Market Microstructure Simulator: developer's point of view

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Overview

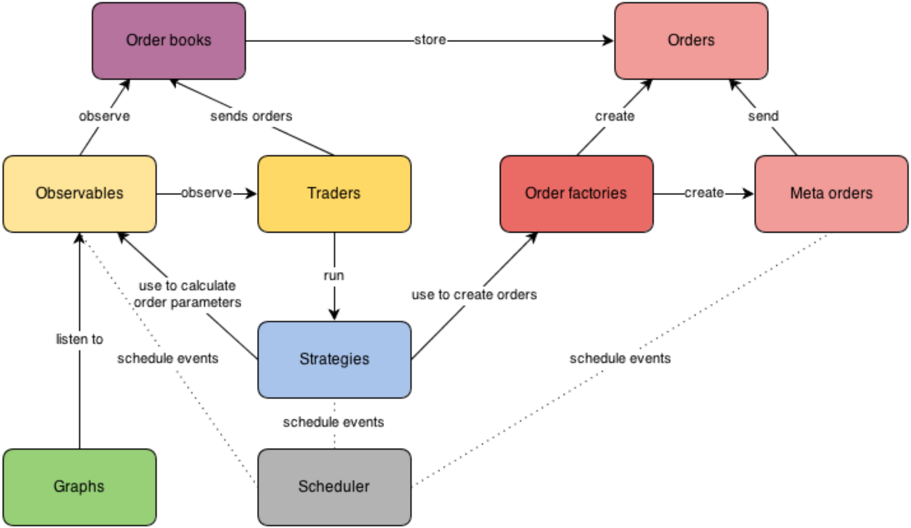
Evolution of the simulator

1. Initial C++ version was developed in 2009-2011.
2. C++ version based on template metaprogramming techniques was suggested in 2012
3. Python version with Web interface is almost finished by June 2013
4. Optimized C++ version based on automatic code generation is to be developed by September 2013

Installation

- OS supported: Linux, Mac OS X, Windows
- Browsers supported: Chrome, Firefox, Safari, Opera
- Python 2.7
- Python packages can be installed using `pip` or `easyinstall`:
    - Veusz (for graph plotting)
    - Flask (to run a Web-server)
    - Blist (sorted collections used by ArbitrageTrader)
- Source code downloadable from SourceForge

Simulator components



Scheduler

- Main class for every discrete event simulation system.
- Maintains a set of actions to fulfill in future and launches them according their action times: from older ones to newer.

Interface:

- Event scheduling:
  - `schedule(actionTime, handler)`
  - `scheduleAfter(dt, handler)`
- Simulation control:
  - `workTill(limitTime)`
  - `advance(dt)`
  - `reset()`

Order book

- Represents a single asset traded in some market (Same asset traded in different markets would be represented by different order books)
- Matches incoming orders
- Stores unfulfilled limit orders in two order queues (`Asks` for sell orders and `Bids` for buy orders)
- Corrects limit order price with respect to tick size
- Imposes order processing fee
- Supports queries about order book structure
- Notifies listeners about trades and price changes

Order book for a remote trader

- Models a trader connected to a market by a communication channel with non-negligible latency
- Introduces delay in information propagation from a trader to an order book and vice versa (so a trader has outdated information about market and orders are sent to the market with a certain delay)
- Assures correct order of messages: older messages always come earlier than newer ones

Basic orders

Orders supported internally by an order book:

- `Market(side, volume)`
- `Limit(side, price, volume)`
- `Cancel(limitOrder)`

Limit and market orders notifies their listeners about all trades they take part in. Factory functions are usually used in order to create orders.

Meta orders

Follow order interface from trader's perspective (so they can be used instead of basic orders) but behave like a sequence of base orders from an order book point of view.

- `Iceberg(volumeLimit, orderToSplit)` splits `orderToSplit` to pieces with volume less than `volumeLimit` and sends them one by one to an order book ensuring that only one order at time is processed there
- `AlwaysBest(volume, limitOrderFactory)` creates a limit-like order with given volume and the most attractive price, sends it to an order book and if the order book best price changes, cancels it and resends with a better price
- `WithExpiry(lifetime, limitOrderFactory)` sends a limit-like order and after `lifetime` cancels it
- `LimitMarket(limitOrderFactory)` is like `WithExpiry` but with `lifetime` equal to 0

Traders

Single asset traders

- send orders to order books
- bookkeep their position and balance
- run a number of trading strategies
- notify listeners about trades done and orders sent

Single asset traders operate on a single or multiple markets. Multiple asset traders are about to be added.

Generic strategy

Generic strategy that wakes up on events given by `eventGen`, chooses side of order to create using `sideFunc` and its volume by `volumeFunc`, creates an order via `orderFactory` and sends the order to the market using its trader

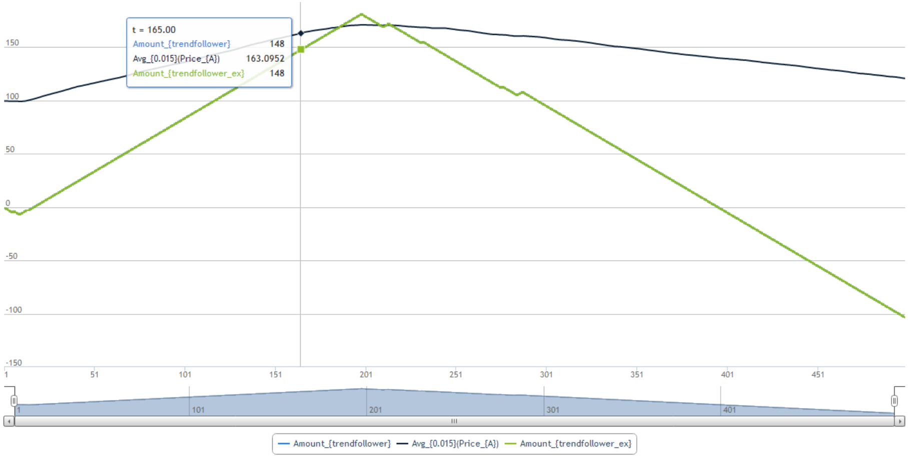
```
class Generic(Strategy):
    def __init__(self):
        event.subscribe(self.eventGen, self._wakeUp, self)

    def _wakeUp(self, _):
        if not self._suspended:
          # determine side and parameters of an order to create
          side = self.sideFunc()
          if side <> None:
            volume = int(self.volumeFunc())
            if volume > 0:
              # create order given side and parameters
              order = self.orderFactory(side)(volume)
              # send order to the order book
              self._trader.send(order)
```

Signal strategy

Signal strategy listens to some discrete signal and when the signal becomes more than some threshold it starts to buy. When the signal gets lower than -threshold the strategy starts to sell.

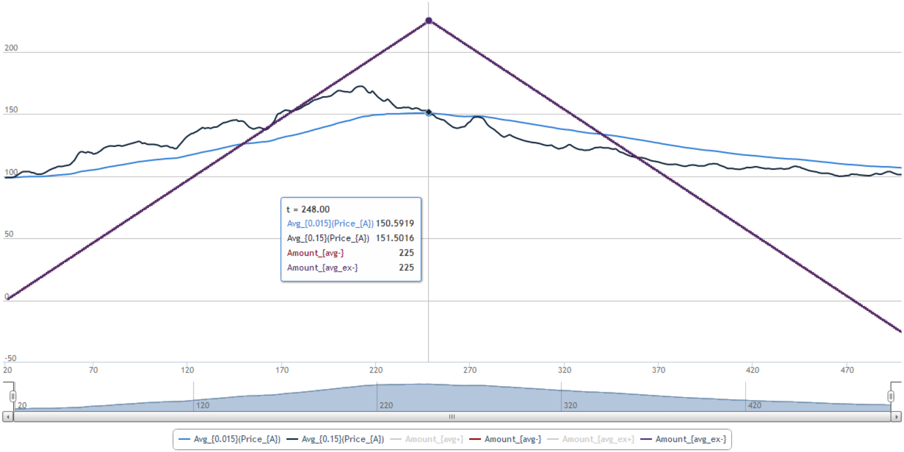
Trend follower strategy

Trend follower is an instance of a signal strategy with signal equal to the first derivative of a moving average of the asset's price (i.e trend).



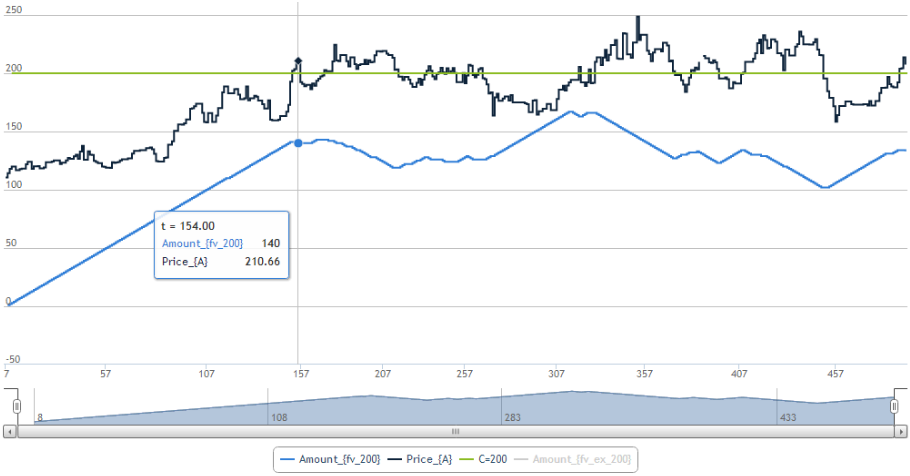
Two averages strategy

Two averages is an instance of a signal strategy with signal equal to the difference between two moving averages of the asset's price (i.e trend).



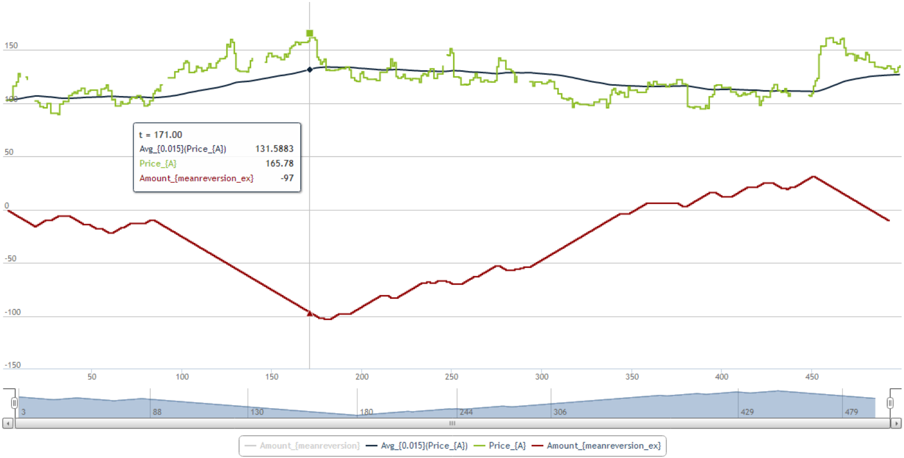
Fundamental value strategy

Fundamental value strategy is an instance of a signal strategy with signal equal to the difference between the asset's price and some fundamental value.



Mean reversion strategy

Mean reversion strategy is an instance of a fundamental value strategy with fundamental value equal to some moving average of the asset's price.



Dependency strategy is an instance of a fundamental value strategy with fundamental value equal to another asset's price multiplied by given factor.

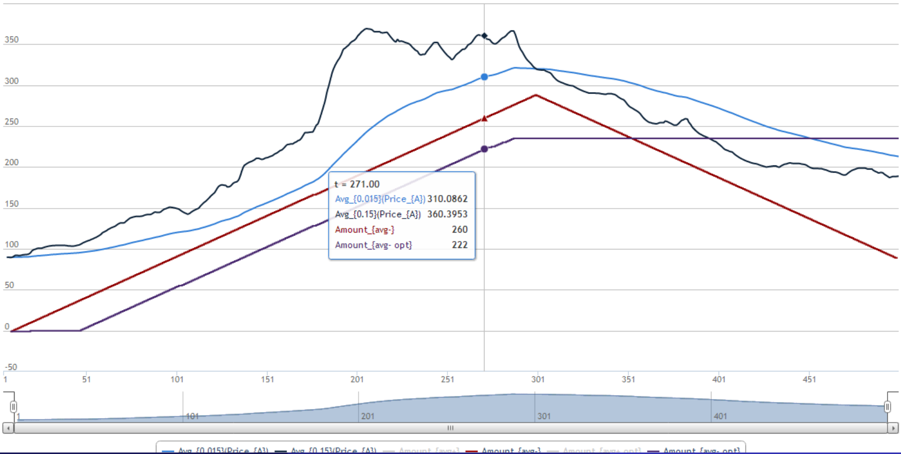
Liquidity provider

Liquidity provider sends limit-like orders with a price equal to the current asset's price multiplied by some randomly chosen factor

```
@registry.expose(["Generic", 'LiquidityProviderSide'], args = ())
def LiquidityProviderSideEx(side                      = Side.Sell,
                            orderFactory              = order.LimitFactory,
                            defaultValue              = 100.,
                            creationIntervalDistr     = mathutils.rnd.expovariate(1.),
                            priceDistr                = mathutils.rnd.lognormvariate(0., .1),
                            volumeDistr               = mathutils.rnd.expovariate(1.)):

    orderBook = orderbook.OfTrader()
    r = Generic(eventGen     = scheduler.Timer(creationIntervalDistr),
                volumeFunc   = volumeDistr,
                sideFunc     = ConstantSide(side),
                orderFactory= order.AdaptLimit(orderFactory,
                                               mathutils.product(
                                                  SafeSidePrice(orderBook, side, defaultValue),
                                                  priceDistr)))

    return r
```

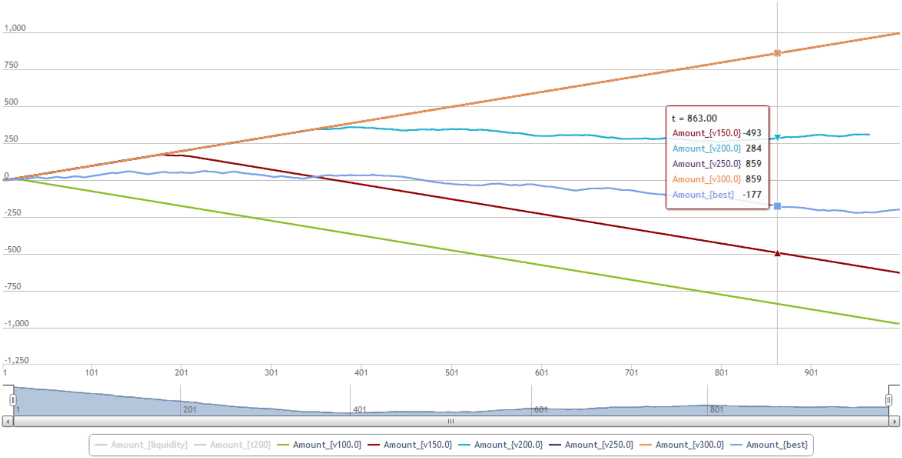
Trade-if-profitable strategy

Suspends or resumes an underlying strategy basing on its performance backtesting. By default, first derivative of a moving average of 'cleared' trader's balance (trader's balance if its position was cleared) is used to evaluate the efficiency.



Choose-the-best strategy

Backtests aggregated strategies and allows to run only to that one who has the best performance. By default, first derivative of a moving average of 'cleared' trader's balance is used to evaluate the efficiency.



Observable

Traders and order books provide basic accessors to their current state but don't collect any statistics. In order to do it in an interoperable way a notion of observable value was introduced: it allows to read its current value and notifies listeners about its change.

- Primitive observables on
    - traders: position, balance, market value of the portfolio, 'cleared' balance etc.
    - order books: ask/mid/bid price, last trade price, price at volume, volume of orders with price better than given one etc.
- `OnEveryDt(dt, dataSource)` evaluates `dataSource` every `dt` moments of time. Often used with `Fold(observable, accumulator)` where `accumulator` may be a moving average or another statistics collector.

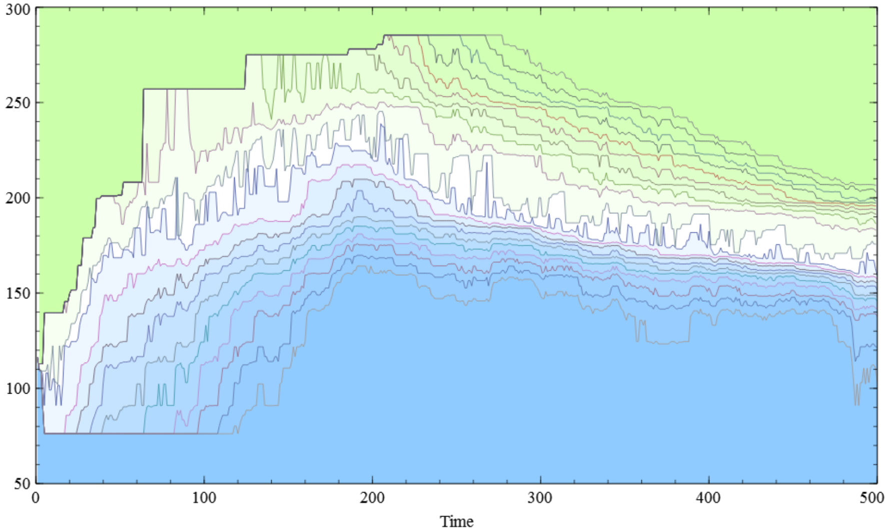
History of an observable can be stored in a `TimeSerie` and rendered later on a graph.

Using Veusz

When developing a new strategy it is reasonable to test it using scripts and visualize results by Veusz

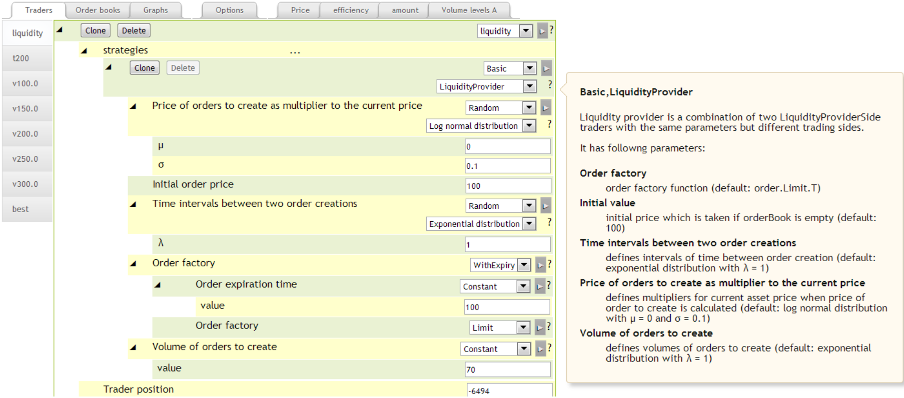
```python
from marketsim import (signal, strategy, observable, mathutils)
from common import run

def Signal(ctx):

    const = mathutils.constant
    linear_signal = signal.RandomWalk(initialValue=20,
                                      deltaDistr=const(-.1),
                                      label="20-0.1t")

    return [
        ctx.makeTrader_A(strategy.LiquidityProvider(volumeDistr=const(4)), "liquidity"),

        ctx.makeTrader_A(strategy.Signal(linear_signal), "signal",
                         [(linear_signal, ctx.amount_graph)]),

        ctx.makeTrader_A(strategy.SignalEx(linear_signal), "signal_ex")
    ]

if __name__ == '__main__':
    run("signal_trader", Signal)
```

Rendering graphs by Veusz



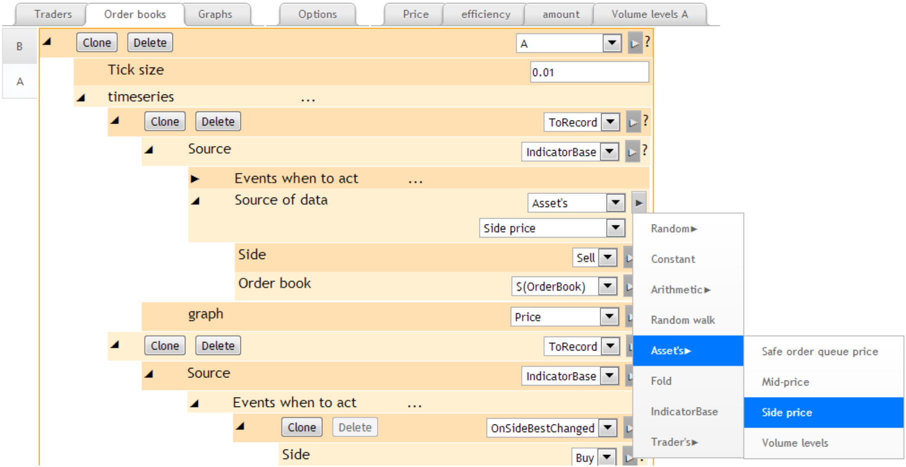
Web interface

Web interface allows to compose a market to simulate from existing objects and set up their parameters

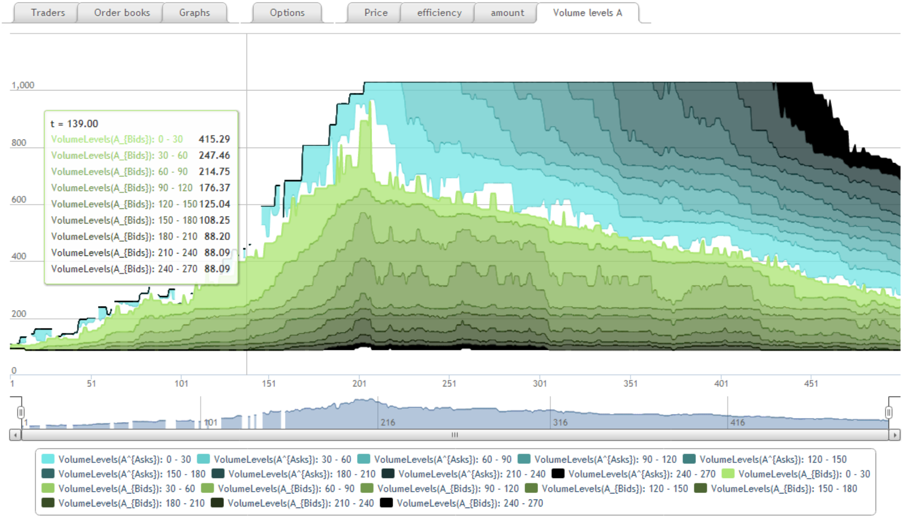


Time series

Timeseries field of a trader or an order book instructs what data should be collected and rendered on graphs

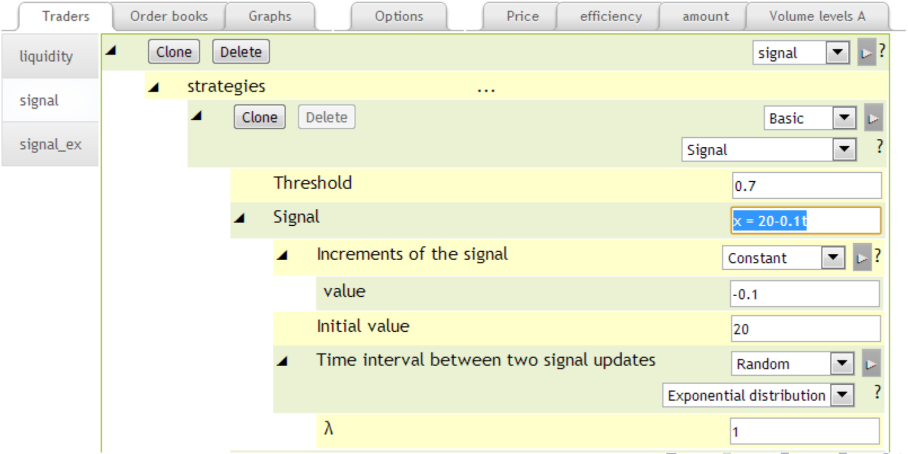


Rendering results



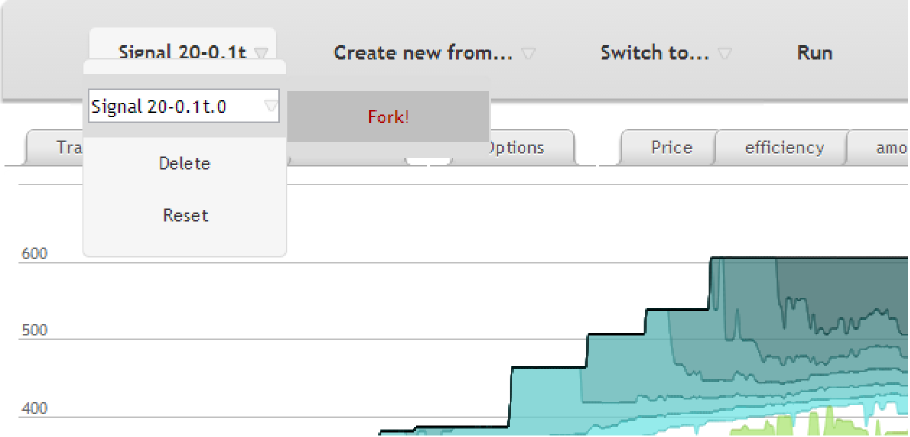
Node aliases

Object tree nodes can be assigned aliases that can be used later to refer to the sub-tree (explicit by-value or by-reference cloning semantics is to be implemented)



Workspaces

Every user (identified by browser cookies) may switch between multiple workspaces. Workspaces can be forked, removed or created from a set of predefined ones.



Exposing Python classes to Web-interface

- displayable label for the class ('Random Walk')
- docstring in rst format
- property names and static constraints on types of their values

```
@registry.expose(['Random walk'])
class RandomWalk(types.IObservable):
    """ A discrete signal with user-defined increments.

        Parameters:

        **initialValue**
            initial value of the signal (default: 0)

        **deltaDistr**
            increment function (default: normal distribution with |mu| = 0, |sigma| = 1)

        **intervalDistr**
            defines intervals between signal updates
            (default: exponential distribution with |lambda| = 1)
    """
    _properties = { 'initialValue' : float,
                    'deltaDistr'   : meta.function((), float),
                    'intervalDistr': meta.function((), float) }
```

Type system

- Primitive types: int, float, string
- Numeric constraints: `less_than(2*math.pi, non_negative)`
- User-defined classes. If a property constraint is type B then any object of type D can be used as its value provided that D derives from B.
- Array types: `meta.listOf(types.IStrategy)`
- Functional types: `meta.function((Side, Price, Volume), IOrder)`

Possible improvements:

- `meta.function((a1, ..., aN), rettype)` could be used where `meta.function((a1, ..., aN, b1, ..., bM), rettype)` is expected
- `meta.function((..., B, ...), rettype)` could be used where `meta.function((..., D, ...), rettype)` is expected if D casts to B
- `meta.function(args, D)` could be used where `meta.function(args, B)` is expected if D casts to B

Future developments

C++ version:

1. Implement core functionality (scheduler, order books, basic orders and traders) in C++ (already done) and provide extension points to allow to a user create strategies and meta orders in Python (or use existing ones)
2. Given object tree describing a simulation model, generate on the fly C++ code as instantiations of template classes corresponding to classes in Python version

C++ version

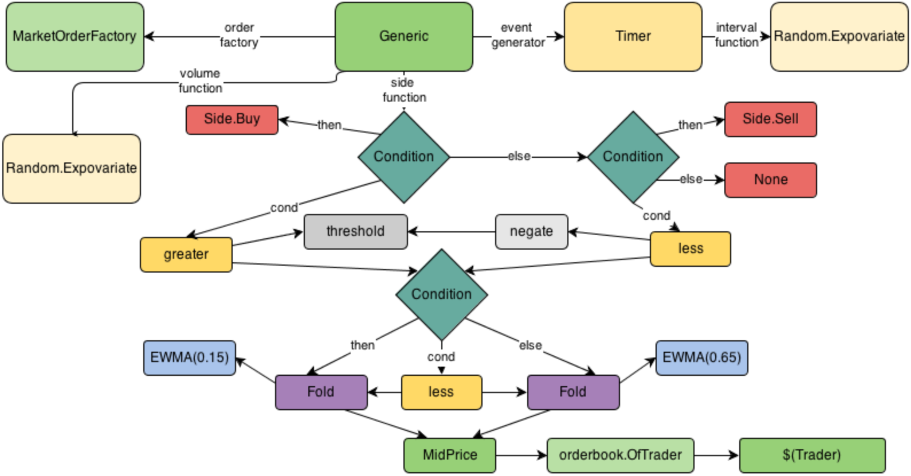
Flexible as Python version and has performance comparable to a C hand-written version. The main problem: simulation configuring is not intuitive, so let's do the configuration automatically by a code generator.

```
template <class Base>
    struct GenericStrategy : Base
    {   using Base::self; // 'this' casted to the most derived class

        GenericStrategy() {
            self().eventGen().subscribe(boost::bind(&GenericStrategy::wakeUp, this));
        }

        void wakeUp() {
            if (boost::optional<Side> side = self().sideFunc()) {
                volume_t volume = self().volumeFunc();
                if (volume > 0) {
                    auto order = self().orderFactory()(*side, volume);
                    self().trader().send(order);
                }
            }
        }
    };
```

Python version/Web interface

- Automatic dependency tracking in Python code (observables/computed observables from KnockoutJs)
- Notion of variables in the Web interface to label common object graph subtrees
- Model graph representation in Web interface (???)

Model graph representation in Web interface



Simulation components (by Karol Podkanski)

- Strategies
  - **Relative strength index (RSI).** Buy/sell when stock is oversold/overbought according to the index
  - **Stop-loss strategy.** Applied to any strategy in order to limit losses if they reach a certain threshold
  - **Multi-armed bandit.** Evaluate an array of strategies and assign them scores based on their efficiency. A strategy is then chosen randomly, with a distribution based on the scores.
  - Other meta-strategies (???)
  - **Pairs trading.** A dependence between two assets is assumed (for example, correlation). A trade is initiated when a function of the two assets (for example: weighted average) deviates from it's mean value.
- Volume management
- Enter/exit time management (currently random or constant)

Simulation components (by Karol Podkanski)

- Observables (Indicators):
  - Volatility
  - Volume
  - Performance
  - Relative strength index
  - Technical analysis
    - Trendline: support and resistance
    - New High/Low
    - Channels
    - Double Top/Bottom
    - Head and Shoulders
- Add position constraints to traders:
  - traders have to allocate their limited resources
  - certain assets cannot be shorted

Thank you!