walk through	8
1.5	Tutorial for Plant Modeling	17
1.6	Examples	21
1.7	unit testing	24
2	Simulation Programming	25
2.1	The simulation in start.py	25
2.2	Agents	30
2.3	Physical goods and services	31
2.4	Trade	33
2.5	Messaging	38
2.6	Firm and production	39
2.7	Household and consumption	42
2.8	Observing agents and logging	43
2.9	Retrieval of the simulation results	46
2.10	NotEnoughGoods Exception	46
3	Advanced	49
3.1	Contracting	49
3.2	Quote	52
3.3	Spatial and Netlogo like Models	53
3.4	Plugins	56
4	Graphical User Interface and Results	59
4.1	Graphical User Interface	59
4.2	Deploying an ABCE simulation on-line	61
5	Frequently asked Questions	63
5.1	How to share public information?	63
5.2	How to share a global state?	63
5.3	How to access other agent's information?	63
5.4	How to make abcEconomics fast?	63
5.5	How to load agent-parameters from a csv / excel / sql file?	64

6 Indices and tables	65
Python Module Index	67
Index	69

ABCE is a Python based modeling platform for economic simulations. ABCE comes with standard functions to simulations of trade, production and consumption. The modeler can concentrate on implementing the logic and decisions of an agents; ABCE takes care of all exchange of goods and production and consumption.

In ABCE goods have the physical properties of goods in reality in the sense that if agent A gives a good to agent B, then - unlike information - agent B receives the good and agent B does not have the good anymore. The ownership and transformations (production or consumption) of goods are automatically handled by the platform.

ABCE models are programmed in standard Python, stock functions of agents can be inherited from archetype classes (Firm or Household). The only not-so-standard Python is that agents are executed in parallel by the Simulation class (in start.py).

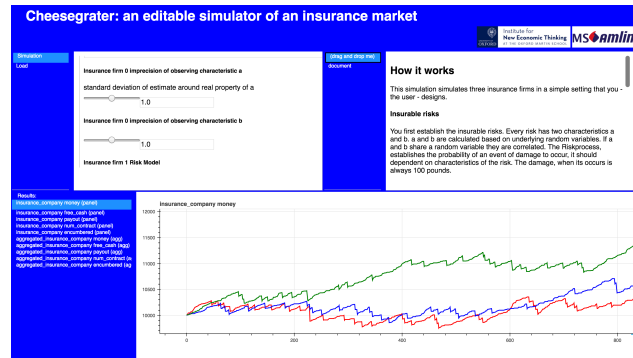
ABCE allows the modeler to program agents as ordinary Python class-objects, but run the simulation on a multi-core/processor computer. It takes no effort or intervention from the modeler to run the simulation on a multi-core system. The speed advantages of using ABCE with multi-processes enabled. ABCE are typically only observed for 10000 agents and more. Below, it might be slower than pure python implementation. ABCE supports pypy3, which is approximately 10 times faster than CPython.

ABCE is a scheduler¹ and a set of agent classes. According to the schedule the simulation class calls - each sub-round - agents to execute some actions. Each agent executes these actions using some of the build-in functions, such as trade, production and consumption of ABCE. The agents can use the full set of commands of the Python general purpose language.

The audience of ABCE are economists that want to model agent-based models of trade and production.

ABCE does support an accounting framework for financial simulations. [ESL can be downloaded here](#).

ABCE runs on macOS, Windows, and Linux. ABCE runs 10x faster on pypy!



¹ the Simulation class

1.1 Design

ABCE's first design goal is that, code can be rapidly written, to enable a modeler to quickly write down code and quickly explore different alternatives of a model.

Execution speed is a secondary concern to the goal of rapid development. Execution speed is achieved by making use of multiple-cores/processors and using C++ for background tasks or using pypy.

Secondly, the modeler can concentrate on programming the behavior of the agents and the specification of goods, production and consumption function. The functions for economic simulations such as production, consumption, trade, communication are provided and automatically performed by the platform.

Python has also been chosen as a programming language, because of its rich environment of standard libraries. Python for example comes with a stock representation of agents in a spacial world, which allow the modeler to model a spatial model.

Python is especially beginner friendly, but also easy to learn for people who already know object oriented programming languages such as Java, C++ or even MATLAB. ABCE uses C++, to handle background tasks to increase speed. Python allows simple, but fully functional, programming for economists. What is more Python is readable even for non Python programmers.

Python is a language that lends itself to writing of code fast, because it has low overhead. In Python variables do not have to be declared, garbage does not have to be collected and classes have no boiler-plate code.

Python, is slower than Java or C, but its reputation for slow speed is usually exaggerated. Various packages for numerical calculations and optimization such as numpy and scipy offer the C like speed to numerical problems. Contrary to the common belief Python is not an interpreted language. Pypy even provides a just in time compiler Python is compiled to bytecode and then executed. ABCE allows to parallelize the code and gain significant speed advantage over single-threaded code, that does not make use of the speed advantage of multi-core or multi-processor computers.

ABCE 0.6 supports Python 3.

For the simulated problem all agents are executed in parallel. This is achieved by randomizing the arrival of messages and orders between sub-rounds. For example if in one sub-round all agents make offers and in the next sub-round all

agents receive and answer the offers, the order in which the agents receive is random, as if the agent's in the round before would make offers in a random order.

1.1.1 Differences to other agent-based modeling platforms

We identified several survey articles as well as a quite complete overview of agent-based modeling software on Wikipedia. [Serenko2002], [Allan2010] [Societies2009], [Tobias2004], [Railsback2006], [abmcomparison-Wikipedia2013]. The articles 'Tools of the Trade' by Madey and Nikolai [Societies2009] and 'Survey of Agent Based Modelling and Simulation Tools' by Allan [Allan2010] attempt to give a complete overview of agent-based modelling platforms/frameworks. The Madey and Nikolai paper categorizes the abm-platforms according to several categories. (Programming Language, Type of License, Operating System and Domain). According to this article, there is only one software platform which aims at the specific domain of economics: JASA. But JASA is a modeling platform that aims specifically at auctions. Wikipedia [abmcomparisonWikipedia2013] lists JAMEL as an economic platform, but JAMEL is a closed source and a non-programming platform. The 'Survey of Agent Based Modelling and Simulation Tools' by Allan [Allan2010] draws our attention to LSD, which, as it states, is rather a system dynamic, than an agent-based modeling platform. We conclude that there is a market for a domain specific language for economics.

While the formerly mentioned modeling platforms aim to give a complete overview, 'Evaluation of free Java - libraries for social scientific agent based simulation' [Tobias2004] by Tobias and Hoffman chooses to concentrate on a smaller number of simulation packages. Tobias and Hoffman discuss: RePast, Swarm, Quicksilver, and VSEit. We will follow this approach and concentrate on a subset of ABM models. First as economics is a subset of social science we dismiss all platforms that are not explicitly targeted at social science. The list of social science platforms according to [Societies2009] Madey and Nikolai is: AgentSheets, LSD, FAMOJA, MAML, MAS-SOC, MIMOSE, NetLogo, Repast SimBioSys, StarLogo, StarLogoT, StarLogo TNG, Sugarscape, VSEit NetLogo and Moduleco. We dismiss some of these frameworks/platforms:

AgentSheets, because it is closed source and not 'programmable'

LSD, because it is a system dynamics rather than an agent-based modeling environment

MAML, because it does not use a standard programming language, but it is its own.

MAS-SOC, because we could not find it in the Internet and its documentation according to [Allan2010] is sparse.

MIMOSE, is an interesting language, but we will not analyze as it is based on a completely different programming paradigm, functional programming, as opposed to object-oriented programming.

SimBioSys, because it has according to Allan [Allan2010] and our research a sparse documentation.

StarLogo, StarLogoT, StarLogo TNG, because they have been superseded by NetLogo

Moduleco, because it has according to Allan [Allan2010] and our research a sparse documentation. Further, it appears not to be updated since roughly 2001

We will concentrate on the most widely used ABM frameworks/platforms: MASON, NetLogo, Repast.

1.1.2 General differences to other agent-based modeling platforms

First of all ABCE is domain specific, that enables it to provide the basic functions such as production, consumption, trade and communication as fully automated stock methods. Because any kind of agent interaction (communication and exchange of goods) is handled automatically ABCE, it can run the agents (virtually) parallel and run simulations on multi-core/processor systems without any intervention by the modeler.

The second biggest difference between ABCE and other platforms is that ABCE introduces the physical good as an ontological object in the simulation. Goods can be exchanged and transformed. ABCE handles these processes automatically, so that for the model a physical good behaves like a physical good and not like a message. That means that if a good is transferred between two agents the first agent does not have this good anymore, and the second agent

has it now. Once, for example, two agents decide to trade a good ABCE makes sure that the transaction is cleared between the two agents.

Thirdly, ABCE is just a scheduler that schedules the actions of the agents and a python base class that enables the agent to produce, consume, trade and communicate. A model written in ABCE, therefore is standard Python code and the modeler can make use of the complete Python language and the Python language environment. This is a particular useful feature because Python comes with about 30.000² publicly available packages, that could be used in ABCE. Particularly useful packages are:

pybrain a neural network package

numpy a package for numerical computation

scipy a package for numerical optimization and statistical functions

sympy a package for symbolic manipulation

turtle a package for spacial representation ala NetLogo

Fourth, many frameworks such as FLAME, NetLogo, StarLogo, Ascape and SugarScape and, in a more limited sense, Repast are designed with spacial representation in mind. For ABCE a spacial representation is possible, but not a design goal. However, since agents in ABCE are ordinary Python objects, they can use python modules such as python-turtle and therefore gain a spacial representation much like NetLogo. This does by no means mean that ABCE could not be a good choice for a problem where the spacial position plays a role. If for example the model has different transport costs or other properties according to the geographical position of the agents, but the agent's do not move or the movement does not have to be represented graphically, ABCE could still be a good choice.

Difference to MASON

Masons is a single-threaded discrete event platform that is intended for simulations of social, biological and economical systems. [Luke]. Mason is a platform that was explicitly designed with the goal of running it on large platforms. MASON distributes a large number of single threaded simulations over deferent computers or processors. ABCE on the other hand is multi-threaded it allows to run agents in parallel. A single run of a simulation in MASON is therefore not faster on a computing cluster than on a potent single-processor computer. ABCE on the other hand uses the full capacity of multi-core/processor systems for a single simulation run. The fast execution of a model in ABCE allow a different software development process, modelers can 'try' their models while they are developing and adjust the code until it works as desired. The different nature of both platforms make it necessary to implement a different event scheduling system.

Mason is a discrete event platform. Events can be scheduled by the agents. ABCE on the other hand is scheduled - it has global list of sub-rounds that establish the sequence of actions in every round. Each of these sub-rounds lets a number of agents execute the same actions in parallel.

MASON, like Repast Java is based on Java, while ABCE is based on Python, the advantages have been discussed before.

Difference to NetLogo

Netlogo is a multi-agent programming language, which is part of the Lisp language family. Netlogo is interpreted. [Tissue2004] Python on the other hand is a compiled³ general programming language. Consequently it is faster than NetLogo.

Netlogo's most prominent feature are the turtle agents. To have turtle agents in ABCE, Python's turtle library has to be used. The graphical representation of models is therefore not part of ABCE, but of Python itself, but needs to be included by the modeler.

² <https://pypi.python.org/>

³ Python contrary to the common believe is compiled to bytecode similar to Java's compilation to bytecode.

One difference between Netlogo and ABCE is that it has the concept of the observer agent, while in ABCE the simulation is controlled by the simulation process.

Difference Repast

Repast is a modeling environment for social science. It was originally conceived as a Java recoding of SWARM. [Collier] [NORTH2005] Repast comes in several flavors: Java, .Net, and a Python like programming language. Repast has been superseded by Repast Symphony which maintains all functionality, but is limited to Java. Symphony has a point and click interface for simple models. [NORTH2005a]

Repast does allow static and dynamic scheduling. [Collier]. ABCE, does not (yet) allow for dynamic scheduling. In ABCE, the order of actions - or in ABCE language order of sub-rounds - is fixed and is repeated for every round. This however is not as restrictive as it sounds, because in any sub-round an agent could freely decide what he does.

The advantage of the somehow more limited implementation of ABCE is ease of use. While in Repast it is necessary to subclass the scheduler in ABCE it is sufficient to specify the schedule and pass it the Simulation class.

Repast is vast, it contains 210 classes in 9 packages [Collier]. ABCE, thanks to its limited scope and Python, has only 6 classes visible to the modeler in a single package.

1.1.3 Physical Goods

Physical goods are at the heart of almost every economic model. The core feature and main difference to other ABM platforms is the implementation of physical goods. In contrast to information or messages, sharing a good means having less of it. In other words if agent A gives a good to agent B then agent A does not have this good anymore. One of the major strength of ABCE is that this is automatically handled.

In ABCE goods can be created, destroyed, traded, given or changed through production and consumption. All these functions are implemented in ABCE and can be inherited by an agent as a method. These functions are automatically handled by ABCE upon decision from the modeler.

Every agent in ABCE must inherit from the `abce.Agent` class. This gives the agent a couple of stock methods: create, destroy, trade and give. Create and destroy create or destroy a good immediately. Because trade and give involve a form of interaction between the agents they run over several sub-rounds. Selling of a good for example works like this:

- **Sub-round 1. The first agent offers the goods.** The good is automatically subtracted from the agents possessions, to avoid double selling.
- **Sub-round 2. The counter agent receives the offer. The agent can**
 1. accept: the goods are added to the counter part's possessions. Money is subtracted.
 2. reject (or equivalently ignore): Nothing happens in this sub-round
 3. partially accept the offer: The partial amount of goods is added to the counter part's possessions. Money is subtracted.
- **Sub-round 3. In case of**
 1. acceptance, the money is credited
 2. rejection the original good is re-credited
 3. partial acceptance the money is credited and the unsold part of the good is re-credited.

1.2 Download and Installation

ABCE works exclusively with python 3!

1.2.1 Installation Ubuntu

1. If python3 and pip not installed in terminal²

```
sudo apt-get install python3
sudo apt-get install python3-pip
```

2. In terminal:

```
sudo pip3 install abce
```

3. download and unzip the [zip file with examples and the template from: https://github.com/AB-CE/examples](https://github.com/AB-CE/examples)

4. Optional for a 10 fold speed increase:

Install pypy3 from <https://pypy.org/download.html>

5. Install pypy3 additionally:

```
sudo pypy3 -m pip install abce
```

6. For pypy execute models with `pypy3 start.py` instead of `python3 start.py`

1.2.2 Installation Mac

1. If you are on OSX Yosemite, download and install: Command line Tools (OS X 10.10) for XCODE 6.4 from <https://developer.apple.com/downloads/>

2. If pip not installed in terminal:

```
sudo python3 -m easy_install pip
```

3. In terminal:

```
sudo pip3 install abce
```

4. If you are on El Capitan, OSX will ask you to install cc - xcode “Command Line Developer Tools”, click accept.¹

5. If XCODE was installed type again in terminal:

```
sudo pip3 install abce
```

6. download and unzip the [zip file with examples and the template from: https://github.com/AB-CE/examples](https://github.com/AB-CE/examples)

7. Optional for a 10 fold speed increase:

Install pypy3 from <https://pypy.org/download.html>

² If this fails `sudo apt-add-repository universe` and `sudo apt-get update`

¹ xcode 7 works only on OSX El Capitan. You need to either upgrade or if you want to avoid updating download xcode 6.4 from here: <https://developer.apple.com/downloads/>

8. Install pypy3 additionally:
`sudo pypy3 -m pip install abce`
9. For pypy execute models with `pypy3 start.py` instead of `python3 start.py`

1.2.3 Installation Windows

ABCE works best with anaconda python 3.5 follow the instructions blow.

1. Install the **python3.5** anaconda distribution from <https://continuum.io/downloads>
3. anaconda prompt or in the command line (cmd) type:

```
pip install abce
```

3. download and unzip the [zip file with examples and the template](https://github.com/AB-CE/examples) from: <https://github.com/AB-CE/examples>

1.2.4 Known Issues

- When you run an IDE such as spyder sometimes the website blocks. In order to avoid that, modify the 'Run Setting' and choose 'Execute in external System Terminal'.
- When the simulation blocks, there is probably a `simulation.finalize()` command missing after the simulation loop

1.2.5 If you have any problems with the installation

Mail to: DavoudTaghawiNejad@gmail.com

1.3 Interactive jupyter notebook Tutorial

1.3.1 You will learn how to:

1.3.2 Create Simulation & Agents

1.3.3 Run a simulation and advance time

1.3.4 Give Goods & Trade

1.3.5 Capturing Data and Pandas

1.3.6 Communication between Simulation and Agents

1.4 Walk through

In order to learn using ABCE we will now dissect and explain a simple ABCE model. Additional to this walk through you should also have a look on the examples in

[<https://github.com/AB-CE/examples>](https://github.com/AB-CE/examples)(<https://github.com/AB-CE/examples>),

Objects the other ontological object of agent-based models.

Objects have a special stance in agent-based modeling:

- objects can be recovered (resources)
- exchanged (trade)
- transformed (production)
- consumed
- destroyed (not really) and time depreciated

ABCE, takes care of trade, production / transformation and consumption of goods automatically. Good categories can also be made to perish or regrow.

Services or labor We can model services and labor as goods that perish and that are replenished every round. This would amount to a worker that can sell one unit of labor every round, that disappears if not used.

Closed economy When we impose that goods can only be transformed. The economy is physically closed (the economy is stock and flow consistent). When the markets are in a complete network our economy is complete. Think “general” in equilibrium economics.

Caveats: If agents hoard without taking their stock into account it’s like destruction.

1.4.1 start.py

```
""" 1. Build a Simulation
    2. Build one Household and one Firm follow_agent
    3. For every labor_endowment an agent has he gets one trade or usable_
↪labor
    per round. If it is not used at the end of the round it disappears.
    4. Firms' and Households' possessions are monitored to the points marked_
↪in
    timeline.
"""

from abce import Simulation, gui
from firm import Firm
from household import Household

def main():
    simulation = Simulation()

    simulation.declare_round_endowment(resource='labor_endowment', units=1,
↪product='labor')
    simulation.declare_perishable(good='labor')

    firms = simulation.build_agents(Firm, 'firm', 1)
    households = simulation.build_agents(Household, 'household', 1)

    for r in range(100):
        simulation.advance_round(r)
        households.sell_labor()
        firms.buy_labor()
```

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```
    firms.production()
    (households + firms).panel_log(possessions=['money', 'GOOD'])
    households.panel_log(variables=['current_utility'])
    firms.sell_goods()
    households.buy_goods()
    households.consumption()

simulation.graphs()

if __name__ == '__main__':
    main()
```

It is of utter most importance to end with either `simulation.graphs()` or `simulation.finalize()`

A simulation with GUI

In `start.py` the simulation, thus the parameters, objects, agents and time line are set up. Further it is declared, what is observed and written to the database.

```
from abce import Simulation, gui
from firm import Firm
from household import Household
```

Here the Agent class `Firm` is imported from the file `firm.py`. Likewise the `Household` class. Further the `Simulation` base class and the graphical user interface (`gui`) are imported

Parameters are specified as a python dictionary

```
parameters = {'name': '2x2',
              'random_seed': None,
              'rounds': 10,
              'slider': 100.0,
              'Checkbox': True,
              'Textbox': 'type here',
              'integer_slider': 100,
              'limited_slider': (20, 25, 50)}

@gui(parameters)
def main(parameters):
    . . .

if __name__ == '__main__':
    main(parameters)
```

The main function is generating and executing the simulation. When the main function is preceded with `@gui(simulation_parameters)` The graphical user interface is started in your browser the `simulation_parameters` are used as default values. If no browser window open you have to go manually to the address `“http://127.0.0.1:8000/”`. The graphical user interface starts the simulation.

During development its often more practical run the simulation without graphical user interface (GUI). In order to switch of the GUI comment out the `#@gui(simulation_parameters)`. In order show graphs at the end of the simulation add `simulation.graphs()` after `simulation.run`, as it is done in `start.py` above.

To set up a new model, you create a class instance a that will comprise your model

```
simulation = Simulation(name="ABCE")

...
```

The order of actions: The order of actions within a round

Every agents-based model is characterized by the order of which the actions are executed. In ABCE, there are rounds, every round is composed of sub-rounds, in which a group or several groups of agents act in parallel. In the code below you see a typical sub-round. Therefore after declaring the `Simulation` the order of actions, agents and objects are added.

```
for round in range(1000):
    simulation.advance_round(round)
    households.sell_labor()
    firms.buy_labor()
    firms.production()
    (households + firms).panel_log(...)
    firms.sell_goods()
    households.buy_goods()
    households.consumption()
```

This establishes the order of the simulation. Make sure you do not overwrite internal abilities/properties of the agents. Such as ‘sell’, ‘buy’ or ‘consume’.

A more complex example could be:

```
for week in range(52):
    for day in ['mo', 'tu', 'we', 'th', 'fr']:
        simulation.advance_round((week, day))
        if day == 'mo':
            households.sell_labor()
            firms.buy_labor()
        firms.production()
        (households + firms).panel()
        for i in range(10):
            firms.sell_goods()
            households.buy_goods()
        households.consumption()
        if week == 26:
            government.policy_change()
```

Interactions happen between sub-rounds. An agent, sends a message in one round. The receiving agent, receives the message the following sub-round. A trade is finished in three rounds: (1) an agent sends an offer the good is blocked, so it can not be sold twice (2) the other agent accepts or rejects it. (3) If accepted, the good is automatically delivered at the beginning of the sub-round. If the trade was rejected: the blocked good is automatically unblocked.

Special goods and services

Now we will establish properties of special goods. A normal good can just be created or produced by an agent; it can also be destroyed, transformed or consumed by an agent. Some goods ‘replenish’ every round. And some goods ‘perish’ every round. These properties have to be declared:

This example declares ‘corn’ perishable and every round the agent gets 100 units of ‘corn’ for every unit of field he possesses. If the corn is not consumed, it automatically disappears at the end of the round.

```
simulation.declare_round_endowment('field', 100, 'corn')

simulation.declare_round_endowment(resource='labor_endowment',
                                   units=1,
                                   product='labor'
                                   )
```

`declare_round_endowment`, establishes that at the beginning of every round, every agent that possesses x units of a resource, gets $x \times \text{units}$ units of the product. Every owner of x fields gets $100 \times x$ units of corn. Every owner of `labor_endowment` gets one unit of labor for each unit of `labor_endowment` he owns. An agent has to create the field or `labor_endowment` by `self.create('field', 5)`, for `labor_endowment` respectively.

```
simulation.declare_perishable('corn')
simulation.declare_perishable(good='labor')
```

`declare_perishable`, establishes that every unit of the specified good that is not used by the end of the round ceases to exist.

Declaring a good as replenishing and perishable is ABCE's way of treating services. In this example every household has some units of labor that can be used in the particular period. `abce.Simulation.declare_service()` is a synthetic way of declaring a good as a service.

One important remark, for a logically consistent **macro-model** it is best to not create any goods during the simulation, but only in `abce.Agent.init()`. During the simulation the only new goods should be created by `abce.Simulation.declare_round_endowment()`. In this way the economy is physically closed.

```
firms.panel_log(posessions=['good1', 'good2']) # a list of firm possessions to track_
↪here

households.agg_log('household', posessions=['good1', 'good2'],
                  variables=['utility']) # a list of household variables to track_
↪here
```

The possessions `good1` and `good2` are tracked, the agent's variable `self.utility` is tracked. There are several ways in ABCE to log data. Note that the variable names a strings.

Alternative to this you can also log within the agents by simply using `self.log('text', variable)` (`abce.Database.log()`) Or `self.log('text', {'var1': var1, 'var2': var2})`. Using one log command with a dictionary is faster than using several separate log commands.

Having established special goods and logging, we create the agents:

```
simulation.build_agents(Firm, 'firm', number=simulation_parameters['number_of_firms'],
↪ parameters=simulation_parameters)
simulation.build_agents(Household, 'household', number=10, parameters=simulation_
↪ parameters)
```

- `Firm` is the class of the agent, that you have imported
- `'firm'` is the group_name of the agent
- `number` is the number of agents that are created
- `parameters` is a dictionary of parameters that the agent receives in the `init` function (which is discussed later)

```
simulation.build_agents(Plant, 'plant',
                       parameters=simulation_parameters,
                       agent_parameters=[{'type': 'coal' 'watt': 20000},
```

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```
{'type':'electric' 'watt': 99}
{'type':'water' 'watt': 100234}})
```

This builds three Plant agents. The first plant gets the first dictionary as a `agent_parameter` {'type': 'coal' 'watt': 20000}. The second agent, gets the second dictionary and so on.

1.4.2 The agents

The Household agent

```
import abce

class Household(abce.Agent, abce.Household, abce.Trade):
    def init(self, simulation_parameters, agent_parameters):
        """ 1. labor_endowment, which produces, because of simulation.declare_
↪ resource(...)
    in start.py one unit of labor per month
    2. Sets the utility function to utility = consumption of good "GOOD"
    """
        self.create('labor_endowment', 1)
        self.set_cobb_douglas_utility_function({"GOOD": 1})
        self.current_utility = 0

    def sell_labor(self):
        """ offers one unit of labor to firm 0, for the price of 1 "money" """
        self.sell('firm', 0,
                  good="labor",
                  quantity=1,
                  price=1)

    def buy_goods(self):
        """ receives the offers and accepts them one by one """
        oo = self.get_offers("GOOD")
        for offer in oo:
            self.accept(offer)

    def consumption(self):
        """ consumes_everything and logs the aggregate utility. current_utility
        """
        self.current_utility = self.consume_everything()
        self.log('HH', self.current_utility)
```

The Firm agent

```
import abce

class Firm(abce.Agent, abce.Firm, abce.Trade):
    def init(self, simulation_parameters, agent_parameters):
        """ 1. Gets an initial amount of money
        2. create a cobb_douglas function: GOOD = 1 * labor ** 1.
        """
```

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```
self.create('money', 1)
self.set_cobb_douglas("GOOD", 1, {"labor": 1})

def buy_labor(self):
    """ receives all labor offers and accepts them one by one """
    oo = self.get_offers("labor")
    for offer in oo:
        self.accept(offer)

def production(self):
    """ uses all labor that is available and produces
    according to the set cobb_douglas function """
    self.produce_use_everything()

def sell_goods(self):
    """ offers one unit of labor to firm 0, for the price of 1 "money" """
    self.sell('household', 0,
              good="GOOD",
              quantity=self.possession("GOOD"),
              price=1)
```

Agents are modeled in a separate file. In the template directory, you will find two agents: `firm.py` and `household.py`.

At the beginning of each agent you will find

An agent has to import the `abce` module and the `abce.NotEnoughGoods` exception

```
import abce
from abce import NotEnoughGoods
```

This imports the module `abce` in order to use the base classes `Household` and `Firm`. And the `NotEnoughGoods` exception that allows us to handle the situation in which the agent has insufficient resources.

An agent is a class and must at least inherit `abce.Agent`. It automatically inherits `abce.Trade` - `abce.Messaging` and `abce.Database`

```
class Agent(abce.Agent):
```

To create an agent that has can create a consumption function and consume

```
class Household(abce.Agent, abce.Household):
```

To create an agent that can produce:

```
class Firm(abce.Agent, abce.Firm)
```

You see our `Household` agent inherits from `abce.Agent`, which is compulsory and `abce.Household`. `Household` on the other hand are a set of methods that are unique for `Household` agents. The `Firm` class accordingly

The init method

When an agent is created its `init` function is called and the simulation parameters as well as the `agent_parameters` are given to him

DO NOT OVERWRITE THE `__init__` method. Instead use ABCE's `init` method, which is called when the agents are created

```
def init(self, parameters, agent_parameters):
    self.create('labor_endowment', 1)
    self.set_cobb_douglas_utility_function({"MLK": 0.300, "BRD": 0.700})
    self.type = agent_parameters['type']
    self.watt = agent_parameters['watt']
    self.number_of_firms = parameters['number_of_firms']
```

The `init` method is the method that is called when the agents are created (by the `abce.Simulation.build_agents()`). When the agents were build, a parameter dictionary and a list of agent parameters were given. These can now be accessed in `init` via the `parameters` and `agents_parameters` variable. Each agent gets only one element of the `agents_parameters` list.

With `self.create` the agent creates the good ‘labor_endowment’. Any good can be created. Generally speaking. In order to have a physically consistent economy goods should only be created in the `init` method. The good money is used in transactions.

This agent class inherited `abce.Household.set_cobb_douglas_utility_function()` from `abce.Household`. With `abce.Household.set_cobb_douglas_utility_function()` you can create a cobb-douglas function. Other functional forms are also available.

In order to let the agent remember a parameter it has to be saved in the `self` domain of the agent.

The action methods and a consuming Household

All the other methods of the agent are executed when the corresponding sub-round is called from the `action_list` in the `Simulation` in `start.py`.

For example when in the action list (‘household’, ‘consumption’) is called the consumption method is executed of each household agent is executed. **It is important not to overwrite abce’s methods with the agents methods.** For example if one would call the `consumption(self)` method below `consume(self)`, `abce`’s `consume` function would not work anymore.

```
class Household(abce.Agent, abce.Household):
    def init(self, simulation_parameters, agent_parameters):
        self.create('labor_endowment', 1)
        self.set_cobb_douglas_utility_function({"GOOD": 1})
        self.current_utility = 0

        . . .

    def consumption(self):
        """ consumes_everything and logs the aggregate utility. current_utility """
        self.current_utility = self.consume_everything()
        self.log('HH', self.current_utility)
```

In the above example we see how a (degenerate) utility function is declared and how the agent consumes. The dictionary assigns an exponent for each good, for example a consumption function that has .5 for both exponents would be `{‘good1’: 0.5, ‘good2’: 0.5}`.

In the method `consumption`, which has to be called form the `action_list` in the `Simulation`, everything is consumed and the utility from the consumption is calculated and logged. The utility is logged and can be retrieved see retrieval of the simulation results

Firms and Production functions

Firms do two things they produce (transform) and trade. The following code shows you how to declare a technology and produce bread from labor and yeast.

```
class Agent(abce.Agent, abce.Firm):
    def init(self):
        set_cobb_douglas('bread', 1.890, {"yeast": 0.333, "labor": 0.667})
        ...

    def production(self):
        self.produce_use_everything()
```

More details in `abce.Firm`. `abce.FirmMultiTechnologies` offers a more advanced interface for firms with layered production functions.

Trade

ABCE clears trade automatically. That means, that goods are automatically exchanged, double selling of a good is avoided by subtracting a good from the possessions when it is offered for sale. The modeler has only to decide when the agent offers a trade and sets the criteria to accept the trade

```
# Agent 1
def selling(self):
    offer = self.sell(buyer, 2, 'BRD', price=1, quantity=2.5)
    self.checkorders.append(offer) # optional
```

```
# Agent 2
def buying(self):
    offers = self.get_offers('cookies')
    for offer in offers:
        if offer.price < 0.5:
            try:
                self.accept(offer)
            except NotEnoughGoods:
                self.accept(offer, self.possession('money') / offer.price)
```

```
# Agent 1
def check_trade(self):
    print(self.checkorders[0])
```

Agent 1 sends a selling offer to Agent 2, which is the agent with the id 2 from the buyer group (`buyer_2`) Agent 2 receives all offers, he accepts all offers with a price smaller than 0.5. If he has insufficient funds to accept an offer an `NotEnoughGoods` exception is thrown. If a `NotEnoughGoods` exception is thrown the except block `self.accept(offer, self.possession('money') / offer.price)` is executed, which leads to a partial accept. Only as many goods as the agent can afford are accepted. If a polled offer is not accepted it is automatically rejected. It can also be explicitly rejected with `self.reject(offer)` (`abce.Trade.reject()`).

You can find a detailed explanation how trade works in `abce.Trade`.

Data production

There are three different ways of observing your agents:

Trade Logging

when you specify `Simulation(..., trade_logging='individual')` all trades are recorded and a SAM or IO matrix is created. These matrices are currently not displayed in the GUI, but accessible as csv files in the `simulation.path` directory

Manual in agent logging

An agent can log a variable, `abce.Agent.possession()`, `abce.Agent.possessions()` and most other methods such as `abce.Firm.produce()` with `abce.Database.log()`:

```
self.log('possessions', self.possessions())
self.log('custom', {'price_setting': 5: 'production_value': 12})
prod = self.production_use_everything()
self.log('current_production', prod)
```

Retrieving the logged data

If the GUI is switched off there must be a `abce.Simulation.graphs()` after `abce.Simulation.run()`. Otherwise no graphs are displayed. If no browser window opens you have to go manually to the address “<http://127.0.0.1:8000/>”

The results are stored in a subfolder of the `./results/` folder. `simulation.path` gives you the path to that folder.

The tables are stored as ‘.csv’ files which can be opened with excel.

1.5 Tutorial for Plant Modeling

1. Let's write the 1st agent:

a. Create a file `chpplant.py` import `abce` and create a `Plant` class.

```
import abce

class CHPPlant(abce.Agent, abce.Firm):
```

b. In `def init(self):` (not `__init__`!) we need to create some initial goods

```
class CHPPlant(...):

    ...
    def init(self):
        self.create('biogas', 100)
        self.create('water', 100)
```

c. Now we need to specify production functions. There are standard production functions like cobb-douglas and leontief already implemented, but our plants get more complicated production functions. We define the production function a firm uses in `def init(self)`. So there add the following lines, `class CHPPlant(...)`:

```
class CHPPlant(...):

    def init(self):
        self.create('biogas', 100)
        self.create('water', 100)

    def production_function(biogas, water):
        electricity = biogas ** 0.25 * water ** 0.5
        steam = min(biogas, water)
        biogas = 0
        water = 0
        return locals()

    self.production_function = production_function
```

The `def production_function(biogas, water):` returns the production result as a dictionary. (try `print(production_function(10, 10))`). Each key is a good that is produced or what remains of a good after the production process. If goods are used up they must be set to 0. For example the function above creates electricity and steam. Electricity is produced by a cobb-douglas production function. While steam is the minimum between the amount of water and fuel used.

The `production_function` function is local function in the `init` method. Make sure the `return locals()` is part of the `def production_function(...):` not of the `def init(self):` method.

1. In order to produce create a production method in `class CHPPlant(...):` insert the following code right after the `def init(self):` method:

```
class CHPPlant(...):
    ...
    def production(self):
        self.produce(self.production_function, {'biogas': 100, 'water': 100})
```

- e. also add:

```
class CHPPlant(...):
    ...
    def refill(self):
        self.create('biogas', 100)
        self.create('water', 100)
```

3. Create a file `start.py` to run this incomplete simulation.

- a. Import `abce` and the plant:

```
import abce
from chpplant import CHPPlant
```

- b. Create a simulation instance:

```
simulation = abce.Simulation()
```

- c. Build an a plant

```
chpplant = simulation.build_agents(CHPPlant, 'chpplant',
    number=1)
```

With this we create 1 agent of type CHPPLANT, it's group name will be `chpplant` and its number 0. Therefore its name is the tuple ('chpplant', 0)

1. Loop over the simulation:

```
for r in range(100):
    simulation.advance_round(r)
    chpplant.production()
    chpplant.panel_log(goods=['electricity', 'biogas', 'water',
↪ 'steam'], variables=[])
    chpplant.refill()

simulation.graphs()
simulation.finalize()
```

This will tell the simulation that in every round, the plant execute the production method we specified in CHPPLant. Then it refills the input goods. Lastly, it creates a snapshot of the goods of chpplant as will be specified in (e).

`simulation.advance_round(r)` sets the time `r`. Lastly **py:**`simulation.graphs()` or `simulation.finalize()` tells the simulation that the loop is done. Otherwise the program hangs at the end.

4. To run your simulation, the best is to use the terminal and in the directory of your simulation type `python start.py`. In SPYDER make sure that BEFORE you run the simulation for the first time you modify the 'Run Setting' and choose 'Execute in external System Terminal'. If you the simulation in the IDE without making this changes the GUI might block.

5. Lets modify the agent so he is ready for trade

- a. now delete the refill function in CHPPlant, both in the agent and in the actionlist delete `chpplant.refill()`
- b. let's simplify the production method in CHPPlant to

```
def production(self):
    self.produce_use_everything()
```

- c. in `init` we create money with `self.create('money', 1000)`

7. Now let's create a second agent ADPlant.

- a. copy `chpplant.py` to `aplant.py` and
- b. in `adplant.py` change the class name to ADPlant
- c. ADPlant will produce biogas and water out of steam and electricity. In order to achieve this forget about thermodynamics and change the production function to

```
def production_function(steam, electricity):
    biogas = min(electricity, steam)
    water = min(electricity, steam)
    electricity = 0
    steam = 0
    return locals()
```

- d. Given the new technology, we need to feed different goods into our machines. Replace the production step

```
def production(self):
    self.produce(self.production_function, {'steam': self['steam'],
↪ 'electricity': self['electricity']})
```

self['steam'], looks up the amount of steam the company owns. self.not_reserved['steam'], would look up the amount of steam a company owns minus all steam that is offered to be sold to a different company.

- e. ADPlant will sell everything it produces to CHPPlant. We know that the group name of chpplant is 'chpplant' and its id number (id) is 0. Add another method to the ADPlant class.

```
def selling(self):
    amount_biogas = self['biogas']
    amount_water = self['water']
    self.sell(('chpplant', 0), good='water', quantity=amount_water, price=1)
    self.sell(('chpplant', 0), good='biogas', quantity=amount_biogas, price=1)
```

This makes a sell offer to chpplant.

- f. In CHPPlant respond to this offer, by adding the following method.

```
def buying(self):
    water_offer = self.get_offers('water')[0]
    biogas_offer = self.get_offers('biogas')[0]

    if (water_offer.price * water_offer.quantity +
        biogas_offer.price * biogas_offer.quantity < self['money']):
        self.accept(water_offer)
        self.accept(biogas_offer)
    else:
        quantity_allocationg_half_my_money = self['money'] / water_offer.price
        self.accept(water_offer, min(water_offer.quantity, quantity_
↪allocationg_half_my_money))
        self.accept(biogas_offer, min(biogas_offer, self['money']))
```

This accepts both offers if it can afford it, if the plant can't, it allocates half of the money for either good.

- g. reversely in CHPPlant:

```
def selling(self):
    amount_electricity = self['electricity']
    amount_steam = self['steam']
    self.sell(('adplant', 0), good='electricity', quantity=amount_electricity,
↪ price=1)
    self.sell(('adplant', 0), good='steam', quantity=amount_steam, price=1)
```

- h. and in ADPlant:

```
def buying(self):
    el_offer = self.get_offers('electricity')[0]
    steam_offer = self.get_offers('steam')[0]

    if (el_offer.price * el_offer.quantity
        + steam_offer.price * steam_offer.quantity < self['money']):
        self.accept(el_offer)
        self.accept(steam_offer)
    else:
        quantity_allocationg_half_my_money = self['money'] / el_offer.price
        self.accept(el_offer, min(el_offer.quantity, quantity_allocationg_
↪half_my_money))
        self.accept(steam_offer, min(steam_offer, self['money']))
```

8. let's modify start.py

- b. in start.py import the ADPlant:


```
from adplant import ADPlant
```

and

```
adplant = simulation.build_agents(ADPlant, 'adplant', number=1)
```

c. change the action list to:

```
for r in range(100):
    simulation.advance_round(r)
    (chpplant + adplant).production()
    (chpplant + adplant).selling()
    (chpplant + adplant).buying()
    chpplant.panel()
```

9. now it should run again.

1.6 Examples

ABCE's examples can be downloaded from here: <https://github.com/AB-CE/examples>

1.6.1 Concepts used in examples

Example	jupyter	pandas	logging	Trade	multi- core	create agents	delete agents	graphical user inter- face	calendar down	perishable	mesa graph- ical spa- cial	contracts
jupyter tutorial	X	X	X	X								
50000_firms					X							
create_agents						X	X					
delete_agent												
one_household_one_firm								X				
									X	X		
pid_controller				X								
mesa_example											X	
sug- arscape												
CCE		X		trade log- ging				GUI	Extended			
cheesegrater								X				X
insur- ance												
2sectors												
Model of Car mar- ket												

Example	pro- duction function	utility func- tion	arbitrary time intervals	multi- core	cre- ate agents	delete agents	graphi- cal user interface	en- dow- ment	per- ish- able	mesa graphical spacial
jupyter_tutorial										
50000_firms				X						
cre- ate_agents delete_agent					X	X				
one_household_one_firm							simple			
								X	X	
pid_controller										
mesa_example sugarscape										X
CCE	X	X					X			
cheeseg- rater insurance							X			
2sectors	X	X								
Model of Car market										
Calendar			X							

1.6.2 Models

CCE

This is the most complete example featuring an agent-based model of climate change tax policies for the United States. It includes a GUI, is databased and uses production and utility functions.

One sector model

One household one firm is a minimalistic example of a ‘macro-economy’. It is ‘macro’ in the sense that the complete circular flow of the economy is represented. Every round the following sub-rounds are executed:

household: sell_labor

firm: buy_labor

firm: production

firm: sell_goods

household: buy_goods

household: consumption

After the firms’ production and the acquisition of goods by the household a statistical panel of the firms’ and the households’ possessions, respectively, is written to the database.

The economy has two goods a representative ‘GOOD’ good and ‘labor’ as well as money. ‘labor’, which is a service that is represented as a good that perishes every round when it is not used. Further the endowment is of the labor good that is replenished every round for every agent that has an ‘adult’. ‘Adults’ are handled like possessions of the household agent.

The household has a degenerate Cobb-Douglas utility function and the firm has a degenerate Cobb-Douglas production function:

```
utility = GOOD ^ 1
GOOD = labor ^ 1
```

The firms own an initial amount of money of 1 and the household has one adult, which supplies one unit of (perishable) labor every round.

First the household sells his unit of labor. The firm buys this unit and uses all available labor for production. The complete production is offered to the household, which in turn buys everything it can afford. The good is consumed and the resulting utility logged to the database.

Two sector model

The two sector model is similar to the one sector model. It has two firms and showcases ABCE's ability to control the creation of agents from an excel sheet.

There are two firms. One firm manufactures an intermediary good. The other firm produces the final good. Both firms are implemented with the same good. The type a firm develops is based on the excel sheet.

The two respective firms production functions are:

```
intermediate_good = labor ^ 1
consumption_good = intermediate_good ^ 1 * labor ^ 1
```

The only difference is that, when firms sell their products the intermediate good firm sells to the final good firm and the final good firm, in the same sub-round sells to the household.

In start.py we can see that the firms that are build are build from an excel sheet:

```
w.build_agents_from_file(Firm, parameters_file='agents_parameters.csv')
w.build_agents_from_file(Household)
```

And here the excel sheet:

```
agent_class number sector firm 1 intermediate_good firm 1 consumption_good household 1 0 household
1 1
```

The advantage of this is that the parameters can be used in the agent. The line `self.sector = agent_parameters['sector']` reads the sector column and assigns it to the `self.sector` variable. The file simulation parameters is read - line by line - into the variable `simulation_parameters`. It can be used in `start.py` and in the agents with `simulation_parameters['columnlabel']`.

50000 agents example

This is a sheer speed demonstration, that lets 50000 agents trade.

PID controllers

PID controller are a simple algorithm for firms to set prices and quantities. PID controller, work like a steward of a ship. He steers to where he wants to go and after each action corrects the direction based on how the ship changed it's direction,

pid_controller analytical

A simulation of the first Model of Ernesto Carrella's paper: Sticky Prices Microfoundations in a Agent Based Supply Chain Section 4 Firms and Production

Here we have one firm and one market agent. The market agent has the demand function $q = 102 - p$. The PID controller uses an analytical model of the optimization problem.

Simple Seller Example

A simulation of the first Model of Ernesto Carrella's paper: Zero-Knowledge Traders, journal of artificial societies and social simulation, December 2013

This is a partial 'equilibrium' model. A firm has a fixed production of 4 it offers this to a fixed population of 10 household. The household willingness to pay is household id * 10 (10, 20, 30 ... 90). The firms sets the prices using a PID controller.

Fully PID controlled

A simulation of the first Model of Ernesto Carrella's paper: Sticky Prices Microfoundations in a Agent Based Supply Chain Section 4 Firms and Production

Here we have one firm and one market agent. The market agent has the demand function $q = 102 - p$. The PID controller has no other knowledge then the reaction of the market in terms of demand.

1.7 unit testing

One of the major problem of doing science with simulations is that results found could be a mere result of a mistake in the software implementation. This problem is even stronger when emergent phenomena are expected. The first hedge against this problem is of course carefully checking the code. ABCE and Pythons brevity and readability are certainly helping this. However structured testing procedures create more robust software.

Currently all trade and exchange related as well as endowment, production utility and data logging facilities are unit tested. It is planned to extend unit testing to quotes, so that by version 1.0 all functions of the agents will be fully unit tested.

The modeler can run the unit testing facilities on his own system and therefore assert that on his own system the code runs correctly.

Unit testing is the testing of the testable part of a the software code. [?]. As in ABCE the most crucial functions are the exchange of goods or information, the smallest testable unit is often a combination of two actions [?]. For example making an offer and then by a second agent accepting or rejecting it. The interaction and concurrent nature of ABCE simulation make it unpractical to use the standard unit testing procedures of Python.

[?] argue that unit-testing is economical. In the analysis of three projects they find that unit-testing finds errors in the code and argue that its cost is often exaggerated. We can therefore conclude that unit-testing is necessary and a cost efficient way of ensuring the correctness of the results of the simulation. For the modeler this is an additional incentive to use ABCE, if he implemented the simulation as a stand alone program he would either have to forgo the testing of the agent's functions or write his own unit-testing facilities.

2.1 The simulation in start.py

The best way to start creating a simulation is by copying the start.py file and other files from 'abce/template' in <https://github.com/AB-CE/examples>.

To see how to create a simulation, read `ipython_tutorial`.

This is a minimal template for a start.py:

```
from agent import Agent
from abce import *

simulation = Simulation(name='ABCE')
agents = simulation.build_agents(Agent, 'agent', 2)
for time in range(100):
    simulation.advance_round(time)
    agents.one()
    agents.two()
    agents.three()
simulation.graphs()
```

Note two things are important: there must be either a

`graphs()` or a `finalize()` at the end otherwise the simulation blocks at the end. Furthermore, every round needs to be announced using `simulation.advance_round(time)`, where time is any representation of time.

```
class abce.Simulation(name='abce', random_seed=None, trade_logging='off', processes=1,
                    check_unchecked_msgs=False)
```

Bases: `object`

This is the class in which the simulation is run. Actions and agents have to be added. Databases and resource declarations can be added. Then run the simulation.

Args:

name: name of the simulation

random_seed (optional): a random seed that controls the random number of the simulation

trade_logging: Whether trades are logged, `trade_logging` can be 'group' (fast) or 'individual' (slow) or 'off'

processes (optional): The number of processes that runs in parallel. Each process hosts a share of the agents. By default, if this parameter is not specified, *processes* is all your logical processor cores times two, using hyper-threading when available. For easy debugging, set *processes* to one and the simulation is executed without parallelization. Sometimes it is advisable to decrease the number of processes to the number of logical or even physical processor cores on your computer. **For easy debugging set processes to 1, this way only one agent runs at a time and only one error message is displayed**

check_unchecked_msgs: check every round that all messages have been received with `get_messages` or `get_offers`.

Example:

```
simulation = Simulation(name='ABCE',
                        trade_logging='individual',
                        processes=None)
```

Example for a simulation:

```
num_firms = 5
num_households = 2000

w = Simulation(name='ABCE',
               trade_logging='individual',
               processes=None)

w.declare_round_endowment(resource='labor_endowment',
                           productivity=1,
                           product='labor')

w.panel('firm', command='after_sales_before_consumption')

firms = w.build_agents(Firm, 'firm', num_firms)
households = w.build_agents(Household, 'household', num_households)

all = firms + households

for r in range(100):
    self.advance_round(r)
    households.receive_connections()
    households.offer_capital()
    firms.buy_capital()
    firms.production()
    if r == 250:
        centralbank.intervention()
    households.buy_product()
    all.after_sales_before_consumption()
    households.consume()

w.finalize()
w.graphs()
```

advance_round (*time*)

build_agents (*AgentClass, group_name, number=None, agent_parameters=None, **parameters*)

This method creates agents.

Args:

AgentClass: is the name of the AgentClass that you imported

group_name: the name of the group, as it will be used in the action list and transactions. Should generally be lowercase of the AgentClass.

number: number of agents to be created.

agent_parameters: a list of dictionaries, where each agent gets one dictionary. The number of agents is the length of the list

any other parameters: are directly passed to the agent

Example:

```
firms = simulation.build_agents(Firm, 'firm',
                               number=simulation_parameters['num_firms'])
banks = simulation.build_agents(Bank, 'bank',
                               agent_parameters=[{'name': 'UBS'},
                                                  {'name': 'amex'}, {'name': 'chase'}],
                               **simulation_parameters,
                               loanable=True)

centralbanks = simulation.build_agents(CentralBank, 'centralbank',
                                       number=1,
                                       rounds=num_rounds)
```

create_agent (*AgentClass, group_name, simulation_parameters=None, agent_parameters=None*)

create_agents (*AgentClass, group_name, simulation_parameters=None, agent_parameters=None, number=1*)

Creates an additional agent in an existing group during the simulation. If agents have been deleted, their id's are reduced.

Args:

AgentClass: the class of agent to create. (can be the same class as the creating agent)

'group_name': the name of the group the agent should belong to. This is the group name string e.G. 'firm', not the group variable e.G. firms in firms = simulation.build_agents(...)

simulation_parameters: a dictionary of parameters

agent_parameters: List of a dictionary of parameters

number: if no agent_parameters list is given the number of agents to be created can be specified

Returns: id of new agent.

Example:

```
self.create_agent(BeerFirm, 'beerfirm',
                  parameters=self.parameters,
                  agent_parameters={'creation': self.time})
```

declare_expiring (*good, duration*)

This type of good lasts for several rounds, but eventually expires. For example computers would last for several years and then become obsolete.

Args:

good: the good, which expires

duration: the duration before the good expires

declare_perishable (*good*)

This good only lasts one round and then disappears. For example labor, if the labor is not used today today's labor is lost. In combination with resource this is useful to model labor or capital.

In the example below a worker has an endowment of labor and capital. Every round he can sell his labor service and rent his capital. If he does not the labor service for this round and the rent is lost.

Args:

```
good:
    the good that perishes

Example::

    w.declare_perishable(good='LAB')
    w.declare_perishable(good='CAP')
```

declare_round_endowment (*resource, units, product*)

At the beginning of every round the agent gets 'units' units of good 'product' for every 'resource' he possesses.

Round endowments are group specific, that means when somebody except the specified group holds them they do not produce.

Args:

```
resource:
    The good that you have to hold to get the other

units:
    the multiplier to get the produced good

product:
    the good that is produced if you hold the first good

groups:
    a list of agent groups, which gain the second good,
    if they hold the first one
```

Example:

```
A farmer gets a ton of harvest for every acre:

w.declare_round_endowment(resource='land',
                           units=1000,
                           product='wheat')
```

declare_service (*human_or_other_resource, units, service*)

When the agent holds the human_or_other_resource, he gets 'units' of service every round the service can be used only with in this round.

Args:


```

human_or_other_resource:
    the good that needs to be in possessions to create the other
    good 'self.create('adult', 2)'
units:
    how many units of the service is available
service:
    the service that is created
groups:
    a list of agent groups that can create the service

```

Example:

```

For example if a household has two adult family members, it gets
16 hours of work

w.declare_service('adult', 8, 'work')

```

delete_agent (*ang)

delete_agents (group, ids)

This deletes a group of agents. The model has to make sure that other agents are notified of the death of agents in order to stop them from corresponding with this agent. Note that if you create new agents after deleting agents the ID's of the deleted agents are reused.

Args:

group: group of the agent

ids: a list of ids of the agents to be deleted in that group

finalize ()

simulation.finalize() must be run after each simulation. It will write all data to disk

Example:

```

simulation = Simulation(...)
...
for r in range(100):
    simulation.advance_round(r)
    agents.do_something()
    ...

simulation.finalize()

```

graphs ()

after the simulation is run, graphs() shows graphs of all data collected in the simulation. Shows the same output as the @gui decorator shows.

Example:

```

simulation = Simulation(...)
for r in range(100):
    simulation.advance_round(r)
    agents.do_something()
    ...

simulation.graphs()

```

path = None

the path variable contains the path to the simulation outcomes it can be used to generate your own graphs

as all resulting csv files are there.

time = None

Returns the current time set with `simulation.advance_round(time)`

2.2 Agents

The `abce.Agent` class is the basic class for creating your agents. It automatically handles the possession of goods of an agent. In order to produce/transforme goods you also need to subclass the `abce.Firm` or to create a consumer the `abce.Household`.

For detailed documentation on:

Trading, see *Trade*

Logging and data creation, see *Observing agents and logging*.

Messaging between agents, see *Messaging*.

```
class abce.Agent(id, agent_parameters, simulation_parameters, group, trade_logging,
                 database, check_unchecked_msgs, expiring, perishable, resource_endowment,
                 start_round=None)
Bases: abce.database.Database, abce.trade.Trade, abce.messaging.Messaging, abce.goods.Goods
```

Every agent has to inherit this class. It connects the agent to the simulation and to other agent. The *abce.Trade*, *abce.Database* and *abce.Messaging* classes are included. An agent can also inheriting from *abce.Firm*, *abce.FirmMultiTechnologies* or *abce.Household* classes.

Every method can return parameters to the simulation.

For example:

```
class Household(abce.Agent, abce.Household):
    def init(self, simulation_parameters, agent_parameters):
        self.num_firms = simulation_parameters['num_firms']
        self.type = agent_parameters['type']
        ...

    def selling(self):
        for i in range(self.num_firms):
            self.sell('firm', i, 'good', quantity=1, price=1)
        ...

    def return_quantity_of_good(self):
        return ['good']
    ...

simulation = Simulation()
households = Simulation.build_agents(household, 'household',
                                     parameters={},
                                     agent_parameters=[{'type': 'a'},
                                                         {'type': 'b'}])

for r in range(10):
    simulation.advance_round(r)
    households.selling()
    print(households.return_quantity_of_good())
```

group = None

self.group returns the agents group or type READ ONLY!

id = None

self.id returns the agents id READ ONLY

init()

This method is called when the agents are build. It can be overwritten by the user, to initialize the agents. Parameters are the parameters given to `abce.Simulation.build_agents()`.

Example:

```
class Student(abce.Agent):
    def init(self, rounds, age, lazy, school_size):
        self.rounds = rounds
        self.age = age
        self.lazy = lazy
        self.school_size = school_size

    def say(self):
        print('I am', self.age, ' years old and go to a school
              that is ', self.school_size')

def main():
    sim = Simulation()
    students = sim.build_agents(Student, 'student',
                                agent_parameters=[{'age': 12, lazy: True},
                                                    {'age': 12, lazy: True},
                                                    {'age': 13, lazy: False},
                                                    {'age': 14, lazy: True}],
                                rounds=50,
                                school_size=990)
```

name = None

self.name returns the agents name, which is the group name and the id

round = None

self.round is depreciated

time = None

self.time, contains the time set with `simulation.advance_round(time)` you can set time to anything you want an integer or (12, 30, 21, 09, 1979) or 'monday'

2.3 Physical goods and services

2.3.1 Goods

An agent can access a good with `self['cookies']` or `self['money']`.

- `self.create(money, 15)` creates money
- `self.destroy(money, 10)` destroys money
- goods can be given, taken, sold and bought
- `self['money']` returns the quantity an agent possesses

2.3.2 Services

Services are like goods, but the need to be declared as services in the simulation `abce.__init__.service()`. In this function one declares a good that creates the other good and how much. For example if one has `self['adults'] = 2`, one could get 16 hours of labor every day. `simulation.declare_service('adults', 8, 'labor')`.

```
class abce.goods.Goods(id, agent_parameters, simulation_parameters, group, trade_logging,
                        database, check_unchecked_msgs, expiring, perishable, re-
                        source_endowment, start_round=None)
```

Bases: `object`

Each agent can access his goods. `self['good_name']` shows the quantity of goods of a certain type an agent owns. Goods can be a string or any other python object.

create (*good, quantity*)

creates quantity of the good out of nothing

Use create with care, as long as you use it only for labor and natural resources your model is macro-economically complete.

Args: 'good': is the name of the good quantity: number

create_timestructured (*good, quantity*)

creates quantity of the time structured good out of nothing. For example:

```
self.creat_timestructured('capital', [10,20,30])
```

Creates capital. 10 units are 2 years old 20 units are 1 year old and 30 units are new.

It can also be used with a quantity instead of an array. In this case the amount is equally split on the years.:

```
self.create_timestructured('capital', 60)
```

In this case 20 units are 2 years old 20 units are 1 year old and 20 units are new.

Args:

'good': is the name of the good

quantity: an arry or number

destroy (*good, quantity=None*)

destroys quantity of the good. If quantity is omitted destroys all

Args:

```
'good':
    is the name of the good
quantity (optional):
    number
```

Raises:

```
NotEnoughGoods: when goods are insufficient
```

not_reserved (*good*)

Returns the amount of goods that are not reserved for a trade

Args: good

possession (*good*)

returns how much of good an agent possesses.

Returns: A number.

possession does not return a dictionary for `self.log(...)`, you can use `self.possessions([...])` (plural) with `self.log`.

Example:

```
if self['money'] < 1:
    self.financial_crisis = True

if not (is_positive(self['money'])):
    self.bancruptcy = True
```

possessions()
returns all possessions

2.4 Trade

```
class abce.Trade(id, agent_parameters, simulation_parameters, group, trade_logging,
                 database, check_unchecked_msgs, expiring, perishable, resource_endowment,
                 start_round=None)
```

Bases: `object`

Agents can trade with each other. The clearing of the trade is taken care of fully by ABCE. Selling a good works in the following way:

1. An agent sends an offer: `sell()`

ABCE does not allow you to sell the same good twice; `self.free(good)` shows how much good is not reserved yet

2. **Next subround:** An agent receives the offer `get_offers()`, and can `accept()`, `reject()` or partially accept it. `accept()`

The good is credited and the price is deducted from the agent's possessions.

3. **Next subround:**

- in case of acceptance *the money is automatically credited.*
- in case of partial acceptance *the money is credited and part of the reserved good is unblocked.*
- in case of rejection *the good is unblocked.*

Analogously for buying: `buy()`

Example:

```
# Agent 1
def sales(self):
    self.remember_trade = self.sell('Household', 0, 'cookies', quantity=5,
    ↪ price=self.price)

# Agent 2
def receive_sale(self):
    oo = self.get_offers('cookies')
    for offer in oo:
        if offer.price < 0.3:
            try:
                self.accept(offer)
```

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```

        except NotEnoughGoods:
            self.accept(offer, self['money'] / offer.price)
        else:
            self.reject(offer)

# Agent 1, subround 3
def learning(self):
    offer = self.info(self.remember_trade)
    if offer.status == 'reject':
        self.price *= .9
    elif offer.status == 'accepted':
        self.price *= offer.final_quantity / offer.quantity

```

Example:

```

# Agent 1
def sales(self):
    self.remember_trade = self.sell('Household', 0, 'cookies', quantity=5,
    price=self.price, currency='dollars')

# Agent 2
def receive_sale(self):
    oo = self.get_offers('cookies')
    for offer in oo:
        if ((offer.currency == 'dollars' and offer.price < 0.3 * exchange_rate)
            or (offer.currency == 'euros' and offer.price < 0.3)):

            try:
                self.accept(offer)
            except NotEnoughGoods:
                self.accept(offer, self['money'] / offer.price)
        else:
            self.reject(offer)

```

If we did not implement a barter class, but one can use this class as a barter class,

accept (*offer, quantity=-999, epsilon=1e-11*)

The buy or sell offer is accepted and cleared. If no quantity is given the offer is fully accepted; If a quantity is given the offer is partial accepted.

Args:

offer: the offer the other party made

quantity: quantity to accept. If not given all is accepted

epsilon (optional): if you have floating point errors, a quantity or prices is a fraction of number to high or low. You can increase the floating point tolerance. See troubleshooting – floating point problems

Return: Returns a dictionary with the good's quantity and the amount paid.

buy (*receiver, good, quantity, price, currency='money', epsilon=1e-11*)

Sends a offer to buy a particular good to somebody. The money promised is reserved. (self.free(currency), shows the not yet reserved goods)

Args:

receiver: The name of the receiving agent a tuple (group, id). e.G. ('firm', 15)

‘good’: name of the good

quantity: maximum units disposed to buy at this price

price: price per unit

currency: is the currency of this transaction (defaults to ‘money’)

epsilon (optional): if you have floating point errors, a quantity or prices is a fraction of number to high or low. You can increase the floating point tolerance. See troubleshooting – floating point problems

get_buy_offers (*good, sorted=True, descending=False, shuffled=True*)

get_buy_offers_all (*descending=False, sorted=True*)

get_offers (*good, sorted=True, descending=False, shuffled=True*)

returns all offers of the ‘good’ ordered by price.

Offers that are not accepted in the same subround (def block) are automatically rejected. However you can also manually reject.

peek_offers can be used to look at the offers without them being rejected automatically

Args:

good: the good which should be retrieved

sorted(bool, default=True): Whether offers are sorted by price. Faster if False.

descending(bool, default=False): False for descending True for ascending by price

shuffled(bool, default=True): whether the order of messages is randomized or correlated with the ID of the agent. Setting this to False speeds up the simulation considerably, but introduces a bias.

Returns: A list of `abce.trade.Offer` ordered by price.

Example:

```
offers = get_offers('books')
for offer in offers:
    if offer.price < 50:
        self.accept(offer)
    elif offer.price < 100:
        self.accept(offer, 1)
    else:
        self.reject(offer) # optional
```

get_offers_all (*descending=False, sorted=True*)

returns all offers in a dictionary, with goods as key. The in each goods-category the goods are ordered by price. The order can be reversed by setting `descending=True`

Offers that are not accepted in the same subround (def block) are automatically rejected. However you can also manually reject.

Args:

descending(optional): is a bool. False for descending True for ascending by price

sorted(default=True): Whether offers are sorted by price. Faster if False.

Returns:

a dictionary with good types as keys and list of `abce.trade.Offer` as values

Example:

```
oo = get_offers_all(descending=False)
for good_category in oo:
    print('The cheapest good of category' + good_category
          + ' is ' + good_category[0])
    for offer in oo[good_category]:
        if offer.price < 0.5:
            self.accept(offer)

for offer in oo.beer:
    print(offer.price, offer.sender)
```

get_sell_offers (good, sorted=True, descending=False, shuffled=True)

get_sell_offers_all (descending=False, sorted=True)

give (receiver, good, quantity, epsilon=1e-11)

gives a good to another agent

Args:

receiver: The name of the receiving agent a tuple (group, id). e.G. ('firm', 15)

good: the good to be transferred

quantity: amount to be transferred

epsilon (optional): if you have floating point errors, a quantity or prices is a fraction of number to high or low. You can increase the floating point tolerance. See troubleshooting – floating point problems

Raises:

AssertionError, when good smaller than 0.

Return: Dictionary, with the transfer, which can be used by self.log(...).

Example:

```
self.log('taxes', self.give('money': 0.05 * self['money']))
```

peak_buy_offers (good, sorted=True, descending=False, shuffled=True)

peak_offers (good, sorted=True, descending=False, shuffled=True)

returns a peak on all offers of the 'good' ordered by price. Peaked offers can not be accepted or rejected and they do not expire.

Args:

good: the good which should be retrieved descending(bool, default=False): False for descending True for ascending by price

Returns: A list of offers ordered by price

Example:

```
offers = get_offers('books')
for offer in offers:
    if offer.price < 50:
        self.accept(offer)
    elif offer.price < 100:
        self.accept(offer, 1)
```

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```

else:
    self.reject(offer)  # optional

```

peak_sell_offers (*good*, *sorted=True*, *descending=False*, *shuffled=True*)

reject (*offer*)

Rejects and offer, if the offer is subsequently accepted in the same subround it is accepted'. Peaked offers can not be rejected.

Args:

offer: the offer to be rejected

sell (*receiver*, *good*, *quantity*, *price*, *currency='money'*, *epsilon=1e-11*)

Sends a offer to sell a particular good to somebody. The amount promised is reserved. (self.free(good), shows the not yet reserved goods)

Args:

receiver: the receiving agent

'good': name of the good

quantity: maximum units disposed to buy at this price

price: price per unit

currency: is the currency of this transaction (defaults to 'money')

epsilon (optional): if you have floating point errors, a quantity or prices is a fraction of number to high or low. You can increase the floating point tolerance. See troubleshooting – floating point problems

Returns: A reference to the offer. The offer and the offer status can be accessed with *self.info(offer_reference)*.

Example:

```

def subround_1(self):
    self.offer = self.sell('household', 1, 'cookies', quantity=5, price=0.1)

def subround_2(self):
    offer = self.info(self.offer)
    if offer.status == 'accepted':
        print(offer.final_quantity, 'cookies have be bought')
    else:
        offer.status == 'rejected':
        print('On diet')

```

take (*receiver*, *good*, *quantity*, *epsilon=1e-11*)

take a good from another agent. The other agent has to accept. using self.accept()

Args:

receiver: the receiving agent

good: the good to be taken

quantity: the quantity to be taken

epsilon (optional): if you have floating point errors, a quantity or prices is a fraction of number to high or low. You can increase the floating point tolerance. See troubleshooting – floating point problems

`abce.trade.Offer` (*sender, receiver, good, quantity, price, currency, sell, id, made*)

2.5 Messaging

This is the agent's facility to send and receive messages. Messages can either be sent to an individual with `messaging.Messaging.message()` or to a group with `messaging.Messaging.message_to_group()`. The receiving agent can either get all messages with `messaging.Messaging.get_messages_all()` or messages with a specific topic with `messaging.Messaging.get_messages()`.

```
class abce.messaging.Messaging(id, agent_parameters, simulation_parameters, group,  
                               trade_logging, database, check_unchecked_msgs, expiring,  
                               perishable, resource_endowment, start_round=None)
```

Bases: `object`

get_messages (*topic='m'*)

`self.messages()` returns all new messages send with `message()` (*topic='m'*). The order is randomized.
`self.messages(topic)` returns all messages with a topic.

A message is a string with the message. You can also retrieve the sender by `message.sender_group` and `message.sender_id` and view the topic with `'message.topic'`. (see example)

If you are sending a float or an integer you need to access the message content with `message.content` instead of only `message`.

! if you want to recieve a **float** or an **int**, you must `msg.content`

Returns a message object:

msg.content: returns the message content string, int, float, ...

msg: returns also the message content, but only as a string

sender_group: returns the group name of the sender

sender_id: returns the id of the sender

topic: returns the topic

Example:

```
... agent_01 ...  
self.messages('firm_01', 'potential_buyers', 'hello message')  
  
... firm_01 - one subround later ...  
potential_buyers = get_messages('potential_buyers')  
for msg in potential_buyers:  
    print('message: ', msg)  
    print('message: ', msg.content)  
    print('group name: ', msg.sender_group)  
    print('sender id: ', msg.sender_id)  
    print('topic: ', msg.topic)
```

get_messages_all()

returns all messages irregardless of the topic, in a dictionary by topic

A message is a string with the message. You can also retrieve the sender by `message.sender_group` and `message.sender_id` and view the topic with `'message.topic'`. (see example)

If you are sending a float or an integer you need to access the message content with `message.content` instead of only `message`.

send(*receiver*, *topic*, *content*)

sends a message to agent. Agents receive it at the beginning of next round with `get_messages()` or `get_messages_all()`.

Args:

```
receiver:
    The name of the receiving agent a tuple (group, id).
    e.G. ('firm', 15)

topic:
    string, with which this message can be received

content:
    string, dictionary or class, that is send.
```

Example:

```
... household_01 ...
self.message('firm', 01, 'quote_sell', {'good':'BRD', 'quantity': 5})

... firm_01 - one subround later ...
requests = self.get_messages('quote_sell')
for req in requests:
    self.sell(req.sender, req.good, req.quantity, self.price[req.good])
```

Example2:

```
self.message('firm', 01, 'm', "hello my message")
```

2.6 Firm and production

class `abce.agents.Firm`

Bases: `object`

With `self.produce` a firm produces a good using production functions. For example the following farm has a cobb-douglas production function:

class `Farm(abce.Agent, abce.Firm):`

def `init(self):`

`self.production_function = create_cobb_douglas({'land': 0.7, 'capital': 0.1, 'labor': 0.2})`

def `firming(self):`

`self.produce(self.production_function, {'land': self['land'], 'capital': self['capital'], 'labor': 2})`

Production functions can be auto generated with:

- `py:meth:~abceagent.Firm.create_cobb_douglas` or
- `py:meth:~abceagent.Firm.create_ces` or
- `py:meth:~abceagent.Firm.create_leontief`

or specified by hand:

A production function looks like this:

```
def production_function(wheels, steel, steering_wheels, plant, machines):
    car = min(wheels / 4, steel / 10, steering_wheels)
    wheels = 0
    steel = 0
    steering_wheels = 0
    machine = machine * 0.9
    return locals()
```

This production function, produces one car for every four wheels, 10 tonnes of steel and one steering_wheel, it also requires one machine. Wheels, steel and steering_wheels are completely used. The plant is not used and the machine depreciates by 10%.

A production function can also produce multiple goods. The last line `return locals()`, can not be omitted. It returns all variables you define in this function as a dictionary.

create_ces (*output, gamma, multiplier=1, shares=None*)
creates a CES production function

A production function is a production process that produces the given input goods according to the CES formula to the output good:

$$Q = F \cdot [\sum_{i=1}^n a_i X_i^\gamma]^\frac{1}{\gamma}$$

Production_functions are then used as an argument in `produce`, `predict_vector_produce` and `predict_output_produce`.

Args:

‘output’: Name of the output good

gamma: elasticity of substitution $= s = \frac{1}{1-\gamma}$

multiplier: CES multiplier F

shares: a_i = Share parameter of input i , $\sum_{i=1}^n a_i = 1$ when `share_parameters` is not specified all inputs are weighted equally and the number of inputs is flexible.

Returns:

A `production_function` that can be used in `produce` etc.

Example:

```
self.stuff_production_function = create_ces('stuff', gamma=0.5, multiplier=1,
                                           shares={'labor': 0.25, 'stone': 0.
↪ 25, 'wood': 0.5})
self.produce(self.stuff_production_function, {'stone' : 20, 'labor' : 1, 'wood
↪ ': 12})
```

create_cobb_douglas (*output, multiplier, exponents*)
creates a Cobb-Douglas production function

A production function is a production process that produces the given input goods according to the Cobb-Douglas formula to the output good. Production_functions are then used as an argument in `produce`, `predict_vector_produce` and `predict_output_produce`.

Args:

‘output’: Name of the output good

multiplier: Cobb-Douglas multiplier

{‘input1’: exponent1, ‘input2’: exponent2 ...}: dictionary containing good names ‘input’ and corresponding exponents

Returns:

A `production_function` that can be used in `produce` etc.

Example:

```
def init(self): self.plastic_production_function = create_cobb_douglas('plastic', {'oil': 10, 'labor': 1}, 0.000001)
```

...

```
def producing(self): self.produce(self.plastic_production_function, {'oil': 20, 'labor': 1})
```

create_leontief (*output, utilization_quantities*)

creates a Leontief production function

A production function is a production process that produces the given input goods according to the Leontief formula to the output good. `Production_functions` are then used as an argument in `produce`, `predict_vector_produce` and `predict_output_produce`.

Args:

‘output’: Name of the output good

multiplier: dictionary of multipliers it min(good1 * a, good2 * b, good3 * c...)

{‘input1’: exponent1, ‘input2’: exponent2 ...}: dictionary containing good names ‘input’ and corresponding exponents

Returns:

A `production_function` that can be used in `produce` etc.

```
Example: self.car_production_function = create_leontief('car', {'wheel': 4, 'chassi': 1})
self.produce(self.car_production_function, {'wheel': 20, 'chassi': 5})
```

produce (*production_function, input_goods, results=False*)

Produces output goods given the specified amount of inputs.

Transforms the Agent’s goods specified in input goods according to a given `production_function` to output goods. Automatically changes the agent’s belonging. Raises an exception, when the agent does not have sufficient resources.

Args:

production_function: A `production_function` produced with `py:meth:~abceagent.Firm.create_production_function`, `py:meth:~abceagent.Firm.create_cobb_douglas` or `py:meth:~abceagent.Firm.create_leontief`

input goods dictionary or list: dictionary containing the amount of input good used for the production or a list of all goods that get completely used.

results: If True returns a dictionary with the used and produced goods.

Raises:

NotEnoughGoods: This is raised when the goods are insufficient.

Example:

```
car = {'tire': 4, 'metal': 2000, 'plastic': 40}
bike = {'tire': 2, 'metal': 400, 'plastic': 20}
try:
    self.produce(car_production_function, car)
```

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```

except NotEnoughGoods:
    A.produce(bike_production_function, bike)

self.produce(car_production_function, ['tire', 'metal', 'plastic']) #
↳produces using all goods

```

2.7 Household and consumption

The Household class extends the agent by giving him utility functions and the ability to consume goods.

```
class abce.agents.Household
```

Bases: `object`

consume (*utility_function, input_goods*)

consumes input_goods returns utility according to the agent's utility function.

A utility_function, has to be set before see py:meth:~abceagent.Household.create_cobb_douglas_utility_function or manually; see example.

Args:

utility_function: A function that takes goods as parameters and returns a utility or returns (utility, left_over_dict). Where left_over_dict is a dictionary of all goods that are not completely consumed

input goods dictionary or list: dictionary containing the amount of input good used consumed or a list of all goods that get completely consumed.

Raises: NotEnoughGoods: This is raised when the goods are insufficient.

Returns: The utility as a number. To log it see example.

Example:

```

def utility_function(car, cookies, bike):
    utility = car ** 0.5 * cookies ** 0.2 * bike ** 0.3
    cookies = 0 # cookies are consumed, while the other goods are not
↳consumed
    return utility, locals()

def utility_function(cake, cookies, bonbons): # all goods get completely
↳consumed
    utility = cake ** 0.5 * cookies ** 0.2 * bonbons ** 0.3
    return utility

self.consumption_set = {'car': 1, 'cookies': 2000, 'bike': 2}
self.consume_everything = ['car', 'cookies', 'bike']
try:
    utility = self.consume(utility_function, self.consumption_set)
except NotEnoughGoods:
    utility = self.consume(utility_function, self.consume_everything)
self.log('utility': {'u': utility})

```

create_cobb_douglas_utility_function (*exponents*)

creates a Cobb-Douglas utility function

Utility_functions are then used as an argument in `consume_with_utility`, `predict_utility` and `predict_utility_and_consumption`.

Args: {'input1': exponent1, 'input2': exponent2 ...}: dictionary containing good names 'input' and corresponding exponents

Returns: A utility_function that can be used in `consume_with_utility` etc.

Example: `self.utility_function = self.create_cobb_douglas({'bread' : 10, 'milk' : 1})`
`self.produce(self.plastic_utility_function, {'bread' : 20, 'milk' : 1})`

2.8 Observing agents and logging

There are different ways of observing your agents:

Trade Logging: ABCE by default logs all trade and creates a SAM or IO matrix.

Manual in agent logging: An agent is instructed to log a variable with `log()` or a change in a variable with `log_change()`.

Aggregate Data: `aggregate()` save agents possessions and variable aggregated over a group

Panel Data: `panel()` creates panel data for all agents in a specific agent group at a specific point in every round. It is set in `start.py`

How to retrieve the Simulation results is explained in [retrieval](#)

2.8.1 Trade Logging

By default ABCE logs all trade and creates a social accounting matrix or input output matrix. Because the creation of the trade log is very time consuming you can change the default behavior in `world_parameter.csv`. In the column 'trade_logging' you can choose 'individual', 'group' or 'off'. (Without the apostrophes!).

2.8.2 Manual logging

All functions except the trade related functions can be logged. The following code logs the production function and the change of the production from last year:

```
output = self.produce(self.inputs)
self.log('production', output)
self.log_change('production', output)
```

Log logs dictionaries. To log your own variable:

```
self.log('price', {'input': 0.8, 'output': 1})
```

Further you can write the change of a variable between a start and an end point with: `observe_begin()` and `observe_end()`.

```
class abce.database.Database(id, agent_parameters, simulation_parameters, group,
                             trade_logging, database, check_unchecked_msgs, expiring,
                             perishable, resource_endowment, start_round=None)
```

Bases: `object`

The database class

log (*action_name*, *data_to_log*)

With log you can write the models data. Log can save variable states and the working of individual functions such as production, consumption, give, but not trade(as its handled automatically). Sending a dictionary instead of several using several log statements with a single variable is faster.

Args:

'name'(string): the name of the current action/method the agent executes

data_to_log: a variable or a dictionary with data to log in the the database

Example:

```
self.log('profit', profit)

self.log('employment_and_rent',
        {'employment': self['LAB'],
         'rent': self['CAP'],
         'composite': self.composite})

self.log(self.produce_use_everything())
```

See also:

log_nested(): handles nested dictionaries

log_change(): loges the change from last round

observe_begin():

log_change (*action_name*, *data_to_log*)

This command logs the change in the variable from the round before. Important, use only once with the same *action_name*.

Args:

'name'(string): the name of the current action/method the agent executes

data_to_log: a dictionary with data for the database

Examples:

```
self.log_change('profit', {'money': self['money']})
self.log_change('inputs',
                {'money': self.possessions(['money', 'gold', 'CAP', 'LAB'])})
```

observe_begin (*action_name*, *data_to_observe*)

observe_begin and **observe_end**, observe the change of a variable. **observe_begin(...)**, takes a list of variables to be observed. **observe_end(...)** writes the change in this variables into the log file

you can use nested **observe_begin** / **observe_end** combinations

Args:

'name'(string): the name of the current action/method the agent executes

data_to_log: a dictionary with data for the database

Example:


```
self.log('production', {'composite': self.composite,
                        self.sector: self.final_product[self.sector]})

... different method ...

self.log('employment_and_rent', {
    'employment': self['LAB'],
    'rent': self['CAP']})
```

observe_end (*action_name*, *data_to_observe*)

This command puts in a database called log, whatever values you want values need to be delivered as a dictionary:

Args:

'name'(string): the name of the current action/method the agent executes

data_to_log: a dictionary with data for the database

Example:

```
self.log('production', {'composite': self.composite,
                        self.sector: self.final_product[self.sector]})

... different method ...

self.log('employment_and_rent', {
    'employment': self['LAB'],
    'rent': self['CAP']})
```

2.8.3 Panel Data

Group.**panel_log** (*variables=[]*, *goods=[]*, *func={}*, *len=[]*)

panel_log(.) writes a panel of variables and goods of a group of agents into the database, so that it is displayed in the gui.

Args:

goods (list, optional): a list of all goods you want to track as 'strings'

variables (list, optional): a list of all variables you want to track as 'strings'

func (dict, optional): accepts lambda functions that execute functions. e.G. `func = lambda self: self.old_money - self.new_money`

len (list, optional): records the length of the list or dictionary with that name.

Example in start.py:

```
for round in simulation.next_round():
    firms.produce_and_sell()
    firms.panel_log(goods=['money', 'input'],
                   variables=['production_target', 'gross_revenue'])
    households.buying()
```

2.8.4 Aggregate Data

Group.**agg_log** (*variables=[]*, *goods=[]*, *func={}*, *len=[]*)

`agg_log(.)` writes a aggregate data of variables and goods of a group of agents into the database, so that it is displayed in the gui.

Args:

goods (list, optional): a list of all goods you want to track as ‘strings’

variables (list, optional): a list of all variables you want to track as ‘strings’

func (dict, optional): accepts lambda functions that execute functions. e.G. `func = lambda self: self.old_money - self.new_money`

len (list, optional): records the length of the list or dictionary with that name.

Example in `start.py`:

```
for round in simulation.next_round():
    firms.produce_and_sell()
    firms.agg_log(goods=['money', 'input'],
                  variables=['production_target', 'gross_revenue'])
    households.buying()
```

2.9 Retrieval of the simulation results

Agents can log their internal states and the simulation can create panel data. `abce.database`.

the results are stored in a subfolder of the `./results/` folder. The exact path is in `simulation.path`. So if you want to post-process your data, you can write a function that changes in to the `simulation.path` directory and manipulates the CSV files there. The tables are stored as ‘.csv’ files which can be opened with excel.

The same data is also as a sqlite3 database ‘`database.db`’ available. It can be opened by ‘`sqlitebrowser`’ in ubuntu.

Example:

```
In start.py

simulation = abce.Simulation(...)
...
simulation.run()

os.chdir(simulation.path)
firms = pandas.read_csv('aggregate_firm.csv')
...
```

2.10 NotEnoughGoods Exception

exception `abce.NotEnoughGoods` (*_agent_name*, *good*, *amount_missing*)

Bases: `Exception`

Methods raise this exception when the agent has less goods than needed

These functions (`self.produce`, `self.offer`, `self.sell`, `self.buy`) should be encapsulated by a try except block:

```
try:
    self.produce(...)
except NotEnoughGoods:
    alternative_statements()
```


3.1 Contracting

Warning: Contracting is experimental and the API is not stable yet

class `abce.Contracting`

Bases: `object`

This is a class, that allows you to create contracts. For example a work contract. One agent commits to deliver a good or service for a set amount of time.

For example you have a firm and a worker class. ‘Labor’ is set as a service meaning that it lasts not longer than one round and the worker how has an adult gets one unit of labor every round see: `abce.declare_service()`. The firm offers a work contract, the worker responds. Every round the worker delivers the labor and the firm pays.:

```
class Firm(abce.Agent, abce.Contract):
    def request_offer(self):
        if self.round % 10 == 0:
            self.given_contract = self.request_contract('contractbuyer', 0,
                                                         good='labor',
                                                         quantity=5,
                                                         price=10,
                                                         duration=10 - 1)

    def deliver_or_pay(self):
        self.pay_contract('labor')

class Worker(abce.Agent, abce.Contract):
    def init(self):
        self.create('adult', 1)
```

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```

def accept_offer(self):
    contracts = self.get_contract_requests('labor')
    for contract in contracts:
        if contract.price < 5:
            self.accepted_contract = self.accept_contract(contract)

def deliver_or_pay(self):
    self.deliver('labor')

```

Firms and workers can check, whether they have been paid/provided with labor using the `is_paid()` and `is_delivered()` methods.

The worker can also initiate the transaction by requesting a contract with `make_contract_offer()`.

A contract has the following fields:

sender_group:

sender_id:

deliver_group:

deliver_id:

pay_group:

pay_id:

good:

quantity:

price:

end_date:

makerequest: 'm' for `make_contract_offer` and 'r' for `request_contract`

id: unique number of contract

accept_contract (*contract*, *quantity=None*)

Accepts the contract. The contract is completely accepted, when the quantity is not given. Or partially when quantity is set.

Args:

contract: the contract in question, received with `get_contract_requests` or `get_contract_offers`

quantity (optional): the quantity that is accepted. Defaults to all.

calculate_assetvalue (*prices={}*, *parameters={}*, *value_functions={}*)

calculate_liabilityvalue (*prices={}*, *parameters={}*, *value_functions={}*)

calculate_netvalue (*prices={}*, *parameters={}*, *value_functions={}*)

calculate_valued_assets (*prices={}*, *parameters={}*, *value_functions={}*)

calculate_valued_liabilities (*prices={}*, *parameters={}*, *value_functions={}*)

contracts_to_deliver (*good*)

contracts_to_deliver_all ()

contracts_to_receive (*good*)

contracts_to_receive_all ()

deliver_contract (*contract*)

delivers on a contract

end_contract (*contract*)

get_contract_offers (*good, descending=False*)

Returns all contract offers and removes them. The contract are ordered by price (ascending), when tied they are randomized.

Args:

good: good that underlies the contract

descending(bool,default=False): False for descending True for ascending by price

Returns: list of contract offers ordered by price

offer_good_contract (*receiver_group, receiver_id, good, quantity, price, duration*)

This method offers a contract to provide a good or service to the receiver. For a given time at a given price.

Args:

receiver_group: group to receive the good

receiver_id: group to receive the good

good: the good or service that should be provided

quantity: the quantity that should be provided

price: the price of the good or service

duration: the length of the contract, if duration is None or not set, the contract has no end date.

Example:

```
self.given_contract = self.make_contract_offer('firm', 1, 'labor', quantity=8,
↪ price=10, duration=10 - 1)
```

pay_contract (*contract*)

delivers on a contract

request_good_contract (*receiver_group, receiver_id, good, quantity, price, duration*)

This method requests a contract to provide a good or service to the sender. For a given time at a given price. For example a job advertisement.

Args:

receiver_group: group of the receiver

receiver_id: id of the receiver

good: the good or service that should be provided

quantity: the quantity that should be provided

price: the price of the good or service

duration: the length of the contract, if duration is None or not set, the contract has no end date.

was_delivered_last_round (*contract*)

was_delivered_this_round (*contract*)

was_paid_last_round (*contract*)

was_paid_this_round (*contract*)

3.2 Quote

class abce.quote.**Quote**

Bases: `object`

Quotes as opposed to trades are uncommitted offers. They can be made even if they agent can not fullfill them. With `accept_quote()` and `accept_quote_partial()`, the receiver of a quote can transform them into a trade.

accept_quote (*quote*)

makes a committed buy or sell out of the counterparties quote. For example, if you receive a buy quote you can accept it and a sell offer is send to the offering party.

Args:: quote: buy or sell quote that is accepted

accept_quote_partial (*quote, quantity*)

makes a committed buy or sell out of the counterparties quote

Args:: quote: buy or sell quote that is accepted quantity: the quantity that is offered/requested it should be less than propsed in the quote, but this is not enforced.

get_quotes (*good, descending=False*)

`self.get_quotes()` returns all new quotes and removes them. The order is randomized.

Args:

good: the good which should be retrieved

descending(bool,default=False): False for descending True for ascending by price

Returns: list of quotes ordered by price

Example:

```
quotes = self.get_quotes()
```

get_quotes_all (*descending=False*)

`self.get_quotes_all()` returns a dictionary with all now new quotes ordered by the good type and removes them. The order is randomized.

Args:

descending(bool,default=False): False for descending True for ascending by price

Returns: dictionary of list of quotes ordered by price. The dictionary itself is ordered by price.

Example:

```
quotes = self.get_quotes()
```

quote_buy (*receiver, good=None, quantity=None, price=None*)

quotes a price to buy quantity of 'good' a receiver. Use None, if you do not want to specify a value.

price (money) per unit offers a deal without checking or committing resources

Args:

receiver_group: agent group name of the agent

receiver_id: the agent's id number

'good': name of the good

quantity: maximum units disposed to buy at this price

price: price per unit

quote_sell (*receiver, good=None, quantity=None, price=None*)

quotes a price to sell quantity of ‘good’ to a receiver. Use None, if you do not want to specify a value.

price (money) per unit offers a deal without checking or committing resources

Args:

receiver_group: agent group name of the agent

receiver_id: the agent’s id number

‘good’: name of the good

quantity: maximum units disposed to sell at this price

price: price per unit

```
abce.quote.Quotation(sender_group, sender_id, receiver_group, receiver_id, good, quantity, price,
                     buysell, id)
```

3.3 Spatial and Netlogo like Models

ABCE deliberately does not provide spatial representation, instead it integrates with other packages that specialize in spatial representation.

3.3.1 Netlogo like models

For Netlogo like models in Python, we recommend using ABCE together with [MESA](#)

A simple example shows how to build a spatial model in ABCE using MESA:

On [github](#)

A wrapper file to start the graphical representation and the simulation

```
""" This is a simple demonstration model how to integrate ABCE and mesa.
The model and scheduler specification are taken care of in
ABCE instead of Mesa.

Based on
https://github.com/projectmesa/mesa/tree/master/examples/boltzmann_wealth_model.

For further reading, see
[Dragulescu, A and Yakovenko, V. Statistical Mechanics of Money, Income, and Wealth:
↪A Short Survey. November, 2002] (http://arxiv.org/pdf/cond-mat/0211175v1.pdf)
"""

from model import MoneyModel
from mesa.visualization.modules import CanvasGrid
from mesa.visualization.ModularVisualization import ModularServer
from mesa.visualization.modules import ChartModule

def agent_portrayal(agent):
    """ This function returns a big red circle, when an agent is wealthy and a
    small gray circle when he is not """
```

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```

    portrayal = {"Shape": "circle",
                 "Filled": "true",
                 "r": 0.5}

    if agent.report_wealth() > 0:
        portrayal["Color"] = "red"
        portrayal["Layer"] = 0
    else:
        portrayal["Color"] = "grey"
        portrayal["Layer"] = 1
        portrayal["r"] = 0.2
    return portrayal

def main(x_size, y_size):
    """ This function sets up a canvas to graphically represent the model 'MoneyModel'
    and a chart, than it runs the server and runs the model in model.py in the
    ↪browser """
    grid = CanvasGrid(agent_portrayal, x_size, y_size, 500, 500)

    chart = ChartModule([{"Label": "Gini",
                          "Color": "Black"}],
                        data_collector_name='datacollector')
    # the simulation uses a class DataCollector, that collects the data and
    # relays it from self.datacollector to the webpage

    server = ModularServer(MoneyModel,
                           [grid, chart],
                           "ABCE and MESA integrated",
                           x_size * y_size, x_size, y_size)
    server.port = 8534 # change this number if address is in use
    server.launch()

if __name__ == '__main__':
    main(25, 25)

```

A file with the simulation itself, that can be executed also without the GUI

```

""" This is a simple demonstration model how to integrate ABCE and mesa.
The model and scheduler specification are taken care of in
ABCE instead of Mesa.

Based on
https://github.com/projectmesa/mesa/tree/master/examples/boltzmann_wealth_model.

For further reading, see
[Dragulescu, A and Yakovenko, V. Statistical Mechanics of Money, Income, and Wealth:
↪A Short Survey. November, 2002] (http://arxiv.org/pdf/cond-mat/0211175v1.pdf)
"""
import abce
from mesa.space import MultiGrid
from mesa.datacollection import DataCollector
from moneyagent import MoneyAgent

```

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```

def compute_gini(model):
    """ calculates the index of wealth distribution form a list of numbers """
    agent_wealths = model.wealths
    x = sorted(agent_wealths)
    N = len(agent_wealths)
    B = sum(xi * (N - i) for i, xi in enumerate(x)) / (N * sum(x))
    return 1 + (1 / N) - 2 * B

class MoneyModel(abce.Simulation): # The actual simulation must inherit from_
↳Simulation
    """ The actual simulation. In order to interoperate with MESA the simulation
    needs to be encapsulated in a class. __init__ sets the simulation up. The step
    function runs one round of the simulation. """

    def __init__(self, num_agents, x_size, y_size):
        abce.Simulation.__init__(self,
                                name='ABCE and MESA integrated',
                                rounds=300,
                                processes=1)

        # initialization of the base class. MESA integration requires
        # single processing
        self.grid = MultiGrid(x_size, y_size, True)
        self.agents = self.build_agents(MoneyAgent, 'MoneyAgent', num_agents,
                                       parameters={'grid': self.grid})

        # ABCE agents must inherit the MESA grid
        self.running = True
        # MESA requires this
        self.datacollector = DataCollector(
            model_reporters={"Gini": compute_gini})
        # The data collector collects a certain aggregate value so the graphical
        # components can access them

        self.wealths = [0 for _ in range(num_agents)]

    def step(self):
        """ In every step the agent's methods are executed, every set the round
        counter needs to be increased by self.next_round() """
        self.next_round()
        self.agents.do('move')
        self.agents.do('give_money')
        self.wealths = self.agents.do('report_wealth')
        # agents report there wealth in a list self.wealth
        self.datacollector.collect(self)
        # collects the data

if __name__ == '__main__':
    """ If you run model.py the simulation is executed without graphical
    representation """
    money_model = MoneyModel(1000, 20, 50)
    for r in range(100):
        print(r)
        money_model.step()

```

A simple agent

```
import abce
import random

class MoneyAgent(abce.Agent):
    """ agents move randomly on a grid and give_money to another agent in the same_
    ↪ cell """

    def init(self, parameters, agent_parameters):
        self.grid = parameters["grid"]
        """ the grid on which agents live must be imported """
        x = random.randrange(self.grid.width)
        y = random.randrange(self.grid.height)
        self.pos = (x, y)
        self.grid.place_agent(self, (x, y))
        self.create('money', random.randrange(2, 10))

    def move(self):
        """ moves randomly """
        possible_steps = self.grid.get_neighborhood(self.pos,
                                                    moore=True,
                                                    include_center=False)

        new_position = random.choice(possible_steps)
        self.grid.move_agent(self, new_position)

    def give_money(self):
        """ If the agent has wealth he gives it to cellmates """
        cellmates = self.grid.get_cell_list_contents([self.pos])
        if len(cellmates) > 1:
            other = random.choice(cellmates)
            try:
                self.give(other.group, other.id, good='money', quantity=1)
            except abce.NotEnoughGoods:
                pass

    def report_wealth(self):
        return self.possession('money')
```

3.4 Plugins

ABCE has one plugin so far. The ABCESL accounting framework. If you want to author your own plugin - its dead simple. All you have to do is write a class that inherits from Agent in agent.py. This class can overwrite:

```
def __init__(self, id, group, trade_logging, database, random_seed, num_managers,
             agent_parameters, simulation_parameters,
             check_unchecked_msgs, start_round=None):
def _begin_subround(self):
def _end_subround(self):
def _advance_round(self, time):
```

For example like this:

```
class UselessAgent(abce.Agent):
    def __init__(self, id, group, trade_logging, database, random_seed, num_managers,
                  agent_parameters, simulation_parameters,
                  check_unchecked_msgs, start_round=None):
        super().__init__(id, group, trade_logging,
                         database, random_seed, num_managers, agent_parameters,
                         simulation_parameters, check_unchecked_msgs,
                         start_round):
        print("Here i begin")

    def _begin_subround(self):
        super()._begin_subround()
        print('subround begins')

    def _end_subround(self):
        super()._end_subround()
        print('subround finishes')

    def _advance_round(self, time):
        super()._advance_round(time)
        print('Super I made it to the next round')

    def ability(self):
        print("its %r o'clock" % self.time)
        print("the simulation called my ability")
```

Do not overwrite the `init(parameters, simulation_parameters)` method

Graphical User Interface and Results

4.1 Graphical User Interface

`python -m abce.show` shows the simulation results in `./result/*`

```
abce.gui.gui(parameter_mask, names=None, header=None, story=None, title='Agent-Based Com-
putational Economics', texts=None, pages=None, histograms=None, serve=False,
runtime='browser-X', truncate_rounds=0, hostname='0.0.0.0', port=80, pypy=None)
```

`gui` is a decorator that can be used to add a graphical user interface to your simulation.

Args:

parameter_mask: a dictionary with the parameter name as key and an example value as value. Instead of the example value you can also put a tuple: (min, default, max)

parameters can be:

- **float:** {'exponent': (0.0, 0.5, 1.1)}
- **int:** {'num_firms': (0, 100, 100000)}
- dict or list, which should be strings of a dict or a list (see example):
{'list_to_edit': ["'brd'", "'mlk'", "'add'"]}
- **a list of options:** {'several_options': ['opt_1', 'opt_2', 'opt_3']}
- **a string:** {'name': '2x2'}

names (optional): a dictionary with the parameter name as key and an alternative text to be displayed instead.

title: a string with the name of the simulation.

header: html string for a bar on the top

story: a dictionary with text to be displayed alongside the graphs. Key must be the graphs title, value can be text or html.

pages: A dictionary with title as key and links to external websites as values, which are displayed on the right hand side.

truncate_rounds: Does not display the initial x rounds, in the result graphs

runtime: webbrowser to start the simulation in, can be 'xui' or python's webbrowser module's webbrowser string.

histograms: specifies in which round histograms are generated. If it is not specified rounds from the menu is used. Alternatively you can create 'histogram' parameter in parameter_mask.

serve: If you run this on your local machine serve must be False. If used as a web server must be True

hostname: Hostname if serve is active, defaults to '0.0.0.0'

port: Port if serve is active, defaults to 80

pypy: Name of the pypy interpreter to run ABCE super fast. e.G. 'pypy' or 'pypy3'. The mainfile needs to be run with cpython e.G.: `python3 start.py`

Example:

```
parameter_mask = {'name': 'name',
                  'random_seed': None,
                  'rounds': 40,
                  'num_firms': (0, 100, 100000),
                  'num_households': (0, 100, 100000),
                  'exponent': (0.0, 0.5, 1.1),
                  'several_options': ['opt_1', 'opt_2', 'opt_3']
                  'list_to_edit': "['brd', 'mlk', 'add']",
                  'dictionary_to_edit': '{"v1": 1, "v2": 2}'}

names = {'num_firms': 'Number of Firms'}

@gui(parameter_mask, names,
      title="Agent-Based Computational Economics",
      serve=False)
def main(simulation_parameters):
    parameter_list = eval(simulation_parameters['list_to_edit'])
    simulation = Simulation()
    firms = simulation.build_agents(Firm,
                                   simulation_parameters['num_firms'])
    households = simulation.build_agents(Household,
                                         simulation_parameters['num_households'])

    for r in range(simulation_parameters['rounds']):
        simulation.advance_round(r)
        firms.work()
        households.buy()

if __name__ == '__main__':
    main(simulation_parameters)
```

`Simulation.graphs()`

after the simulation is run, `graphs()` shows graphs of all data collected in the simulation. Shows the same output as the `@gui` decorator shows.

Example:


```
simulation = Simulation(...)
for r in range(100):
    simulation.advance_round(r)
    agents.do_something()
    ...

simulation.graphs()
```

4.2 Deploying an ABCE simulation on-line

4.2.1 Prepare your simulation to be displayed on the web

In order for your simulation to be able to be run on the web it must be running in the web browser. for this you need to add `@gui(...)` before the main function. Further `@gui` needs to be switched to `serve`:

```
...

title = "Computational Complete Economy Model on Climate Gas Reduction"
text = """ This simulation simulates climate change
"""

parameters = OrderedDict({'wage_stickiness': (0, 0.5, 1.0),
                           'price_stickiness': (0, 0.5, 1.0),
                           'network_weight_stickiness': (0, 0.5, 1.0),
                           'carbon_tax': (0, 50.0, 80.0),
                           'tax_change_time': 100,
                           'rounds': 200})

@gui(parameters, text=text, title=title, serve=True)
def main(simulation_parameters):
    ...

    simulation = Simulation(processes=1)
    simulation.run()

    #simulation.graphs() This must be commented out or deleted
    simulation.finalize()

if __name__ == '__main__':
    main(parameters)
```

It is important to note that the `main()` function is not called, when `start.py` is imported! if `__name__ == '__main__':`, means that it is not called when `start.py` is imported. you can also simply delete the call of `main()`.

`@gui` is the part that generates the web application and runs it. `serve` must be set to `True` in `@gui(simulation_parameters, text=text, title=title, serve=True)`

The easiest way to get your code to the server is via github. For this follow the following instructions. Push the simulation to github. If you are unsure what git and github is, refer to this 'gitimersion.com<<http://gitimersion.com>>'. If your code is not yet a git repository change in your directory:

```
git init
git add --all
git commit -m"initial commit"
```

Go to github sign up and create a new repository. It will then display you instruction how to push an existing repository from the command line your, they will look like this:

```
git remote add origin https://github.com/your_name/myproject.git
git push -u origin master
```

4.2.2 Deploy you ABCE simulation on amazon ec2 or your own Ubuntu server

create an amazon ec2 instance following ‘[Amazon’s tutorial here](http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ec2-launch-instance_linux.html)<http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ec2-launch-instance_linux.html>’_

make sure that in step 7b, configure the security groups, such that you have a HTTP access. This setting allows access to port 80 (HTTP) from anywhere, and ssh access only from your IP address.

then	Protocol	Port Range	Source
from	TCP	22	My IP
the HTTP	TCP	80	Anywhere

con-
sole
ssh into your account

```
ssh -i amazoninstanceweb2py.pem ubuntu@ec2-54-174-70-207.compute-1.amazonaws.com
```

Install the server software and ABCE requirements:

```
sudo pip3 install abce
```

copy or clone your ABCE simulation into the ~/myproject directory the easiest way is to use a git repository, but you can also use scp:

```
git clone https://github.com/your_name/myproject.git
```

start simulation with nohup:

```
cd myproject

nohup sudo python3 start.py &
tail -f nohup.out
```

The last line displays the logging messages.

If something does not work delete all files and directories that have root as user. (find them with ll)

Frequently asked Questions

5.1 How to share public information?

Agents can return information via a return statement at the end of a method. The returned variables are returned to start.py as a list of the values. It is often useful to include the agents name e.G. `return (self.name, info)`

The returned information can than be passed as arguments for another method:

```
for r in range(100):
    simulation.advance_round(r)
    agents.do_something()
    info = agents.return_info()
    agents.receive_public_information(info=info)
```

Currently only named function parameters are supported.

5.2 How to share a global state?

A shared global state, breaks multiprocessing, so if you want to run the simulation on multiple cores see ‘How to share public information’. In single processing mode, you can give each agent a dictionary as a parameter. All information in this dictionary is shared.

5.3 How to access other agent’s information?

Once again this breaks multiprocessing. But you can return an agent’s self and give it as a parameter to other agents.

5.4 How to make abcEconomics fast?

There is several ways:

1. Use pypy3 instead of CPython, it can be downloaded here: <https://pypy.org/download.html>. With pypy3 you can run the same code as with CPython, but about 30 times faster.
2. If you use scipy pypy3 might not work. Use numba instead. <http://numba.pydata.org>
3. Run the simulation with a different number of processes. With very simple agents and many messages one is optimal, with compute intensive agents number of physical processors minus one is usually most efficient. But experimenting even with more processes than physical processors might be worth it.
4. Use kernprof to find which agent's method is slowest. https://github.com/rkern/line_profiler

5.5 How to load agent-parameters from a csv / excel / sql file?

The list of parameters can be passed as `agent_parameters` and is passed to `init`, as keyword arguments:

```
with open('emirati.csv', 'r') as f:
    emirati_file = csv.DictReader(f)
    emiratis_data = list(emirati_file)

emiratis = sim.build_agents(Emirati, 'emirati', agent_parameters=emiratis_data)
```

Note that `list(file)` is necessary.

CHAPTER 6

Indices and tables

- `genindex`
- `modindex`
- `search`

a

`abce.goods`, [32](#)

A

abce (*module*), 25
 abce.agent (*module*), 30
 abce.agents.household (*module*), 42
 abce.goods (*module*), 32
 abce.messaging (*module*), 38
 abce.show (*module*), 59
 accept () (*abce.Trade method*), 34
 accept_contract () (*abce.Contracting method*), 50
 accept_quote () (*abce.quote.Quote method*), 52
 accept_quote_partial () (*abce.quote.Quote method*), 52
 advance_round () (*abce.Simulation method*), 26
 Agent (*class in abce*), 30
 agg_log () (*abce.group.Group method*), 46

B

build_agents () (*abce.Simulation method*), 26
 buy () (*abce.Trade method*), 34

C

calculate_assetvalue () (*abce.Contracting method*), 50
 calculate_liabilityvalue () (*abce.Contracting method*), 50
 calculate_netvalue () (*abce.Contracting method*), 50
 calculate_valued_assets () (*abce.Contracting method*), 50
 calculate_valued_liabilities () (*abce.Contracting method*), 50
 consume () (*abce.agents.Household method*), 42
 Contracting (*class in abce*), 49
 contracts_to_deliver () (*abce.Contracting method*), 50
 contracts_to_deliver_all () (*abce.Contracting method*), 50
 contracts_to_receive () (*abce.Contracting method*), 50

contracts_to_receive_all () (*abce.Contracting method*), 50
 create () (*abce.goods.Goods method*), 32
 create_agent () (*abce.Simulation method*), 27
 create_agents () (*abce.Simulation method*), 27
 create_ces () (*abce.agents.Firm method*), 40
 create_cobb_douglas () (*abce.agents.Firm method*), 40
 create_cobb_douglas_utility_function () (*abce.agents.Household method*), 42
 create_leontief () (*abce.agents.Firm method*), 41
 create_timestructured () (*abce.goods.Goods method*), 32

D

Database (*class in abce.database*), 43
 declare_expiring () (*abce.Simulation method*), 27
 declare_perishable () (*abce.Simulation method*), 28
 declare_round_endowment () (*abce.Simulation method*), 28
 declare_service () (*abce.Simulation method*), 28
 delete_agent () (*abce.Simulation method*), 29
 delete_agents () (*abce.Simulation method*), 29
 deliver_contract () (*abce.Contracting method*), 50
 destroy () (*abce.goods.Goods method*), 32

E

end_contract () (*abce.Contracting method*), 51

F

finalize () (*abce.Simulation method*), 29
 Firm (*class in abce.agents*), 39

G

get_buy_offers () (*abce.Trade method*), 35
 get_buy_offers_all () (*abce.Trade method*), 35

get_contract_offers() (*abce.Contracting method*), 51
 get_messages() (*abce.messaging.Messaging method*), 38
 get_messages_all() (*abce.messaging.Messaging method*), 38
 get_offers() (*abce.Trade method*), 35
 get_offers_all() (*abce.Trade method*), 35
 get_quotes() (*abce.quote.Quote method*), 52
 get_quotes_all() (*abce.quote.Quote method*), 52
 get_sell_offers() (*abce.Trade method*), 36
 get_sell_offers_all() (*abce.Trade method*), 36
 give() (*abce.Trade method*), 36
 Goods (*class in abce.goods*), 32
 graphs() (*abce.Simulation method*), 29, 60
 group (*abce.Agent attribute*), 30
 gui() (*in module abce.gui*), 59

H

Household (*class in abce.agents*), 42

I

id (*abce.Agent attribute*), 31
 init() (*abce.Agent method*), 31

L

log() (*abce.database.Database method*), 43
 log_change() (*abce.database.Database method*), 44

M

Messaging (*class in abce.messaging*), 38

N

name (*abce.Agent attribute*), 31
 not_reserved() (*abce.goods.Goods method*), 32
 NotEnoughGoods, 46

O

observe_begin() (*abce.database.Database method*), 44
 observe_end() (*abce.database.Database method*), 45
 Offer() (*in module abce.trade*), 37
 offer_good_contract() (*abce.Contracting method*), 51

P

panel_log() (*abce.group.Group method*), 45
 path (*abce.Simulation attribute*), 29
 pay_contract() (*abce.Contracting method*), 51
 peak_buy_offers() (*abce.Trade method*), 36
 peak_offers() (*abce.Trade method*), 36
 peak_sell_offers() (*abce.Trade method*), 37

possession() (*abce.goods.Goods method*), 32
 possessions() (*abce.goods.Goods method*), 33
 produce() (*abce.agents.Firm method*), 41

Q

Quotation() (*in module abce.quote*), 53
 Quote (*class in abce.quote*), 52
 quote_buy() (*abce.quote.Quote method*), 52
 quote_sell() (*abce.quote.Quote method*), 53

R

reject() (*abce.Trade method*), 37
 request_good_contract() (*abce.Contracting method*), 51
 round (*abce.Agent attribute*), 31

S

sell() (*abce.Trade method*), 37
 send() (*abce.messaging.Messaging method*), 39
 Simulation (*class in abce*), 25

T

take() (*abce.Trade method*), 37
 time (*abce.Agent attribute*), 31
 time (*abce.Simulation attribute*), 30
 Trade (*class in abce*), 33

W

was_delivered_last_round() (*abce.Contracting method*), 51
 was_delivered_this_round() (*abce.Contracting method*), 51
 was_paid_last_round() (*abce.Contracting method*), 51
 was_paid_this_round() (*abce.Contracting method*), 51