

YUIMA: An R Framework for Simulation and Inference for Stochastic Processes

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Overview of the `yuima`
package

What contains a `yuima`
object ?

What is possible to do
with a `yuima` object in
hands?

How does it work?

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The Yuima Project Team

Overview of the yuima package

What contains a yuima object ?

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How does it work?



N. Yoshida (Tokyo Univ., JP)
M. Uchida (Osaka Univ., JP)
S.M. Iacus (Milan Univ., IT)
H. Masuda (Kyushu Univ., JP)
A. Brouste (Univ. Le Mans, FR)
M. Fukasawa (Osaka Univ. JP)
H. Hino (Waseda Univ., Tokyo, JP)
K. Kengo (Tokyo Univ., JP)
Y. Shimitzu (Osaka Univ., JP)
L. Mercuri (Milan Univ., IT)
... And many others.

The yuima package is developed by academics working in mathematical statistics and finance, who actively publish results in the field, have some knowledge of R, and have the feeling on “what’s next” in the field.

Aims at filling the gap between theory and practice!

The `yuima` package goal: fill the gap between theory and practice

The Yuima Project aims at implementing, via the `yuima` package, a very abstract framework to describe probabilistic and statistical properties of stochastic processes in a way which is the closest as possible to their mathematical counterparts but also computationally efficient.

The main classes of stochastic processes, all multidimensional and eventually parametric models, are:

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- Compound Poisson process

$$M_t = m_0 + \sum_{i=1}^{N_t} Y_{\tau_i}, \quad N_t \sim \text{Poisson}(\Lambda(t, \theta)), \quad Y_{\tau_i} \text{ i.i.d. } \sim \mathcal{L}(\theta)$$

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- Diffusions with jumps or pure Lévy processes

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

where Z_t is a Lévy process.

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- Compound Poisson process

$$M_t = m_0 + \sum_{i=1}^{N_t} Y_{\tau_i}, \quad N_t \sim \text{Poisson}(\Lambda(t, \theta)), \quad Y_{\tau_i} \text{ i.i.d. } \sim \mathcal{L}(\theta)$$

- Diffusions with jumps or pure Lévy processes

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

where Z_t is a Lévy process.

- CARMA(p, q) & COGARCH(p, q) models driven by Lévy noise
- Point Processes (including Hawkes processes)

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What contains a `yuima` object ?

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The main object is the `yuima` object which allows to describe the model in a mathematically sound way.

An object of type `yuima` contains the following slots:

- `data`: an object of class `yuima.data` that stores real or simulated data.
- `model`: an object of class `yuima.model` that is a mathematical description of the model.
- `sampling`: an object of class `yuima.sampling` that is the sampling structure.
- `characteristic`: additional informations about model such as number of equations and time-scale.
- `functional`: This slot is filled if we want to compute the functional of stochastic process.

The package exposes very few generic functions like `simulate`, `qml`, `plot`, etc. and some other model constructor functions, such as, `setModel`, `setCarma`, `setCogarch`, `setPpr`, `setPoisson`, `setFunctional`, `setMap`, `setIntegral`, `setLaw` and other special functions for specific inference tasks.

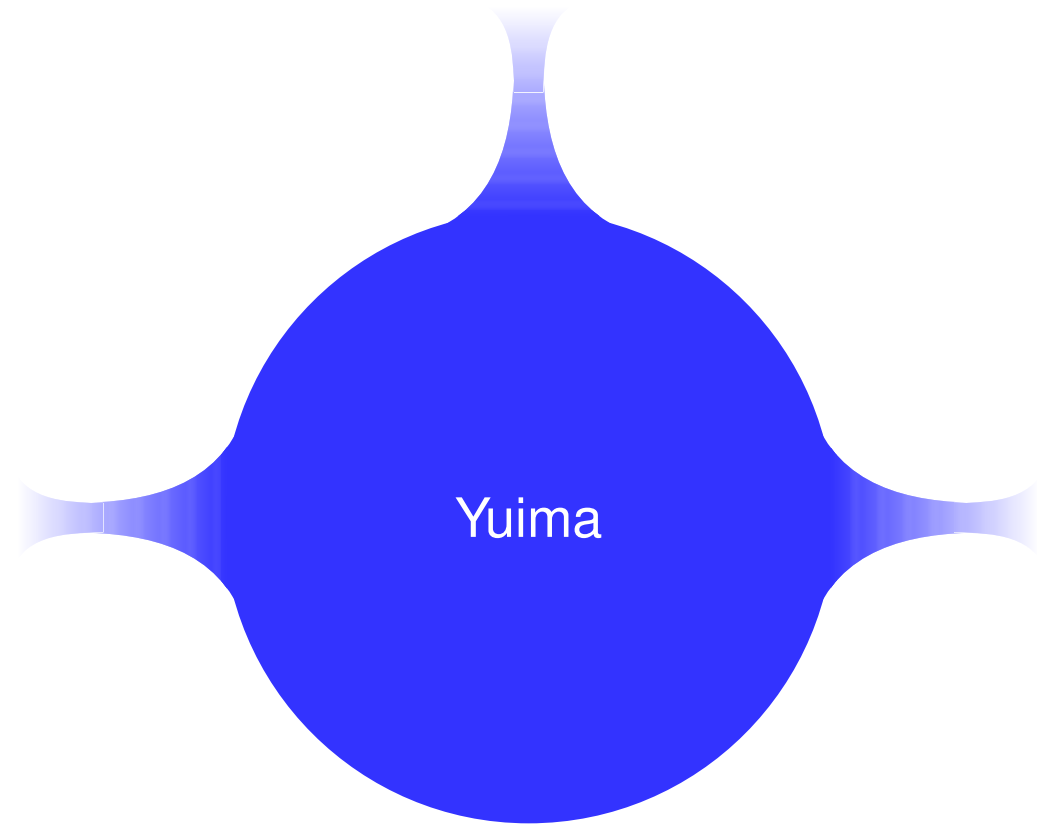
Overview of the `yuima`
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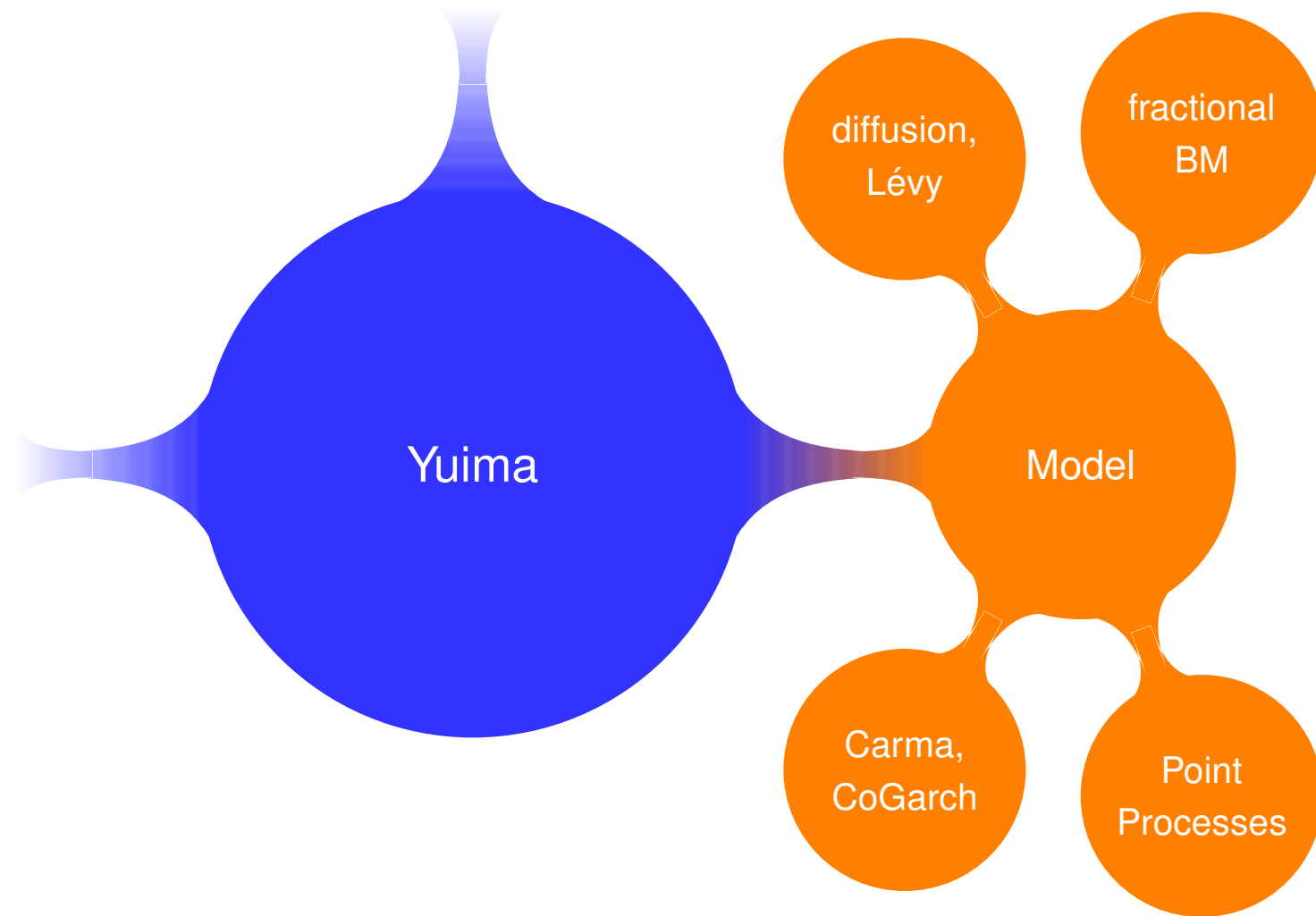
What contains a `yuima`
object ?

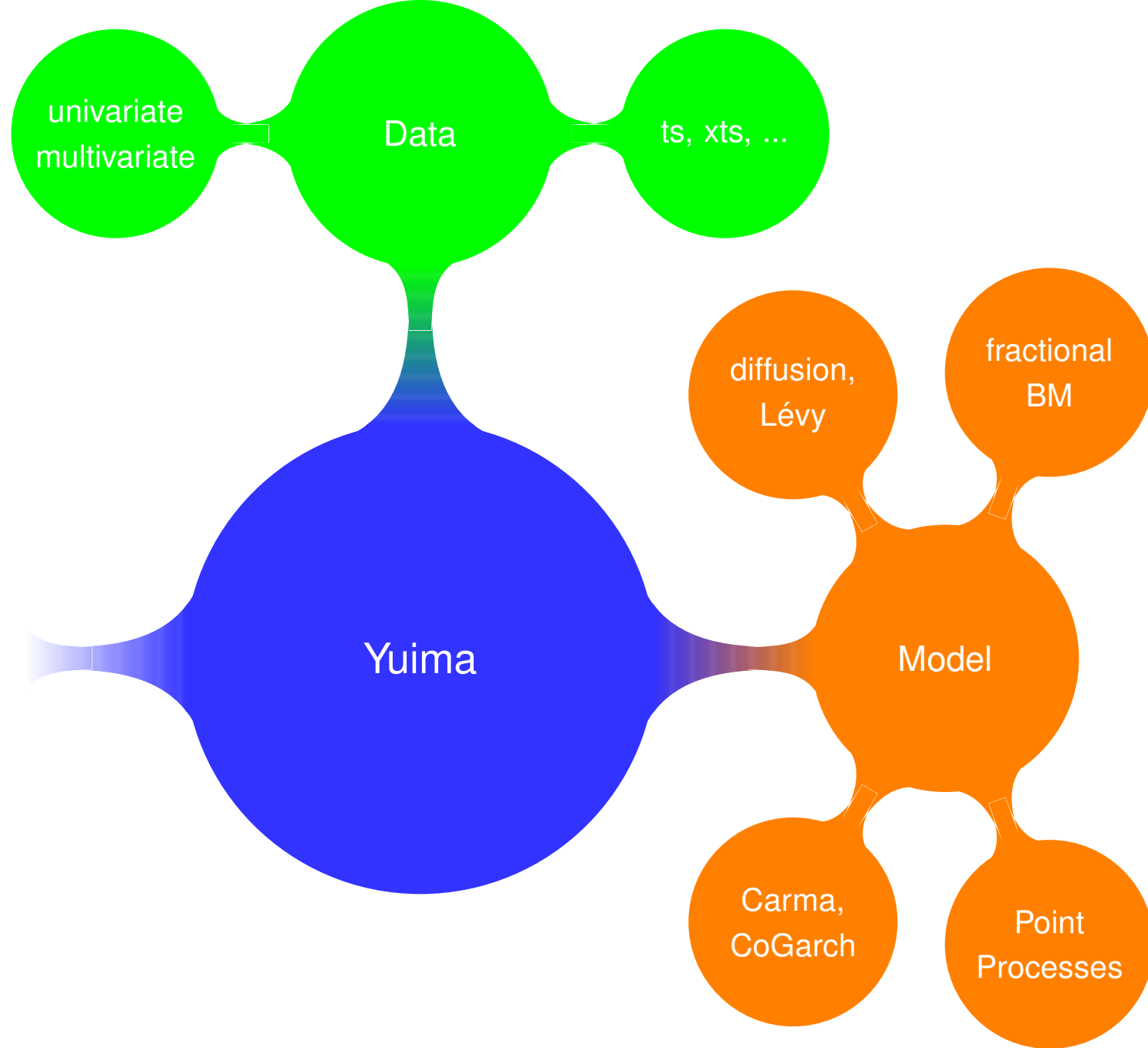
What is possible to do
with a `yuima` object in
hands?

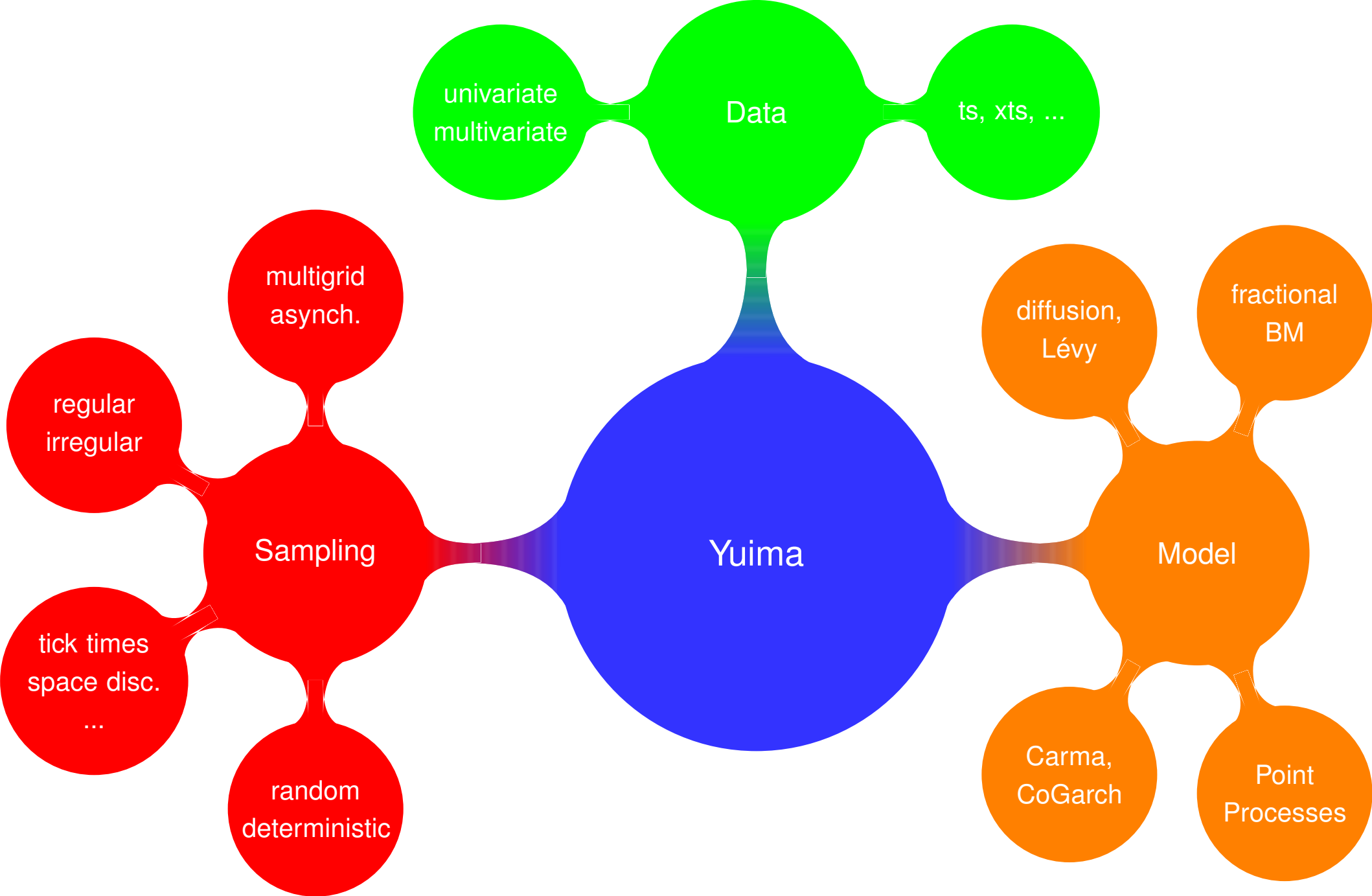
How does it work?

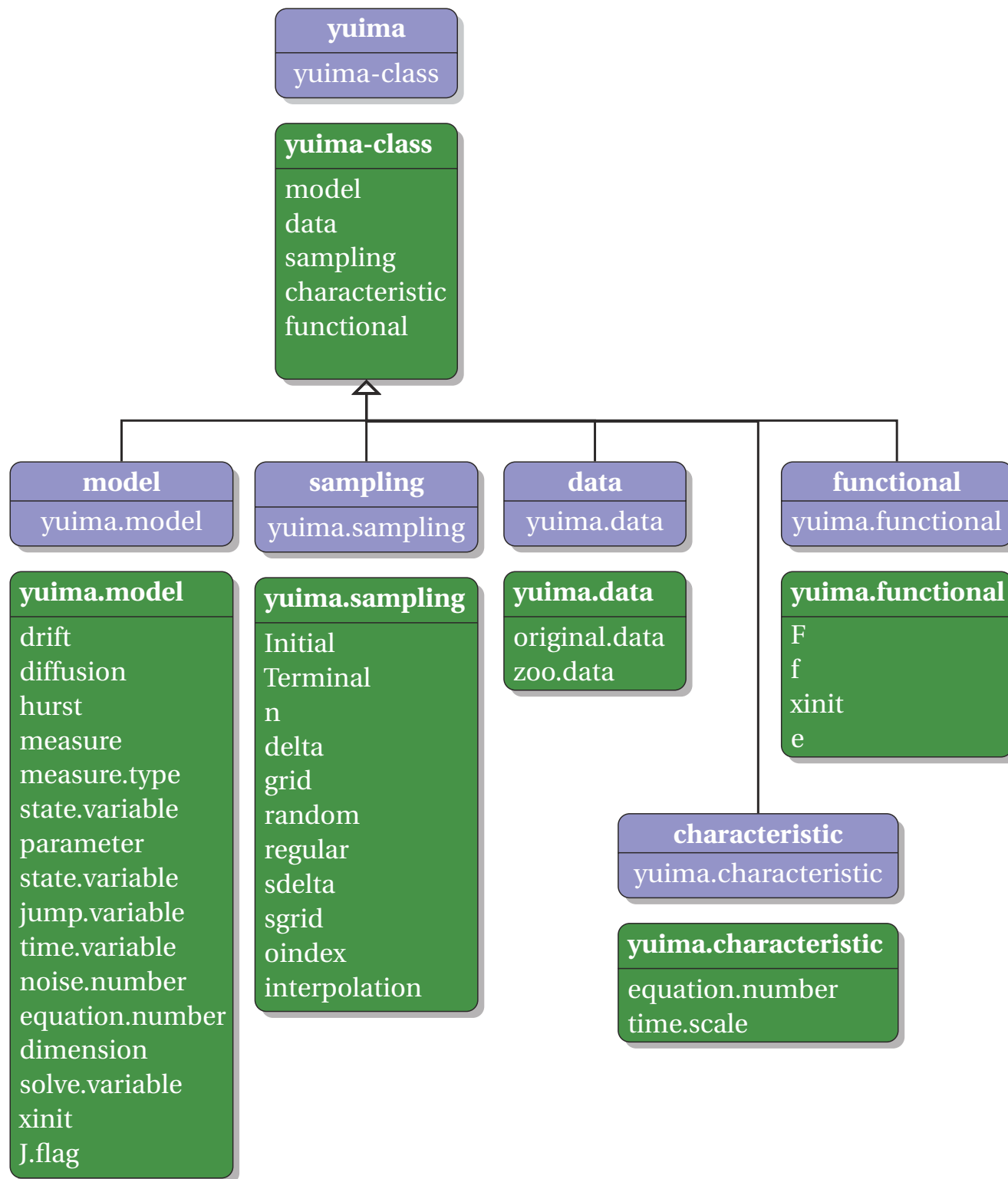
What contains a `yuima` object ?











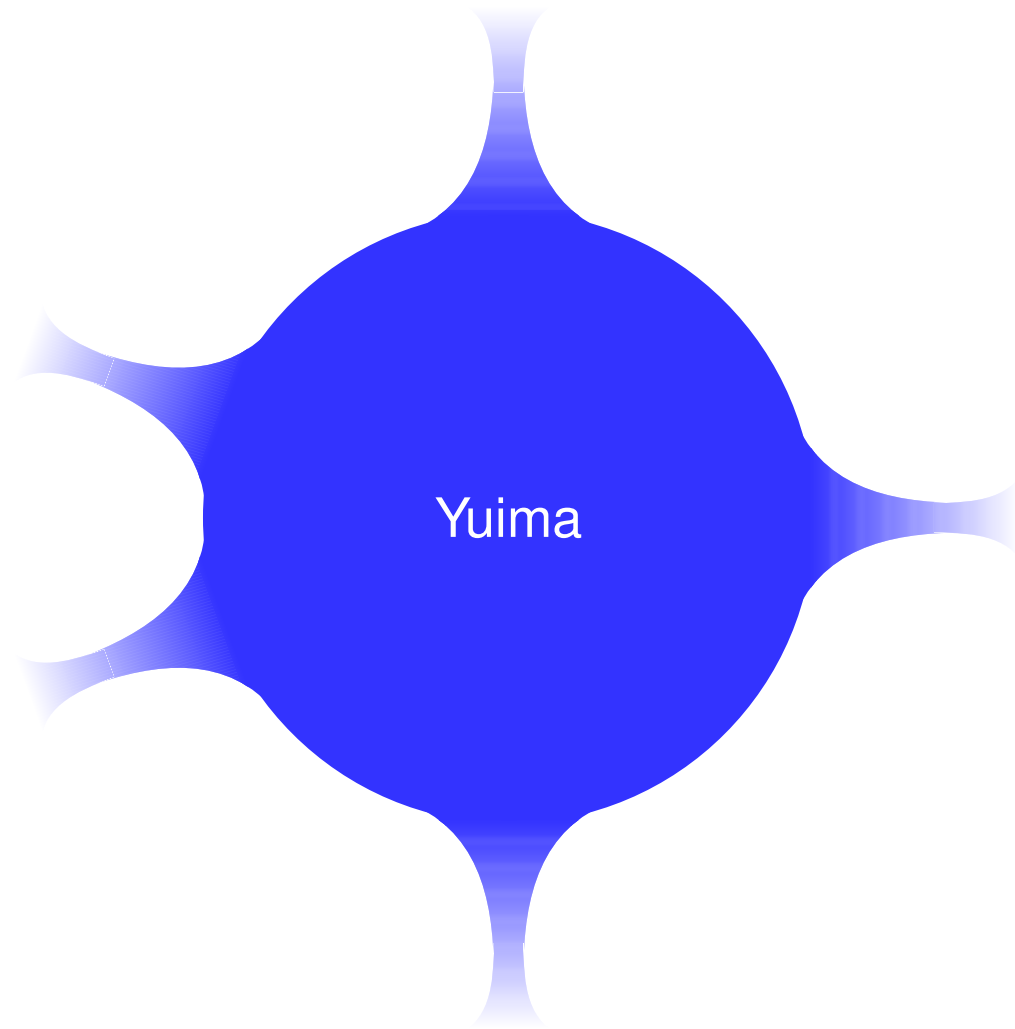
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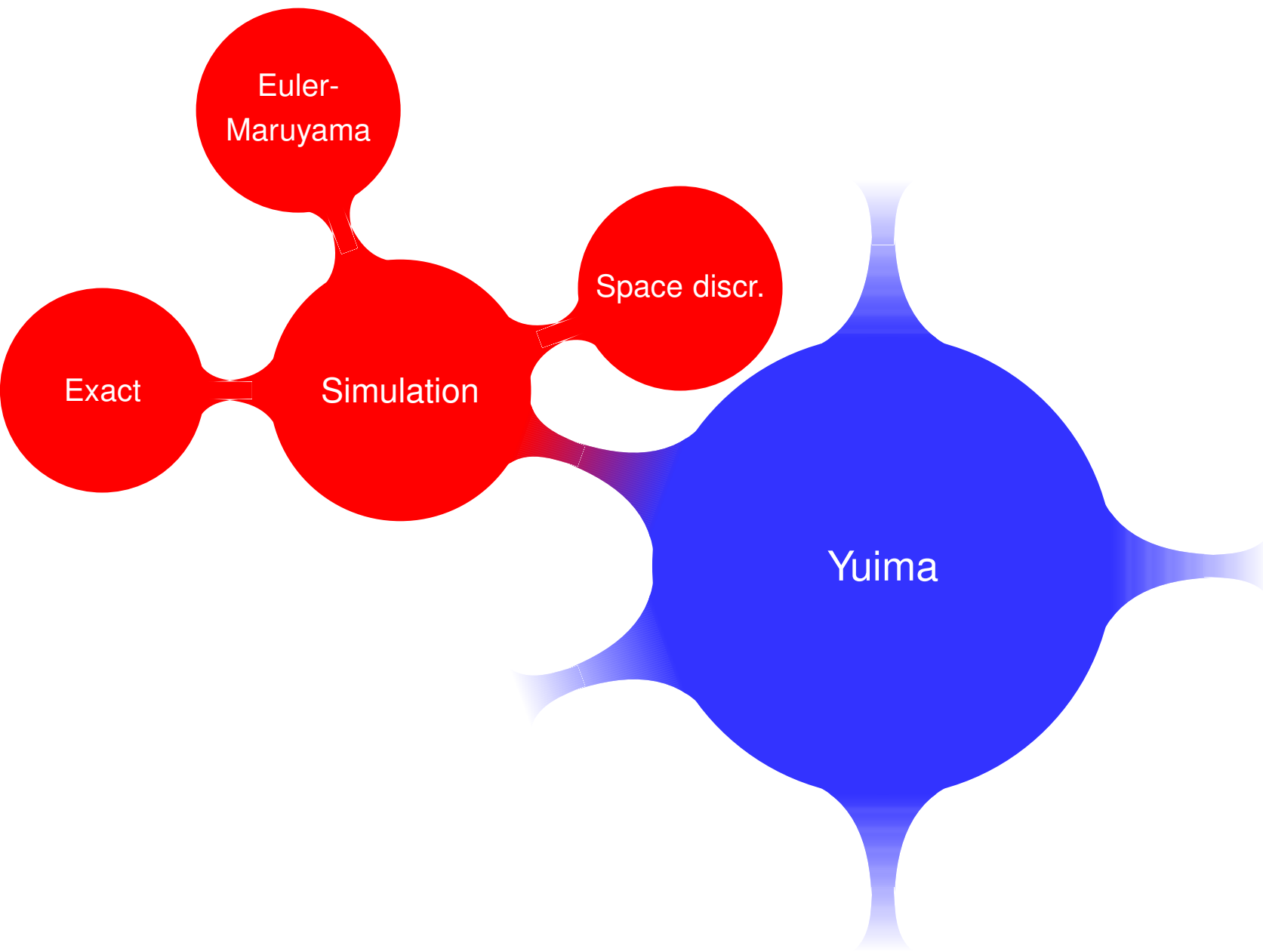
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Yuima



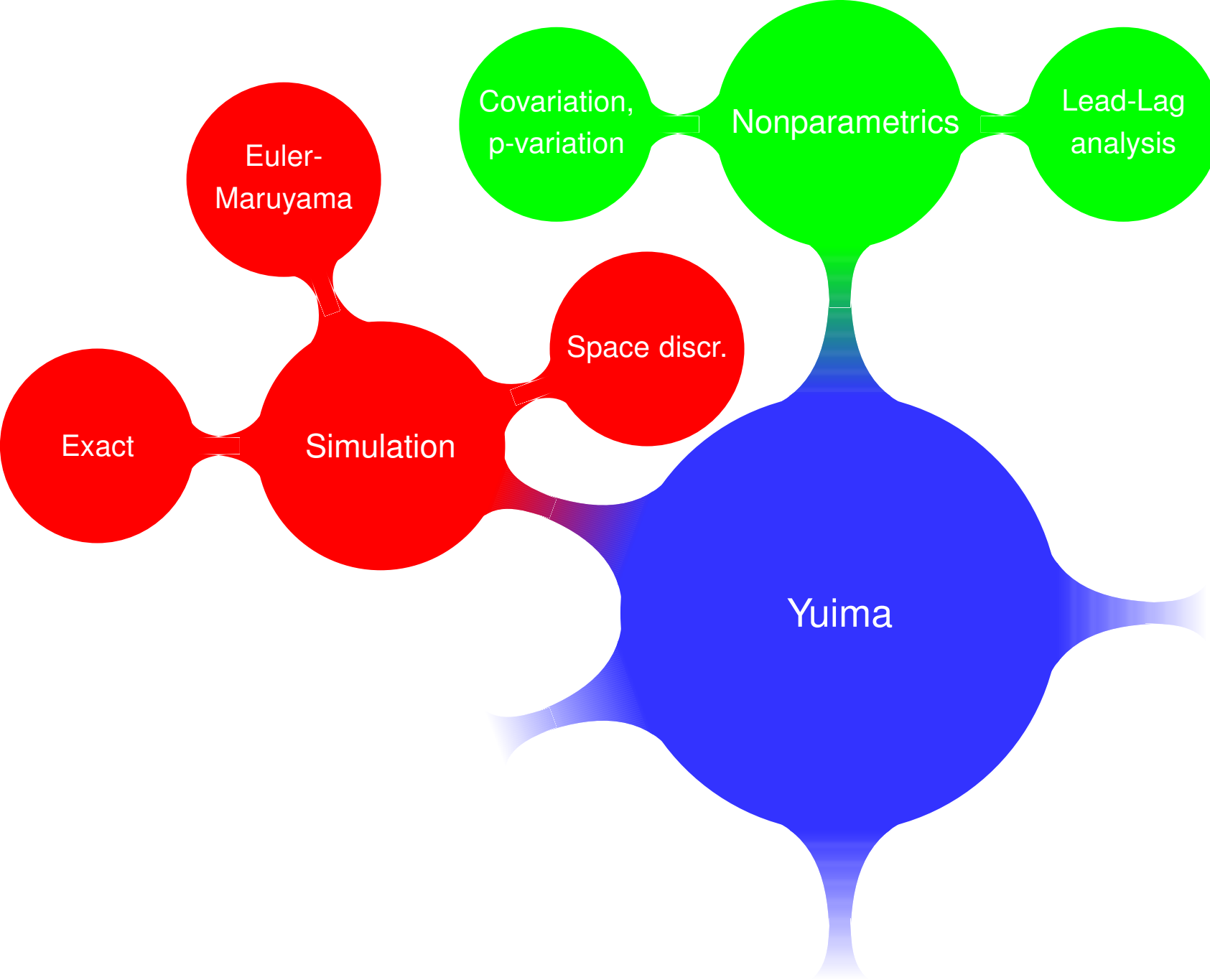
Euler-
Maruyama

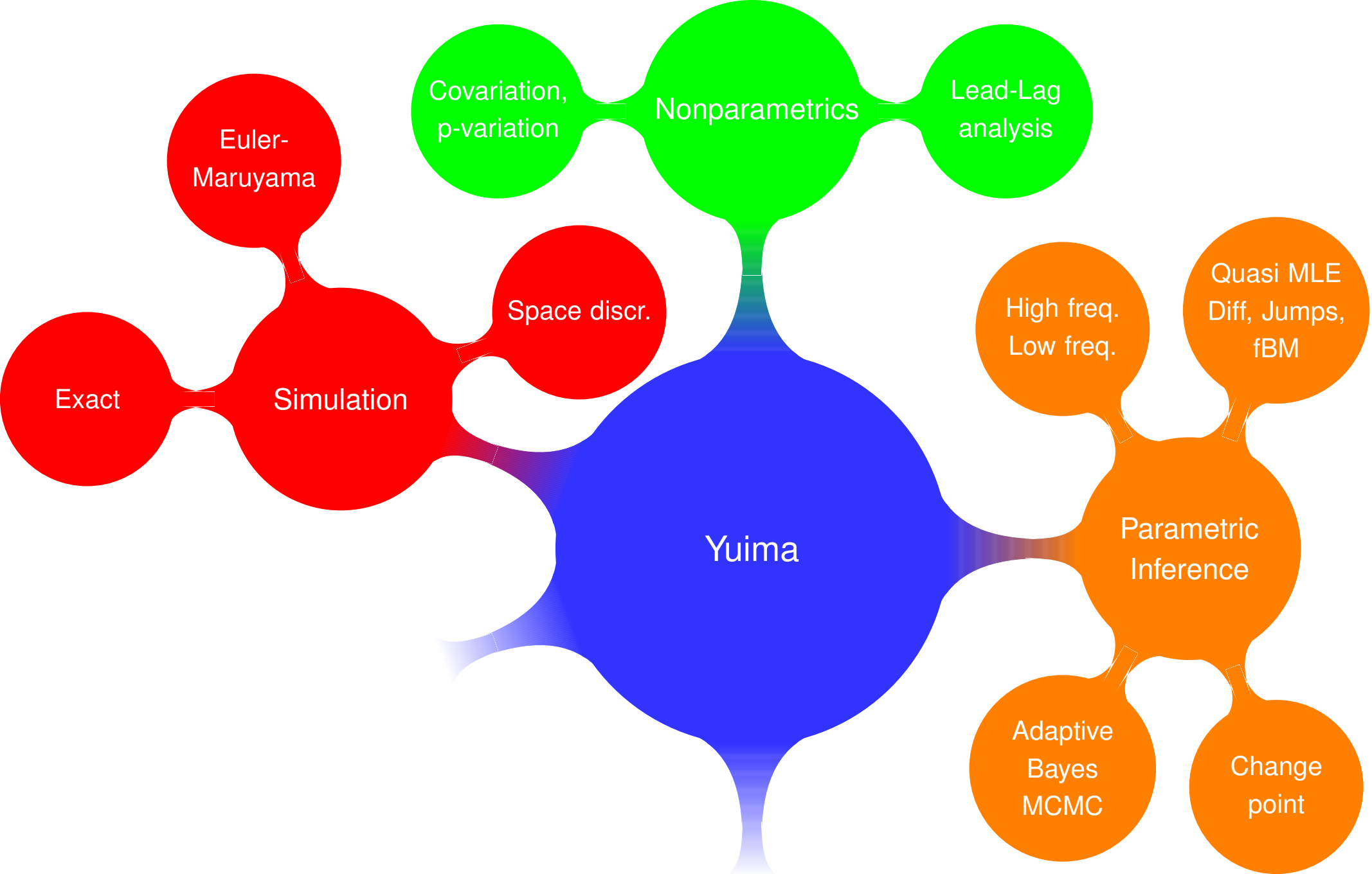
Exact

Simulation

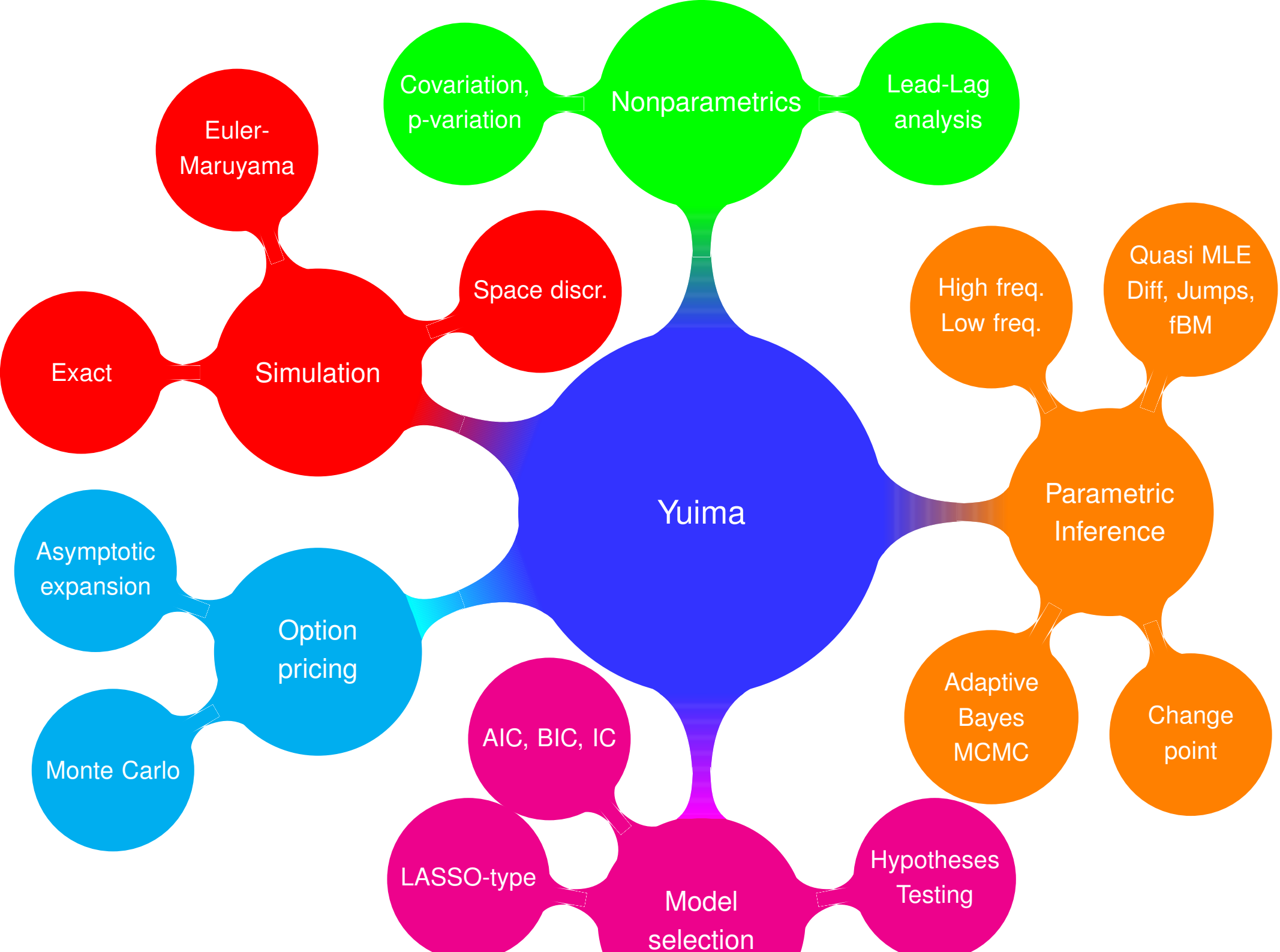
Space discr.

Yuima









Which tools have been developed so far?

- Quasi-MLE for multidimensional diffusions (Yoshida, 1992, 2005).
- Quasi-MLE for SDE with jumps of Poisson type (Shimizu & Yoshida, 2006)
- MLE for inhomogeneous Compound Poisson processes (Kutoyants, 1998)
- Adaptive Bayes type estimators for diffusion processes (Yoshida, 2005)
- Change point estimation for the volatility in a multidimensional Itô process (Iacus & Yoshida, 2009)
- Asymptotic expansion of functional of diffusion processes (Yoshida, 2005)
- Simple AIC and LASSO-type model selection (De Gregorio & Iacus, 2010)
- Hypotheses testing (De Gregorio & Iacus, 2012)
- Asynchronous covariance estimator of Yoshida-Hayashi (2005) for multidimensional Itô processes
- Estimation for the fractional OU process (Brouste & Iacus, 2013)
- Lead-Lag estimation (Hoffman, Rosenbaum & Yoshida, 2013)
- Quasi-MLE for CARMA(p,q) models with Lévy innovations (Iacus & Mercuri, 2014)
- GMM and Quasi-MLE for COGARCH(p,q) models with Lévy innovations (Iacus, Mercuri & Rroji, 2016, 2018)
- Estimation for general Point Processes (Mercuri & Yoshida, 2016), Hawkes processes with applications to LBO (Limit Book Order)
- a dedicated GUI to exploit graphically some of the above functionalities

Just not to be too vague, let us consider the exact formulations of some of the problems which can be handled by the `yuima` package.

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YUIMA Law
Compound Poisson
Process
Inference
Inference

How does it work?

$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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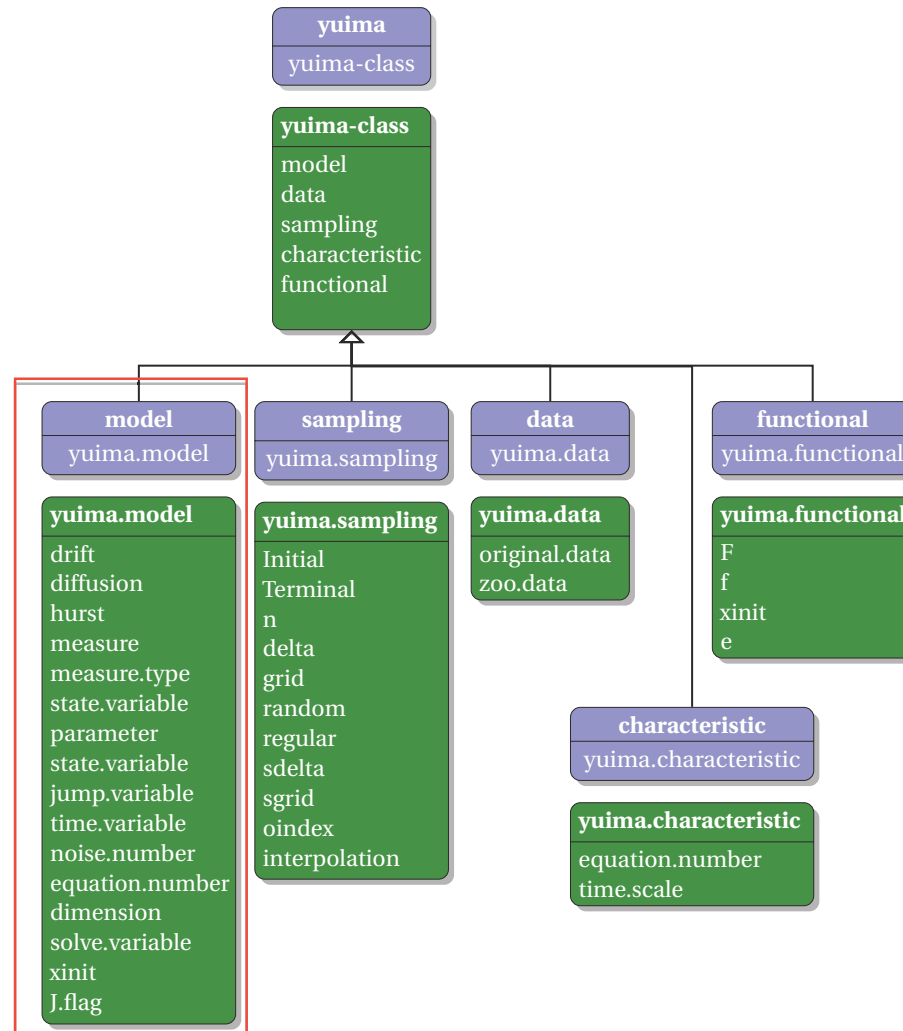
Inference

Inference

```
> mod1 <- setModel(drift = "-3*x", diffusion = "1/(1+x^2)")
```

$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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> mod1 <- setModel(drift = "-3*x", diffusion = "1/(1+x^2)")
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```
> mod1 <- setModel(drift = "-3*x", diffusion = "1/(1+x^2)")
```

```
> str(mod1)
Formal class 'yuima.model' [package "yuima"] with 16 slots
 ..@ drift      : expression((-3 * x))
 ..@ diffusion  : List of 1
 .. ..$ : expression(1/(1 + x^2))
 ..@ hurst      : num 0.5
 ..@ jump.coeff : expression()
 ..@ measure    : list()
 ..@ measure.type : chr(0)
 ..@ parameter  : Formal class 'model.parameter' [package "yuima"] with 6 slots
 .. .. ..@ all      : chr(0)
 .. .. ..@ common   : chr(0)
 .. .. ..@ diffusion: chr(0)
 .. .. ..@ drift    : chr(0)
 .. .. ..@ jump     : chr(0)
 .. .. ..@ measure  : chr(0)
 ..@ state.variable : chr "x"
 ..@ jump.variable  : chr(0)
 ..@ time.variable  : chr "t"
 ..@ noise.number   : num 1
 ..@ equation.number: int 1
 ..@ dimension      : int [1:6] 0 0 0 0 0 0
 ..@ solve.variable : chr "x"
 ..@ xinit          : num 0
 ..@ J.flag         : logi FALSE
```

$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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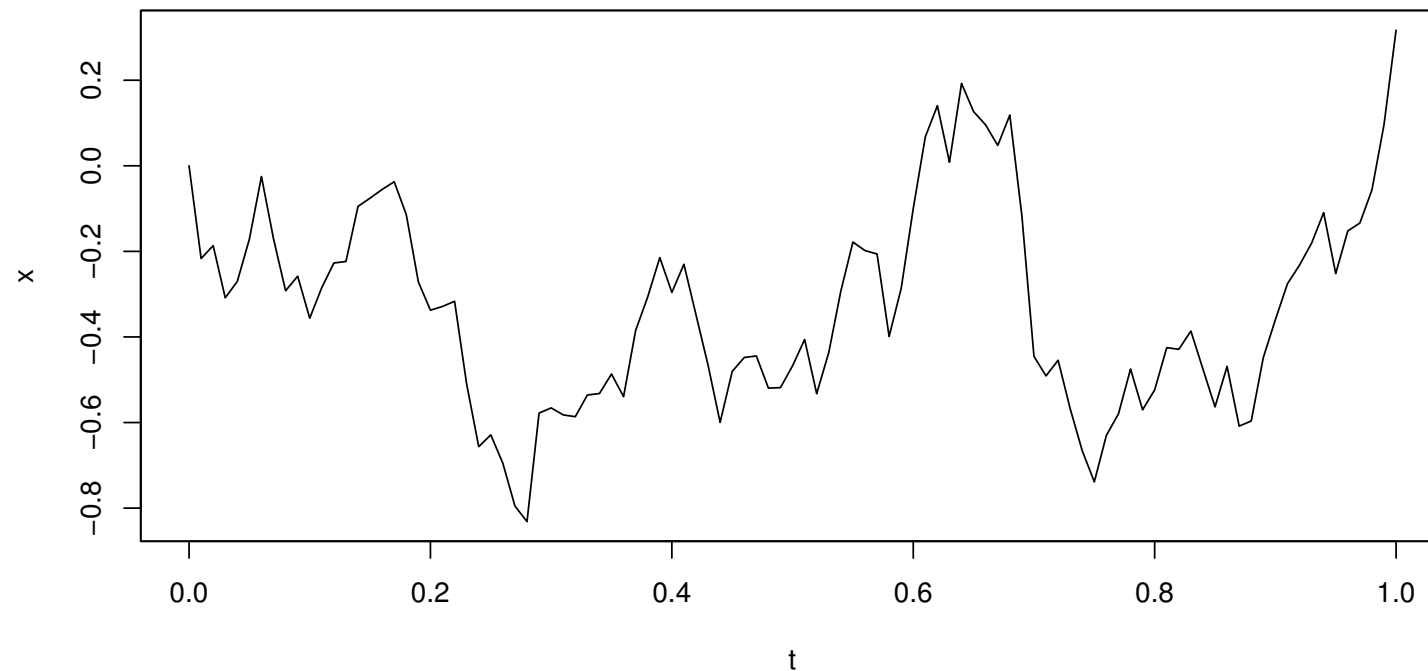
Compound Poisson Process

Inference

Inference

And we can easily simulate and plot the model like

```
> mod1 <- setModel(drift = "-3*x", diffusion = "1/(1+x^2)")
> set.seed(123)
> X <- simulate(mod1)
> plot(X)
```



$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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YUIMA Law

Compound Poisson
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Inference

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The `simulate` function fills the slots `data` and `sampling`

```
> str(X)
```

$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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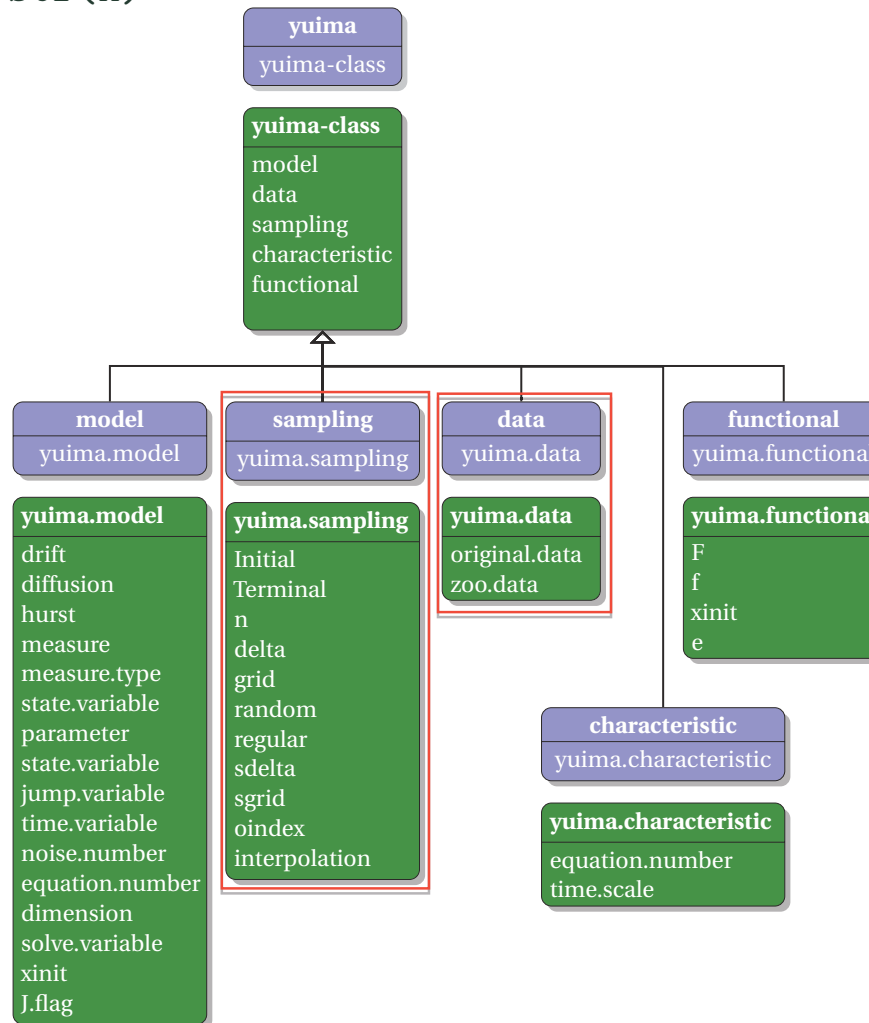
Compound Poisson Process

Inference

Inference

The `simulate` function fills the slots `data` and `sampling`

> `str(X)`



$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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YUIMA Law

Compound Poisson Process

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The `simulate` function fills the slots `data` and `sampling`

```
> str(X)
```

```
Formal class 'yuima' [package "yuima"] with 5 slots
 ..@ data      :Formal class 'yuima.data' [package "yuima"] with 2 slots
 .. .. ..@ original.data: ts [1:101, 1] 0 -0.217 -0.186 -0.308 -0.27 ...
 .. .. ..- attr(*, "dimnames")=List of 2
 .. .. .. .. ..$ : NULL
 .. .. .. .. ..$ : chr "Series 1"
 .. .. .. ..- attr(*, "tsp")= num [1:3] 0 1 100
 .. .. ..@ zoo.data      :List of 1
 .. .. .. ..$ Series 1:'zooreg' series from 0 to 1
 ..@ model        :Formal class 'yuima.model' [package "yuima"] with 16 slots

(...) output dropped

 ..@ sampling     :Formal class 'yuima.sampling' [package "yuima"] with 11 slots
 .. .. ..@ Initial      : num 0
 .. .. ..@ Terminal     : num 1
 .. .. ..@ n            : num 100
 .. .. ..@ delta        : num 0.1
 .. .. ..@ grid         : num(0)
 .. .. ..@ random       : logi FALSE
 .. .. ..@ regular      : logi TRUE
 .. .. ..@ sdelta       : num(0)
 .. .. ..@ sgrid        : num(0)
 .. .. ..@ oindex       : num(0)
 .. .. ..@ interpolation: chr "none"
```

$$dX_t = -3X_t dt + \frac{1}{1+X_t^2} dW_t$$

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YUIMA Law

Compound Poisson Process

Inference

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The `simulate` function fills the slots `data` and `sampling`

```
> X
```

```
Diffusion process
```

```
Number of equations: 1
```

```
Number of Wiener noises: 1
```

```
Number of original time series: 1
```

```
length = 101, time range [0 ; 1]
```

```
Number of zoo time series: 1
```

```
          length time.min time.max delta
Series 1    101         0         1 0.01
```

Parametric model: $dX_t = -\theta X_t dt + \frac{1}{1+X_t^\gamma} dW_t$

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Compound Poisson Process

Inference

Inference

```
> mod2 <- setModel(drift = "-theta*x", diffusion = "1/(1+x^gamma)")
```

Automatic extraction of the **parameters** for further inference

```
> str(mod2)
Formal class 'yuima.model' [package "yuima"] with 16 slots
 ..@ drift      : expression((-theta * x))
 ..@ diffusion   :List of 1
 .. ..$ : expression(1/(1 + x^gamma))
 ..@ hurst      : num 0.5
 ..@ jump.coeff  : expression()
 ..@ measure    : list()
 ..@ measure.type : chr(0)
 ..@ parameter  :Formal class 'model.parameter' [package "yuima"] with 6 slots
 .. .. ..@ all   : chr [1:2] "theta" "gamma"
 .. .. ..@ common : chr(0)
 .. .. ..@ diffusion: chr "gamma"
 .. .. ..@ drift  : chr "theta"
 .. .. ..@ jump   : chr(0)
 .. .. ..@ measure : chr(0)
 ..@ state.variable : chr "x"
 ..@ jump.variable  : chr(0)
 ..@ time.variable  : chr "t"
 ..@ noise.number   : num 1
 ..@ equation.number: int 1
 ..@ dimension      : int [1:6] 2 0 1 1 0 0
 ..@ solve.variable : chr "x"
 ..@ xinit          : num 0
 ..@ J.flag         : logi FALSE
```

Parametric model: $dX_t = -\theta X_t dt + \frac{1}{1+X_t^\gamma} dW_t$

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YUIMA Law

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Inference

> mod2

Automatic extraction of the **parameters** for further inference

Diffusion process

Number of equations: 1

Number of Wiener noises: 1

Parametric model with 2 parameters

Parametric model: $dX_t = -\theta X_t dt + \frac{1}{1+X_t^\gamma} dW_t$

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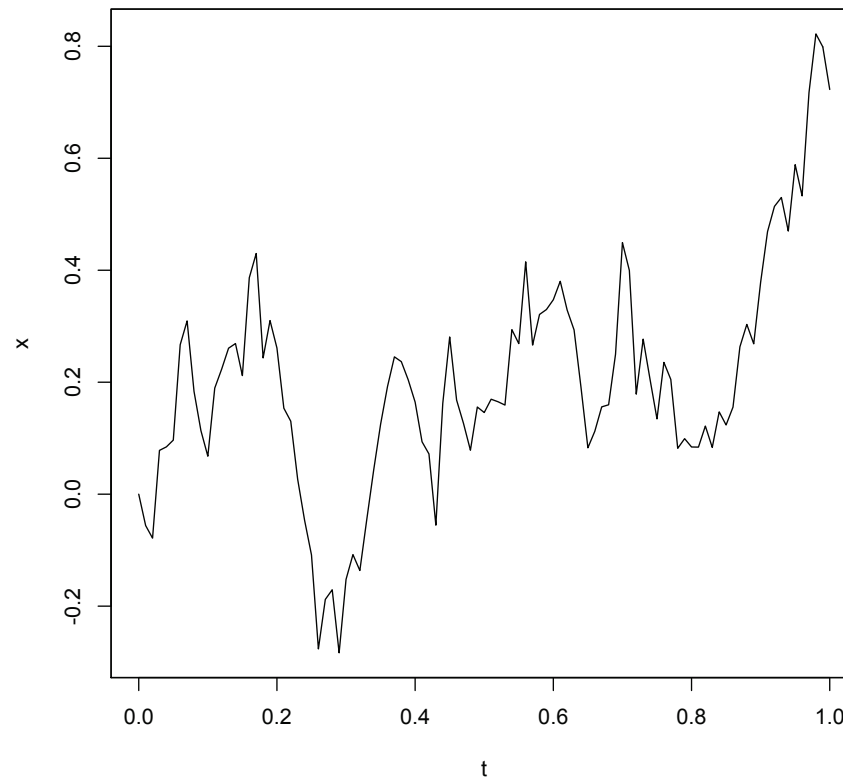
Compound Poisson Process

Inference

Inference

And this can be simulated specifying the parameters

```
> set.seed(123)
> plot(simulate(mod2, true.par=list(theta=1, gamma=3)))
```



2-dimensional diffusions with 3 noises

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$$dX_t^1 = -3X_t^1 dt + dW_t^1 + X_t^2 dW_t^3$$

$$dX_t^2 = -(X_t^1 + 2X_t^2)dt + X_t^1 dW_t^1 + 3dW_t^2$$

has to be organized into matrix form

$$\begin{pmatrix} dX_t^1 \\ dX_t^2 \end{pmatrix} = \begin{pmatrix} -3X_t^1 \\ -X_t^1 - 2X_t^2 \end{pmatrix} dt + \begin{pmatrix} 1 & 0 & X_t^2 \\ X_t^1 & 3 & 0 \end{pmatrix} \begin{pmatrix} dW_t^1 \\ dW_t^2 \\ dW_t^3 \end{pmatrix}$$

```
> sol <- c("x1","x2") # variable for numerical solution
> a <- c("-3*x1","-x1-2*x2") # drift vector
> b <- matrix(c("1","x1","0","3","x2","0"),2,3) # diffusion matrix
> mod3 <- setModel(drift = a, diffusion = b, solve.variable = sol)
> mod3
```

Diffusion process

Number of equations: 2

Number of Wiener noises: 3

2-dimensional diffusions with 3 noises

$$dX_t^1 = -3X_t^1 dt + dW_t^1 + X_t^2 dW_t^3$$
$$dX_t^2 = -(X_t^1 + 2X_t^2) dt + X_t^1 dW_t^1 + 3dW_t^2$$

```
> str(mod3)
Formal class 'yuima.model' [package "yuima"] with 16 slots
..@ drift      : expression((-3 * x1), (-x1 - 2 * x2))
..@ diffusion  : List of 2
.. ..$ : expression(1, 0, x2)
.. ..$ : expression(x1, 3, 0)
..@ hurst      : num 0.5
..@ jump.coeff : expression()
..@ measure    : list()
..@ measure.type : chr(0)
..@ parameter  : Formal class 'model.parameter' [package "yuima"] with 6 slots
.. .. ..@ all      : chr(0)
.. .. ..@ common   : chr(0)
.. .. ..@ diffusion: chr(0)
.. .. ..@ drift    : chr(0)
.. .. ..@ jump     : chr(0)
.. .. ..@ measure  : chr(0)
..@ state.variable : chr "x"
..@ jump.variable  : chr(0)
..@ time.variable  : chr "t"
..@ noise.number   : int 3
..@ equation.number: int 2
..@ dimension      : int [1:6] 0 0 0 0 0 0
..@ solve.variable : chr [1:2] "x1" "x2"
..@ xinit          : num [1:2] 0 0
..@ J.flag         : logi FALSE
```

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Compound Poisson Process

Inference

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Plot methods inherited by zoo

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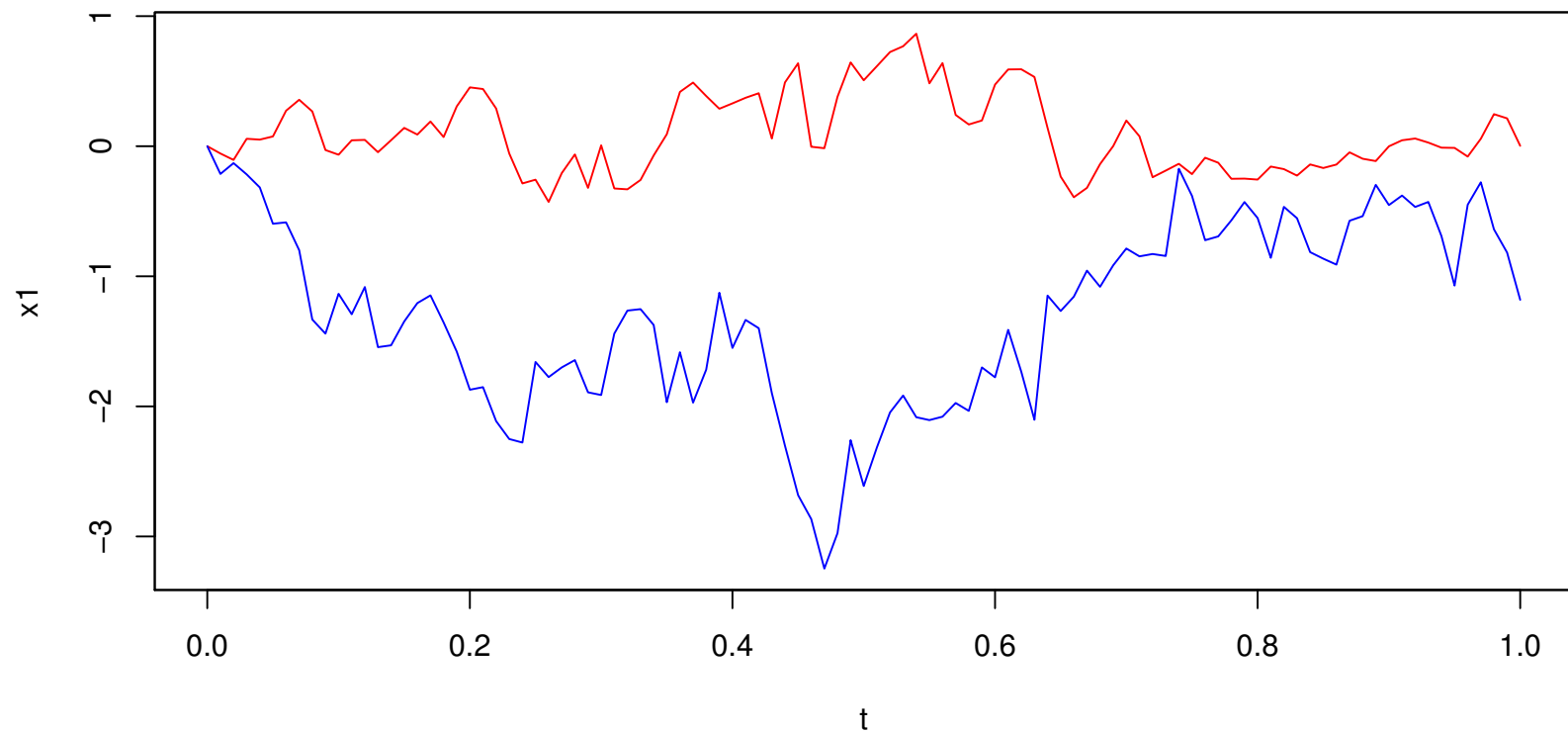
YUIMA Law

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```
> set.seed(123)
> X <- simulate(mod3)
> plot(X,plot.type="single",col=c("red","blue"))
```



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Inference

Also models like this can be specified

$$\begin{cases} dX_t^1 = X_t^2 |X_t^1|^{2/3} dW_t^1, \\ dX_t^2 = g(t) dX_t^3, \\ dX_t^3 = X_t^3 (\mu dt + \sigma (\rho dW_t^1 + \sqrt{1 - \rho^2} dW_t^2)) \end{cases},$$

where $g(t) = 0.4 + (0.1 + 0.2t)e^{-2t}$

The above is an example of parametric SDE with more equations than noises.

Fractional Gaussian Noise $dY_t = 3Y_t dt + dW_t^H$

```
> mod4 <- setModel(drift="3*y", diffusion=1, hurst=0.3, solve.var="y")
```

Fractional Gaussian Noise $dY_t = 3Y_t dt + dW_t^H$

```
> mod4 <- setModel(drift="3*y", diffusion=1, hurst=0.3, solve.var="y")
```

The hurst slot is filled

```
> mod4
```

```
Diffusion process with Hurst index:0.30  
Number of equations: 1  
Number of Wiener noises: 1
```

```
> str(mod4)
```

```
Formal class 'yuima.model' [package "yuima"] with 16 slots  
..@ drift      : expression((3 * y))  
..@ diffusion  : List of 1  
.. ..$ : expression(1)  
..@ hurst      : num 0.3  
.. .. ..  
.. .. ..  
.. .. ..  
.. .. ..  
..@ time.variable : chr "t"  
..@ noise.number  : num 1  
..@ equation.number: int 1  
..@ dimension     : int [1:6] 0 0 0 0 0 0  
..@ solve.variable : chr "y"  
..@ xinit        : num 0  
..@ J.flag       : logi FALSE
```

Fractional Gaussian Noise $dY_t = 3Y_t dt + dW_t^H$

Overview of the `yuima` package

What contains a `yuima` object?

What is possible to do with a `yuima` object in hands?

How does it work?

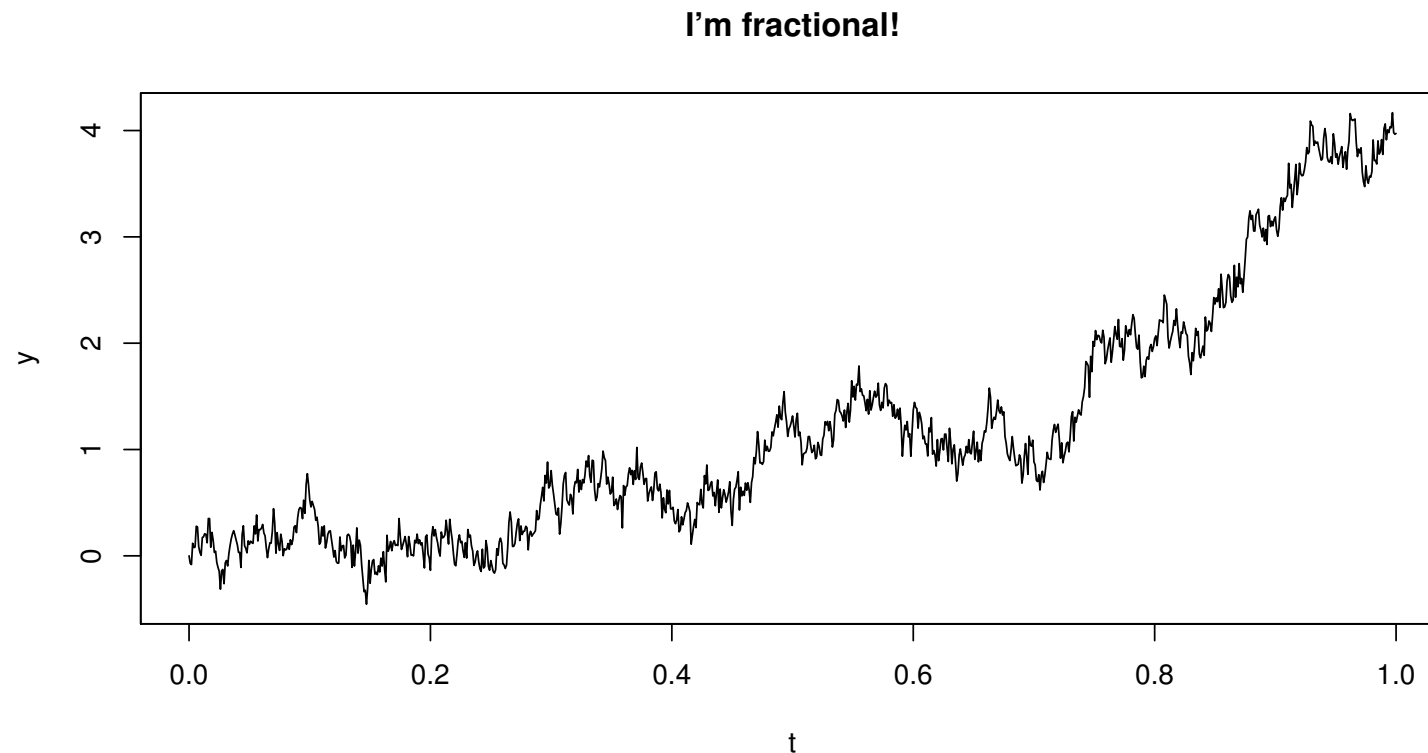
YUIMA Law

Compound Poisson Process

Inference

Inference

```
> mod4 <- setModel(drift="3*y", diffusion=1, hurst=0.3, solve.var="y")
> set.seed(123)
> X <- simulate(mod4, n=1000)
> plot(X, main="I'm fractional!")
```



Overview of the `yuima` package

What contains a `yuima` object ?

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YUIMA Law
Compound Poisson Process

Inference

Inference

Jump processes can be specified in different ways in mathematics (and hence in `yuima` package).

Let Z_t be a Compound Poisson Process (i.e. jumps follow some distribution, e.g. Gaussian)

Then it is possible to consider the following SDE which involves jumps

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

Next is an example of Poisson process with intensity $\lambda = 10$ and Gaussian jumps.

In this case we specify `measure.type` as “CP” (Compound Poisson)

Jump process: $dX_t = -\theta X_t dt + \sigma dW_t + Z_t$

Overview of the yuima package

What contains a yuima object?

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How does it work?

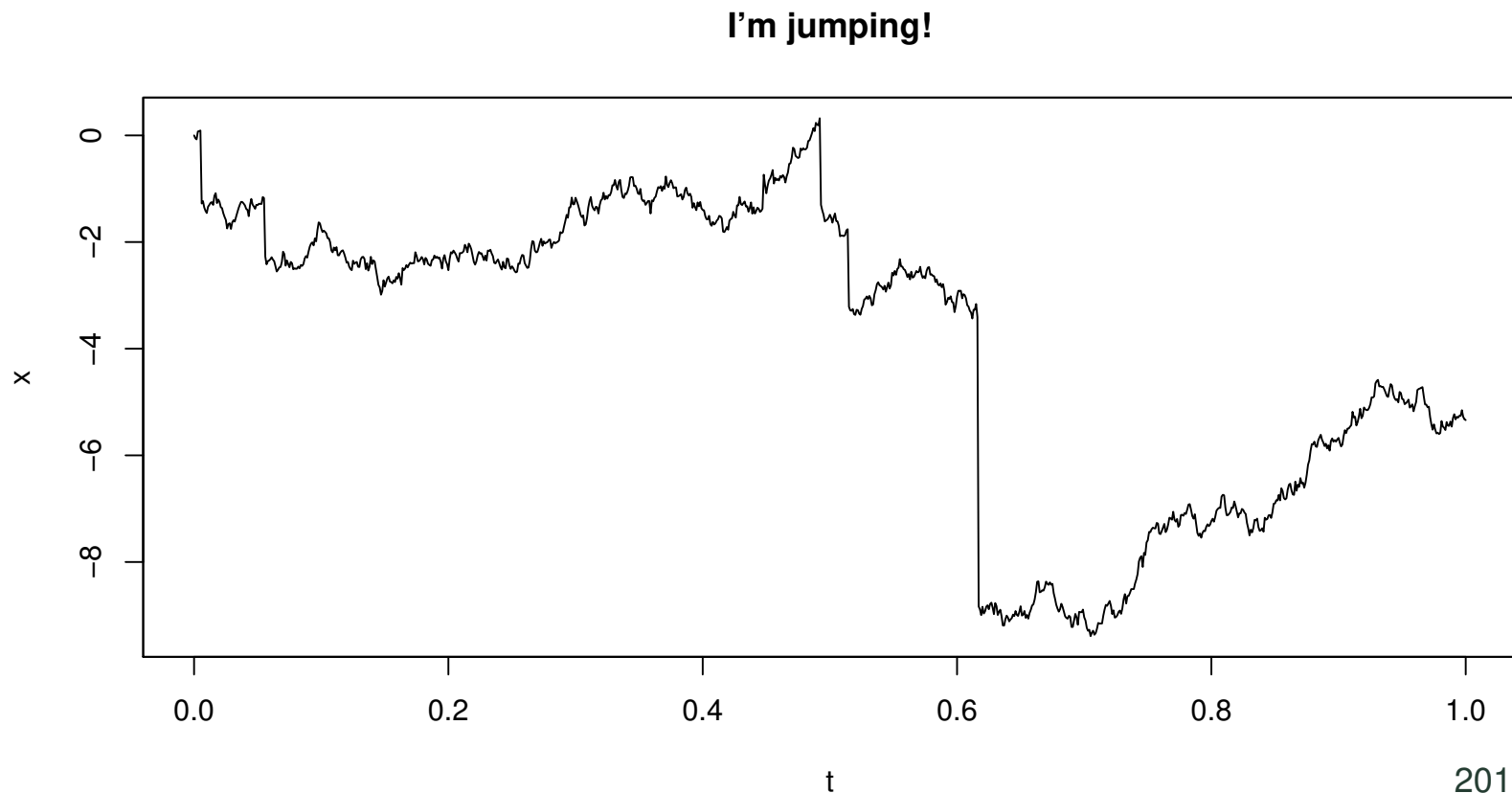
YUIMA Law

Compound Poisson Process

Inference

Inference

```
> mod5 <- setModel(drift="-theta*x", diffusion="sigma",
  jump.coeff="1", measure=list(intensity="10", df=list("dnorm(z, 0, 1)")),
  measure.type="CP", solve.variable="x")
> set.seed(123)
> X <- simulate(mod5, true.p=list(theta=1,sigma=3),n=1000)
> plot(X, main="I'm jumping!")
```



Overview of the `yuima` package

What contains a `yuima` object?

What is possible to do with a `yuima` object in hands?

How does it work?

YUIMA Law
Compound Poisson
Process

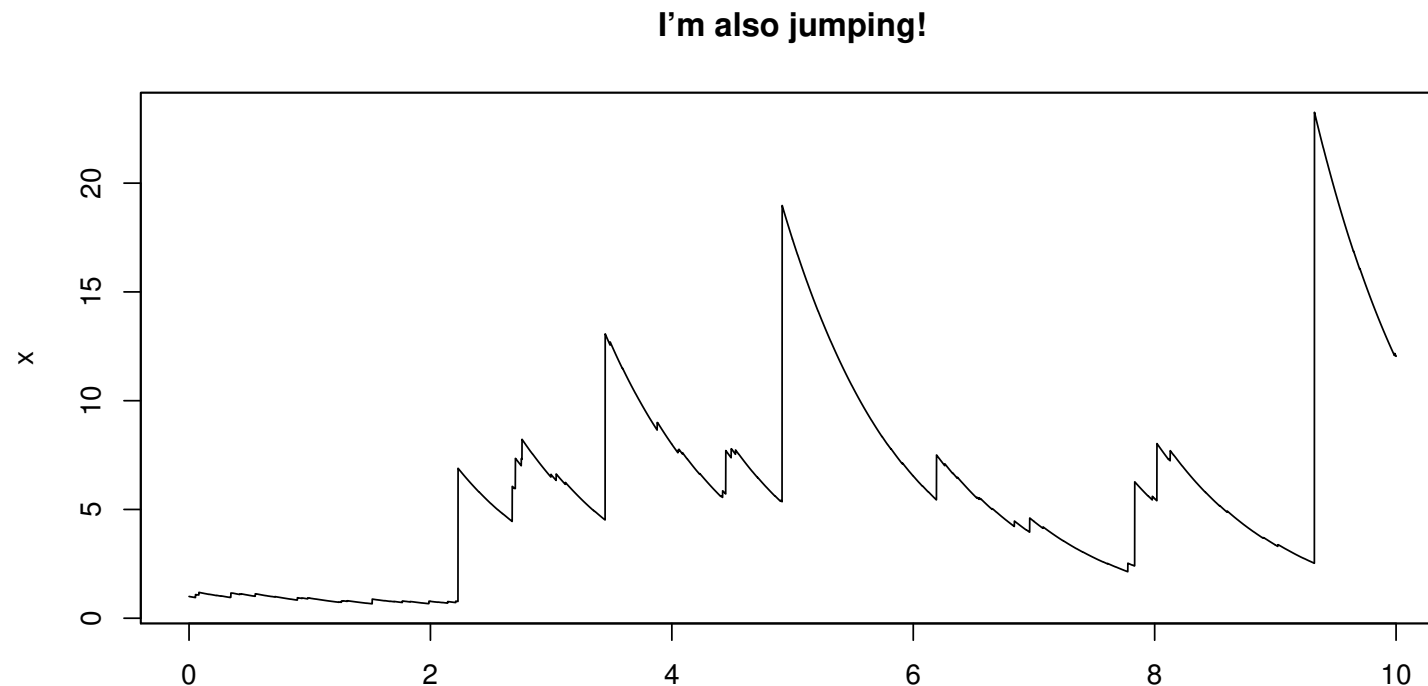
Inference

Inference

Another way is to specify the Lévy measure. Without going into too much details, here is an example of a simple OU process with IG Lévy measure

$$dX_t = -X_t dt + dZ_t$$

```
> mod6 <- setModel(drift="-x", xinit=1, jump.coeff="1",  
  measure.type="code", measure=list(df="rIG(z, 1, 0.1)"))  
> set.seed(123)  
> plot( simulate(mod6, Terminal=10, n=10000), main="I'm also jumping!")
```



Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How does it work?

YUIMA Law

Compound Poisson Process

Inference

Inference

Models are specified via

```
setModel(drift, diffusion, hurst = 0.5, jump.coeff, measure, measure.type,  
state.variable = "x", jump.variable = "z", time.variable = "t",  
solve.variable, xinit) in
```

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

The package implements many multivariate RNG to simulate Lévy paths including rIG, rNIG, rbgamma, rngamma, rstable.

Other user-defined or packages-defined RNG can be used freely.

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How does it work?

YUIMA Law

Compound Poisson Process

Inference

Inference

Models are specified via

```
setModel(drift, diffusion, hurst = 0.5, jump.coeff, measure, measure.type,  
state.variable = "x", jump.variable = "z", time.variable = "t",  
solve.variable, xinit) in
```

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

The package implements many multivariate RNG to simulate Lévy paths including rIG, rNIG, rbgamma, rngamma, rstable.

Other user-defined or packages-defined RNG can be used freely.

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How does it work?

YUIMA Law

Compound Poisson Process

Inference

Inference

Models are specified via

```
setModel(drift, diffusion, hurst = 0.5, jump.coeff, measure, measure.type,  
state.variable = "x", jump.variable = "z", time.variable = "t",  
solve.variable, xinit) in
```

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

The package implements many multivariate RNG to simulate Lévy paths including `rIG`, `rNIG`, `rbgamma`, `rngamma`, `rstable`.

Other user-defined or packages-defined RNG can be used freely.

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How does it work?

YUIMA Law

Compound Poisson Process

Inference

Inference

Models are specified via

```
setModel(drift, diffusion, hurst = 0.5, jump.coeff, measure, measure.type,  
state.variable = "x", jump.variable = "z", time.variable = "t",  
solve.variable, xinit) in
```

$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

The package implements many multivariate RNG to simulate Lévy paths including `rIG`, `rNIG`, `rbgamma`, `rngamma`, `rstable`.

Other user-defined or packages-defined RNG can be used freely.

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How does it work?

YUIMA Law

Compound Poisson Process

Inference

Inference

Models are specified via

```
setModel(drift, diffusion, hurst = 0.5, jump.coef, measure, measure.type,  
state.variable = "x", jump.variable = "z", time.variable = "t",  
solve.variable, xinit) in
```

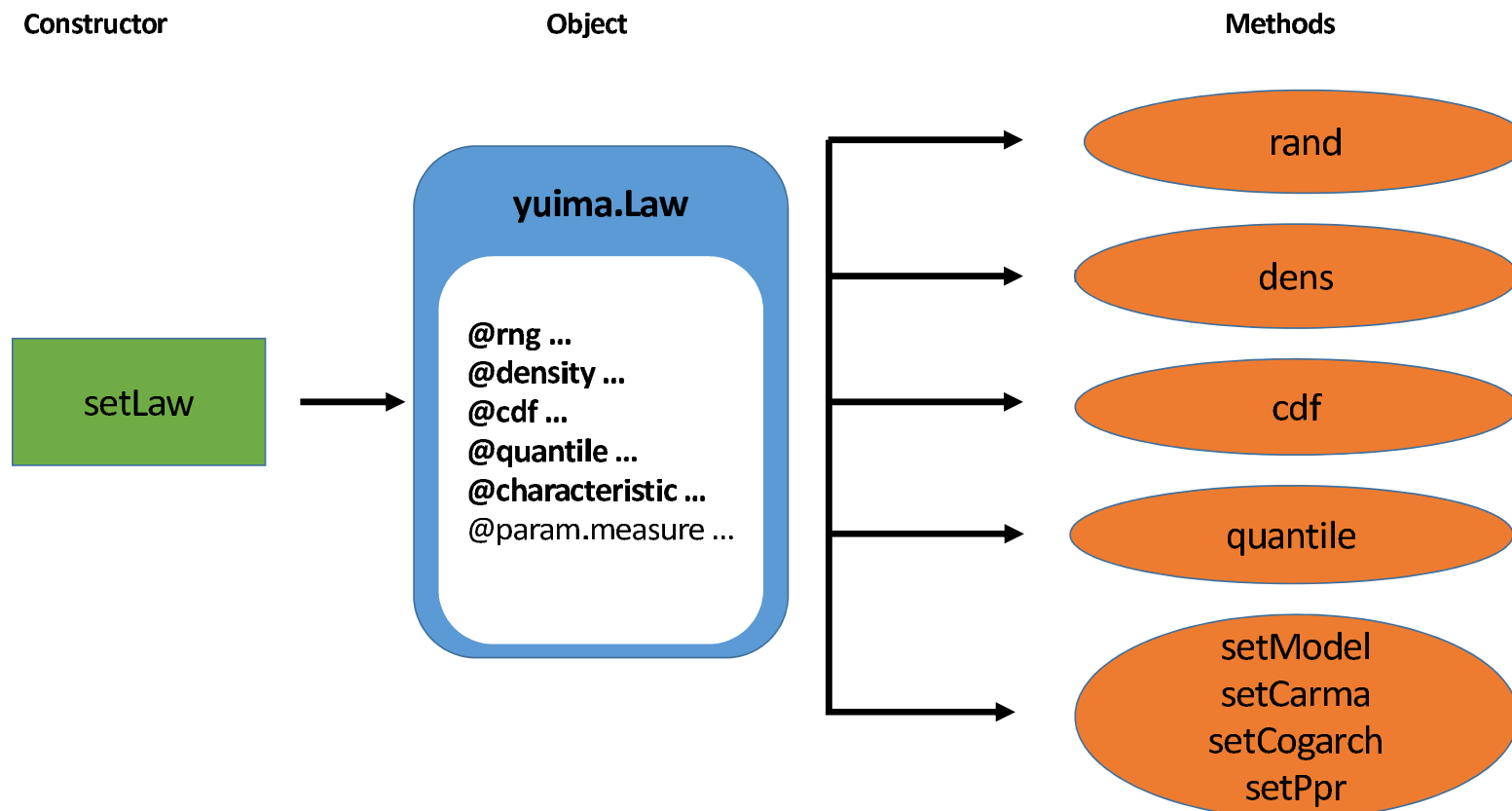
$$dX_t = a(t, X_t, \theta)dt + b(t, X_t, \theta)dW_t + c(t, X_t, \theta)dZ_t$$

The package implements many multivariate RNG to simulate Lévy paths including `rIG`, `rNIG`, `rbgamma`, `rngamma`, `rstable`.

Other user-defined or packages-defined RNG can be used freely.

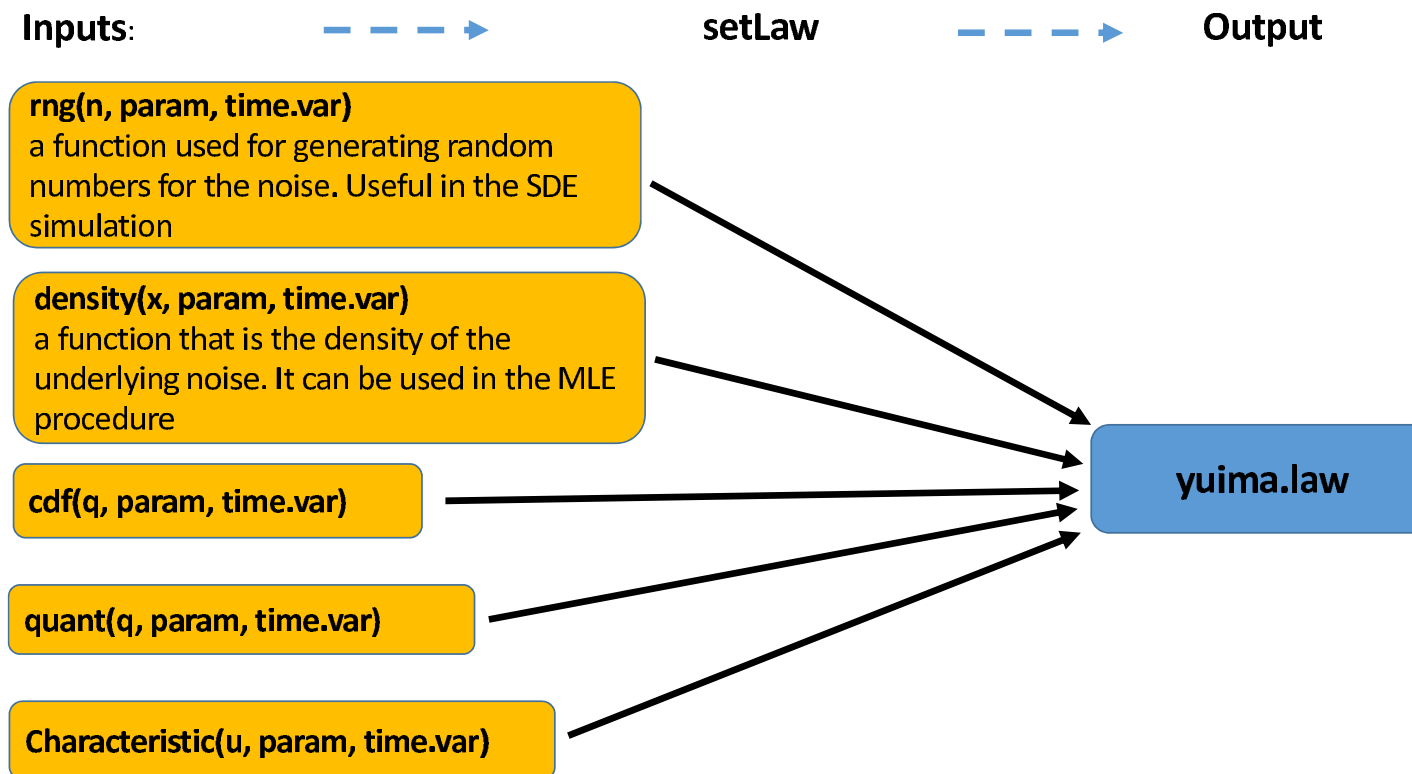
YUIMA Law object

The `yuimaLaw` object is a mathematical description of probability models which include also the RNG, quantiles, characteristic function, etc.



YUIMA Law constructor

The `yuimaLaw` object is prepared with some constructor function `setLaw` where the user can specify all or part of its components.



The `yuimaLaw` object is prepared with some constructor function `setLaw` where the user can specify all or part of its components; in the example, only the RNG has been specified:

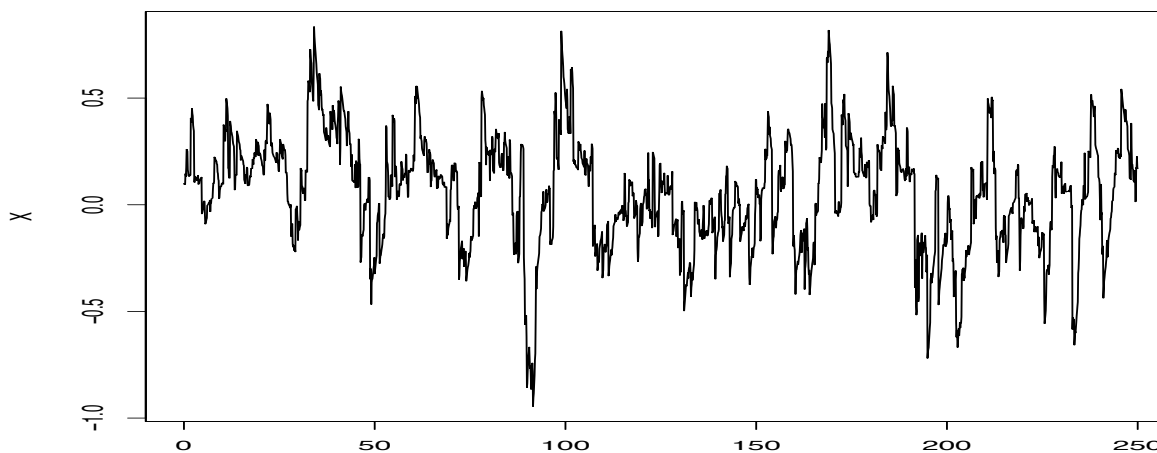
```
> my.randMixedTS <- function(n, a, alpha, lambda_p, lambda_m, t {  
  par <- setMixedTS.param(mu0 = 0, mu = 0, sigma = 1, a = a * t,  
    alpha = alpha, lambda_p = lambda_p, lambda_m = lambda_m)  
  rand <- rMixedTS(object = par, x=n)@Data  
  return(as.matrix(rand))  
}  
> my.L <- setLaw(rng = my.randMixedTS)
```

Suppose we want to specify and simulated this model:

$$dX_t = 0.4(0.1 - X_t)dt + 0.2dL_t$$

where L_t has a mixed tempered stable distribution.

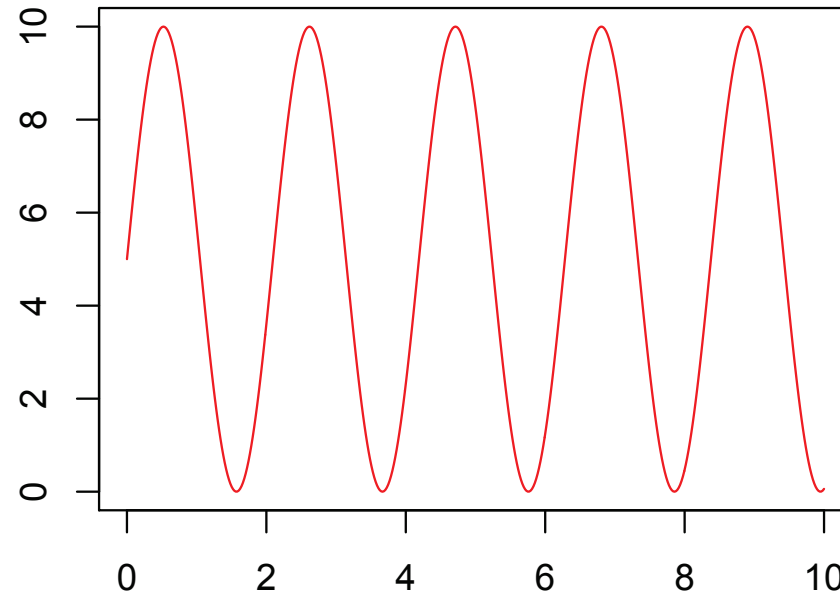
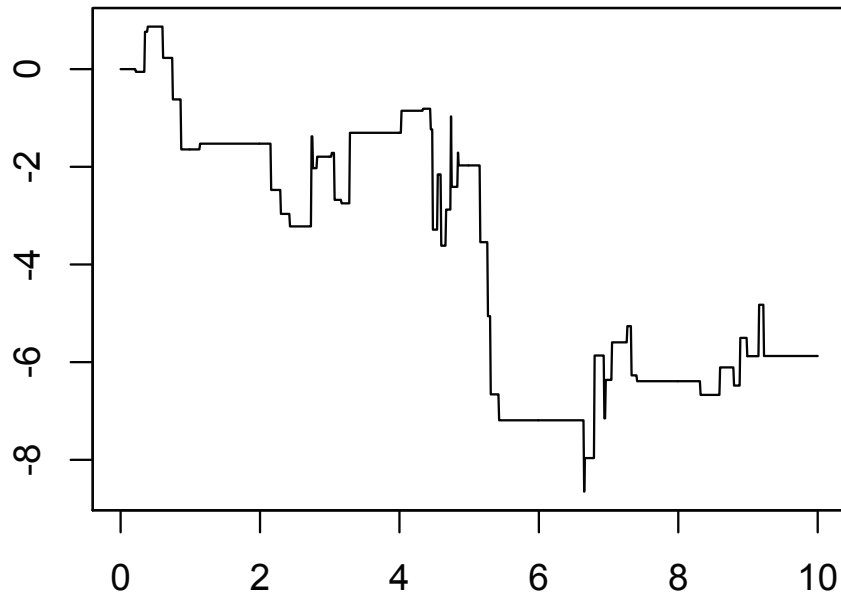
```
> mod1 <- setModel(drift = c("0.4*(0.1-X)"), diffusion = c("0"), jump.coef = c("0.2"),  
  measure = list(df = my.L), measure.type = c("code"), solve.variable = c("X"), xinit=c("0.1"))  
> par <- par <- list(a = 1.5, alpha = 1.5, lambda_p = 1, lambda_m = 1)  
> sim1 <- simulate(object = mod1, true.parameter = par,  
  sampling = setSampling(0,250, n = 2500))  
> plot(sim1)
```



Compound Poisson Processes

There is a simplified way to specify directly Compound Poisson Processes using `setPoisson`. The next code defines and simulates an inhomogeneous Compound Poisson Process with Gaussian jumps:

```
> samp <- setSampling(Terminal=10, n=1000)
> mod7 <- setPoisson(intensity="beta*(1+sin(lambda*t))", df=list("dnorm(z,0,1)"))
> f <- function(t) beta*(1+sin(lambda*t))
> set.seed(123); lambda <- 3; beta <- 5
> y7 <- simulate(mod7, true.par=list(lambda=lambda, beta=beta),sampling=samp)
> plot(y7); curve(f, 0, 10, col="red",n=500)
```



Hawkes Process and beyond

Let N_t is a Poisson process, with $\Lambda_t = \int_0^t \lambda(s) ds$. Assume further that $\lambda(t, N_t, X_t)$ is stochastic and dependent also on the process itself (feedback effect) and some other covariate process X_t (regression model).

An Hawkes process Y_t is a Point Process Regression (PPR) Model consisting of

$$Y_t = [X_t, N_t]^T$$

More precisely, the intensity function of N_t can be described as

$$\begin{aligned} \lambda_t &= g(t, Y_t, \theta) + \int_{t_0}^{t^-} K(t-s, Y_t, \theta) dY_s \\ &= g(t, [X_t, N_t]^T, \theta) + \int_{t_0}^{t^-} K(t-s, [X_t, N_t]^T, \theta) d \begin{pmatrix} X_s \\ N_s \end{pmatrix} \end{aligned}$$

The function $g(t, Y_t, \theta)$ is a non negative predictable process $K(t-s, Y_s, \theta)$ is a non-negative predictable matrix process.

$$Y_t = [r_t, Q_t, N_t]^T$$

$$\lambda_t = \exp(\mu_0 + \mu_1 \cdot \ln(1 + r_t) + \mu_2 \cdot \ln(1 + Q_t)) + \int_0^t c \cdot e^{-a \cdot (t-s)} dN_s$$

```
> my.rMTY <- function(n,t){
  res0 <- t(t(rgamma(n, 0.1*t)))
  res1 <- t(t(rgamma(n, 0.1*t)))
  res2 <- t(t(rep(1,n)))
  res <- cbind(res0,res1,res2)
  return(res)
}
> Law.MTY <- setLaw(rng = my.rMTY) # we prepare the law
# we prepare the covariate process
> modMTY <- setModel(drift = c("0.4*(0.1-Q)", ".4*(0.1-R)", "0"), diffusion = c("0", "0", "0"),
  jump.coef = matrix(c("1", "0", "0", "0", "1", "0", "0", "0", "1"), 3, 3),
  measure = list(df = Law.MTY), measure.type = c("code", "code", "code"),
  solve.variable = c("Q", "R", "N"), xinit=c("0.25", "0.25", "0"))
```

$$Y_t = [r_t, Q_t, N_t]^T$$

$$\lambda_t = \exp(\mu_0 + \mu_1 \cdot \ln(1 + r_t) + \mu_2 \cdot \ln(1 + Q_t)) + \int_0^t c \cdot e^{-a \cdot (t-s)} dN_s$$

```
> gFun <- "exp(mu0 + mu1*log(1+R)+mu2*log(1+Q))"
```

```
> Kernel <- "c*exp(-a*(t-s))"
```

```
# definition of Hawkes process
```

```
> prvMTY <- setPpr(yuima = modMTY, counting.var="N", gFun=gFun, Kernel = as.matrix(Kernel),  
  lambda.var = "lambda", var.dx = "N", lower.var="0", upper.var = "t")
```

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How does it work?

YUIMA Law

Compound Poisson Process

Inference

Inference

Let Z_t is a Lévy process and p, q non-negative integers such that $p > q \geq 0$.

The CARMA(p,q) process (see Brockwell, 2001) is defined as:

$$a(D)Y_t = b(D)DZ_t \quad (1)$$

D is the differentiation operator with respect to t while $a(\cdot)$ and $b(\cdot)$ are two polynomials:

$$a(u) = u^p + a_1u^{p-1} + \dots + a_p$$

$$b(u) = b_0 + b_1u^1 + \dots + b_{p-1}u^{p-1}$$

where $a_1; \dots ; a_p$ and b_0, \dots , b_q are coefficients such that $b_q \neq 0$ and $b_j = 0 \forall j > q$.

CARMA(p,q): state-space representation

It is more convenient to use the following **state space representation** of a CARMA(p,q) model

$$Y_t = \mathbf{b}^\top X_t$$

where X_t is a vector process of dimension p satisfying the following system of stochastic differential equations:

$$dX_t = AX_t dt + \mathbf{e} dZ_t$$

with A is the $p \times p$ matrix defined as:

$$A = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \dots & \vdots \\ 0 & 0 & 0 & \dots & 1 \\ -a_p & -a_{p-1} & -a_{p-2} & \dots & -a_1 \end{bmatrix}$$

The $p \times 1$ vectors \mathbf{e} and \mathbf{b} are respectively: $\mathbf{e} = [0, \dots, 0, 1]^\top$ and $\mathbf{b} = [b_0, \dots, b_{p-1}]^\top$.

Back to CARMA: the `yuima.carma` class

An object of the class `yuima.carma` contains all informations related to a **general linear state space** model that encompasses the CARMA model described in the previous slides. The mathematical description of this general model is given by the following system of equations:

$$\begin{aligned} Y_t &= \mu + \sigma \cdot \mathbf{b}^\top X_t \\ dX_t &= AX_t dt + \mathbf{e} (\gamma_0 + \gamma^\top X_t) dZ_t \end{aligned} \tag{2}$$

where $\mu \in \mathbb{R}$ and $\sigma \in (0, +\infty)$ are **location** and **scale** parameters respectively. The vector $\mathbf{b} \in \mathbb{R}^p$ contains the **moving average** parameters $b_0, b_1, \dots, b_q \neq 0, b_{q+1} = \dots = b_{p-1} = 0$ while the A is a $p \times p$ matrix whose last row contains the **autoregressive** parameters a_1, \dots, a_p ; A and \mathbf{e} are as before.

The setCARMA function

We use the constructor `setCARMA` for building an object of class `yuima.carma`.

The arguments used in a call to the constructor `setCARMA()` are:

```
setCARMA(p,q,loc.par=NULL,scale.par=NULL,ar.par="a",ma.par="b",  
lin.par=NULL,CARMA.var="v",Latent.var="x",XinExpr=FALSE, ...)
```

- `p` is a integer number the indicates the dimension of autoregressive coefficients.
- `q` is the dimension of moving average parameters.
- `XinExpr` is a logical variable. If `XinExpr=FALSE`, the starting condition of X_t is zero otherwise each component of X_t has a parameter as a starting point.

By default `setCARMA` build a CARMA model driven by a standard Brownian motion.

The `dots` arguments are used to pass information when the underlying noise is a (jump) Lévy process. In particular the following two arguments are necessary

- `measure` Lévy measure of jump variables.
- `measure.type` type specification for Lévy measure. "CP" for compound poisson, "code" for other Lévy processes such as Inverse Gaussian, Normal Inverse Gaussian, Gamma, Variance Gamma, Bilateral Gamma and etc.

For an object of `yuima.carma` methods for simulation (`simulate`) and for estimation (`qml`) are available and they are based on the state space representation.

The setCARMA function

Assume that we want to build a CARMA($p=3,q=1$) model driven by a standard Brownian Motion with location parameter. In this case, the state space model in (2) can be written in an explicit way as follows:

$$\begin{aligned}Y_t &= b_0 X_{0,t} + b_1 X_{1,t} \\dX_{0,t} &= X_{1,t} dt \\dX_{1,t} &= X_{2,t} dt \\dX_{2,t} &= [-a_3 X_{0,t} - a_2 X_{1,t} - a_1 X_{2,t}] dt + dZ_t\end{aligned}$$

where $Z_t = W_t$ is a Wiener process. For this reason, we instruct `yuima` to create an object of class `yuima.carma` using the code listed below.

```
> carma.mod <- setCARMA(p=3,q=1,loc.par="c0",CARMA.var="y",Latent.var="X")
> carma.mod
CARMA process p=3, q=1
Number of equations: 4
Number of Wiener noises: 1
Parametric model with 8 parameters
```

The CARMA(3,1) model is represented internally in `yuima` as:

$$d \begin{bmatrix} Y_t \\ X_{0,t} \\ X_{1,t} \\ X_{2,t} \end{bmatrix} = \begin{bmatrix} b_0 X_{0,t} + b_1 & X_{1,t} & & \\ & X_{1,t} & & \\ & & X_{2,t} & \\ -a_3 X_{0,t} - a_2 & X_{1,t} - a_1 & X_{2,t} & \end{bmatrix} dt + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} dZ_t \quad (3)$$

Notice that, since we define the CARMA(p,q) model using the standard `yuima` mathematical description, we need to rewrite the observable process Y_t as a stochastic differential equation. The location parameter c_0 is contained in the slot `xinit` where the starting condition of the variable Y_t is:

$$Y_0 = c_0 + b_0 X_{0,0} + b_1 X_{1,0}$$

To ensure the existence of a second order solution, we choose the autoregressive coefficients $\mathbf{a} := [a_1, a_2, a_3]$ such that the eigenvalues of the matrix A are real and negative. Indeed, $a_1 = 4$, $a_2 = 4.75$ and $a_3 = 1.5$, it is easy to verify that the eigenvalues of matrix A are $\lambda_1 = -0.5$, $\lambda_2 = -1.5$ and $\lambda_3 = -2$.

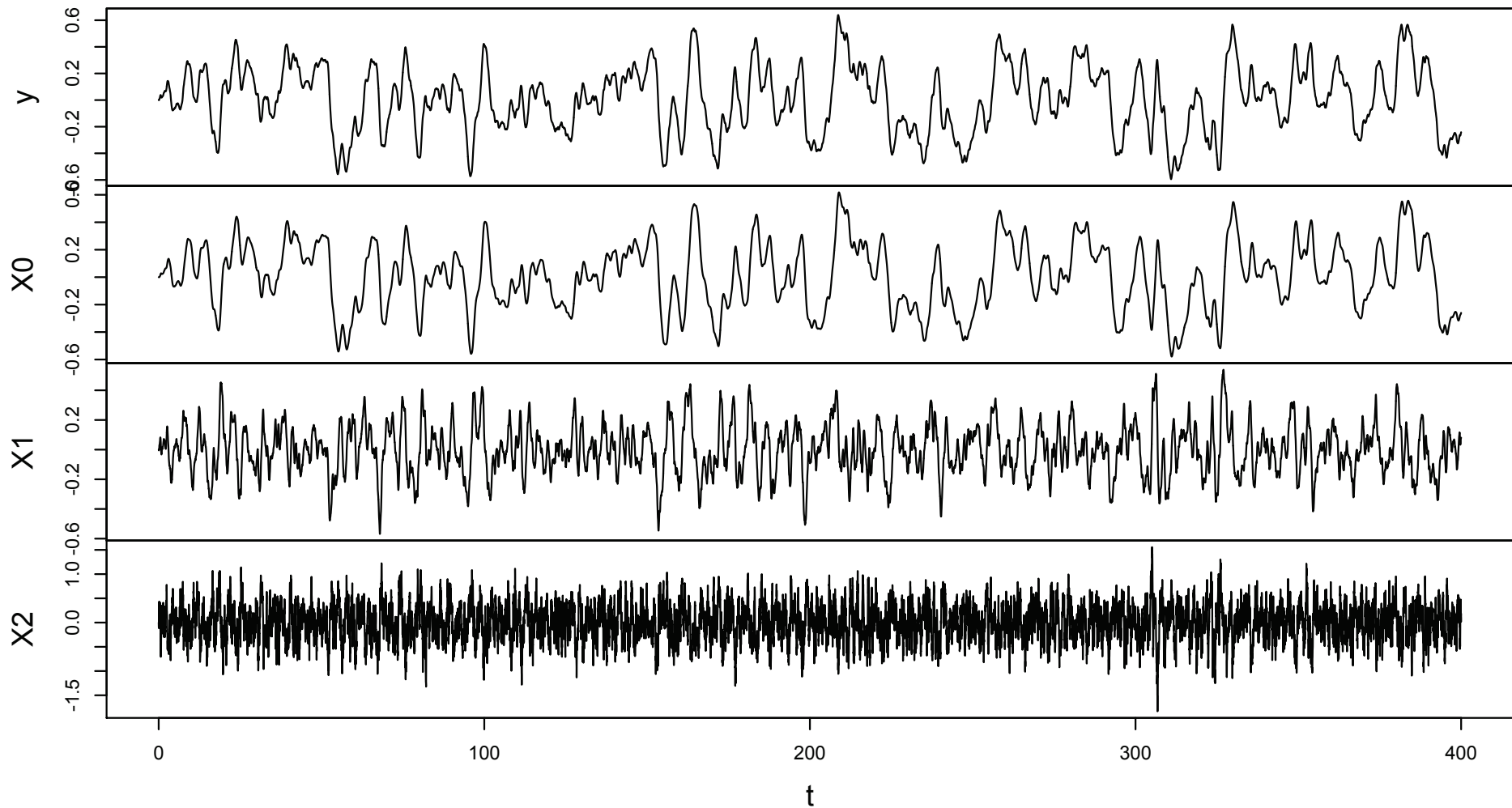
We now set the parameters, prepare the sampling scheme and simulate a trajectory of the CARMA process

```
> par.carma <- list(a1=4,a2=4.75,a3=1.5,b0=1,b1=0.23,c0=0)
> samp <- setSampling(Terminal=400, n=16000)
> set.seed(123)
> carma <-simulate(carma.mod, true.parameter=par.carma, sampling=samp)
```

we can now plot the simulated trajectory

```
> plot(carma)
```

An example of CARMA(3,1) trajectory



Example of CARMA(2,1) and VG jumps

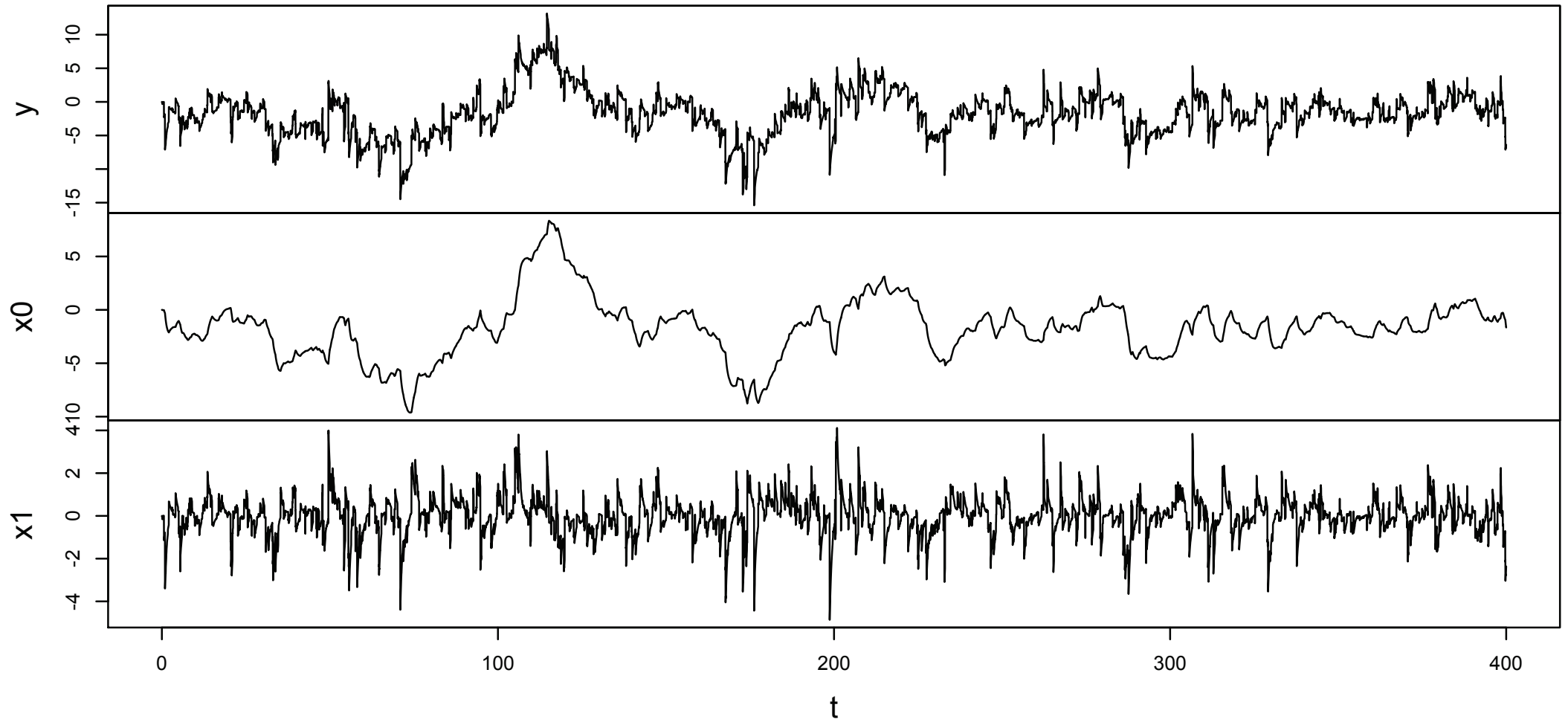
In this case, the underlying Lévy is a Variance Gamma model (Madan, 1990). We setup the model as follows

```
> modVG <- setCARMA(p=2,q=1,CARMA.var="y",  
  measure=list("rngamma(z,lambda,alpha,beta,mu)"), measure.type="code")  
> true.parmVG <- list(a1=1.39631, a2=0.05029, b0=1, b1=2, lambda=1, alpha=1, beta=0, mu=0)  
> set.seed(100)  
> simVG <- simulate(modVG, true.parameter=true.parmVG, sampling=samp)  
> plot(simVG)
```

we can now plot the simulated trajectory

```
> plot(simVG)
```

An example of CARMA(2,1) & VG trajectory



The COGARCH(p, q) process, introduced in Brockwell *et al* (2006) is defined as:

$$\begin{cases} dG_t = \sqrt{V_t} dZ_t \\ V_t = a_0 + \mathbf{a}^\top Y_{t-} \\ dY_t = AY_{t-} dt + \mathbf{e} (a_0 + \mathbf{a}^\top Y_{t-}) d[Z, Z]_t^d \end{cases} \quad (4)$$

where $q \geq p \geq 1$, $Y_t = [Y_{1,t}, \dots, Y_{q,t}]^\top$, $\mathbf{a} = [a_1, \dots, a_p, a_{p+1}, \dots, a_q]^\top$ with $a_{p+1} = \dots = a_q = 0$,

$$A = \begin{bmatrix} 0 & 1 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 1 \\ -b_q & -b_{q-1} & \dots & -b_1 \end{bmatrix}.$$

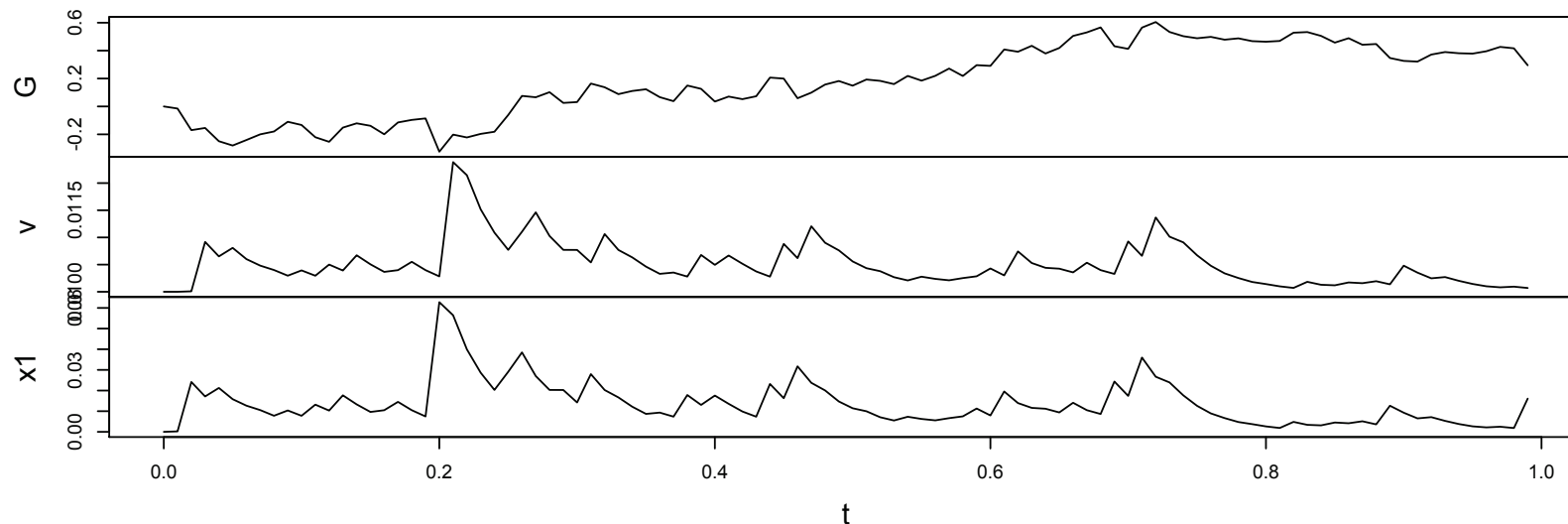
$\mathbf{e} \in R^q$ contains zero entries except for the last component that is equal to one and

$$[Z, Z]_t^d := \sum_{0 \leq s \leq t} (\Delta Z_s)^2. \quad (5)$$

is the discrete part of the quadratic variation of the underlying Lévy process.

The constructor function is called `setCogarch` and it is quite similar to `setCogarch`. Suppose we want to define a COGARCH(1,1) model with a Variance Gamma Lévy noise. We proceed as follows:

```
> model1 <- setCogarch(p = 1, q = 1,  
+   measure = list(df="rvgamma(z, 100, 2, .1, .1)"),  
+   measure.type = "code", Cogarch.var = "G", V.var = "v",  
+   Latent.var = "x", XinExpr = TRUE)  
> param1 <- list(a1 = 0.038, b1 = 30, a0 = 0.01, x01 = 0)  
> set.seed(123); plot( simulate(model1, true.parameter = param1) )
```



Inference for Stochastic Processes and much more

For all the models presented so far, there exists the `qmle` for Quasi-maximum Likelihood estimation which has an interface similar to the standard `mle` with the only difference that instead of a likelihood function, the input is one of the above `yuima` models.

The only exception is the fractional Gaussian case which makes use of `gmm`-type approach.

Hypotheses testing, AIC, Adaptive Bayes Estimation, Change Point analysis and much more have been developed for general SDEs.

Overview of the Yuima Project

Overview of the `yuima` package

What contains a `yuima` object ?

What is possible to do with a `yuima` object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Quasi Maximum Likelihood Analysis

Volatility Change-Point Estimation

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Consider the multidimensional diffusion process

$$dX_t = b(\theta_2, X_t)dt + \sigma(\theta_1, X_t)dW_t$$

where W_t is an r -dimensional standard Wiener process independent of the initial value $X_0 = x_0$. Quasi-MLE assumes the following approximation of the true log-likelihood for multidimensional diffusions

$$\ell_n(\mathbf{X}_n, \theta) = -\frac{1}{2} \sum_{i=1}^n \left\{ \log \det(\Sigma_{i-1}(\theta_1)) + \frac{1}{\Delta_n} \Sigma_{i-1}^{-1}(\theta_1) [\Delta X_i - \Delta_n b_{i-1}(\theta_2)]^{\otimes 2} \right\}$$

where $\theta = (\theta_1, \theta_2)$, $\Delta X_i = X_{t_i} - X_{t_{i-1}}$, $\Sigma_i(\theta_1) = \Sigma(\theta_1, X_{t_i})$, $b_i(\theta_2) = b(\theta_2, X_{t_i})$, $\Sigma = \sigma^{\otimes 2}$, $A^{\otimes 2} = A^T A$ and A^{-1} the inverse of A .

Then the QML estimator of θ is

$$\tilde{\theta}_n = \arg \min_{\theta} \ell_n(\mathbf{X}_n, \theta)$$

To estimate a model we make use of the `qml` function. Consider the model

$$dX_t = -\theta_2 X_t dt + \theta_1 dW_t$$

with $\theta_1 = 0.3$ and $\theta_2 = 0.1$

```
> diff.matrix <- matrix(c("theta1"), 1, 1)
> ymodel <- setModel(drift = c("(-1)*theta2*x"), diffusion = diff.matrix,
+   time.variable = "t", state.variable = "x", solve.variable = "x")
> n <- 100
> ysamp <- setSampling(Terminal = (n)^(1/3), n = n)
> yuima <- setYuima(model = ymodel, sampling = ysamp)
> set.seed(123)
> yuima <- simulate(yuima, xinit = 1, true.parameter = list(theta1 = 0.3, theta2 = 0.1))
```

Now `yuima` contains information about the model and the simulated data.

The true values of the parameters θ_1 and θ_2 were specified for the simulation, but unknown to the `yuima` object.

we can now call `qmle` on the `yuima` object which now contains informations about the model and the data.

```
> mle1 <- qmle(yuima, start = list(theta1 = 0.8, theta2 = 0.7),  
+           lower = list(theta1=0.05, theta2=0.05), upper = list(theta1=0.5, theta2=0.5),  
+           method = "L-BFGS-B")
```

```
> coef(mle1)
```

```
      theta1      theta2  
0.30766981 0.05007788
```

```
> summary(mle1)
```

```
Maximum likelihood estimation
```

```
Call:
```

```
qmle(yuima = yuima, start = list(theta1 = 0.8, theta2 = 0.7),  
      method = "L-BFGS-B", lower = list(theta1 = 0.05, theta2 = 0.05),  
      upper = list(theta1 = 0.5, theta2 = 0.5))
```

```
Coefficients:
```

```
      Estimate Std. Error  
theta1 0.30766981 0.02629925  
theta2 0.05007788 0.15144393
```

```
-2 log L: -280.0784
```

Overview of the Yuima Project

Overview of the `yuima` package

What contains a `yuima` object ?

What is possible to do with a `yuima` object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Asymptotic Expansion

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

The yuima package can handle asymptotic expansion of functionals of d -dimensional diffusion process

$$dX_t^\varepsilon = a(X_t^\varepsilon, \varepsilon)dt + b(X_t^\varepsilon, \varepsilon)dW_t, \quad \varepsilon \in (0, 1]$$

with W_t and r -dimensional Wiener process, i.e. $W_t = (W_t^1, \dots, W_t^r)$.

The functional is expressed in the following abstract form

$$F^\varepsilon(X_t^\varepsilon) = \sum_{\alpha=0}^r \int_0^T f_\alpha(X_t^\varepsilon, d) dW_t^\alpha + F(X_t^\varepsilon, \varepsilon), \quad W_t^0 = t$$

Estimation of functionals. Example.

Example: B&S asian call option

$$dX_t^\varepsilon = \mu X_t^\varepsilon dt + \varepsilon X_t^\varepsilon dW_t$$

and the B&S price is related to $\mathbb{E} \left\{ \max \left(\frac{1}{T} \int_0^T X_t^\varepsilon dt - K, 0 \right) \right\}$. Thus the functional of interest is

$$F^\varepsilon(X_t^\varepsilon) = \frac{1}{T} \int_0^T X_t^\varepsilon dt, \quad r = 1$$

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Estimation of functionals. Example.

Example: B&S asian call option

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and the B&S price is related to $\mathbb{E} \left\{ \max \left(\frac{1}{T} \int_0^T X_t^\varepsilon dt - K, 0 \right) \right\}$. Thus the functional of interest is

$$F^\varepsilon(X_t^\varepsilon) = \frac{1}{T} \int_0^T X_t^\varepsilon dt, \quad r = 1$$

with

$$f_0(x, \varepsilon) = \frac{x}{T}, \quad f_1(x, \varepsilon) = 0, \quad F(x, \varepsilon) = 0$$

in

$$F^\varepsilon(X_t^\varepsilon) = \sum_{\alpha=0}^r \int_0^T f_\alpha(X_t^\varepsilon, d) dW_t^\alpha + F(X_t^\varepsilon, \varepsilon)$$

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Estimation of functionals. Example.

So, the call option price requires the composition of a smooth functional

$$F^\varepsilon(X_t^\varepsilon) = \frac{1}{T} \int_0^T X_t^\varepsilon dt, \quad r = 1$$

with the irregular function

$$\max(x - K, 0)$$

Monte Carlo methods require a HUGE number of simulations to get the desired accuracy of the calculation of the price, while asymptotic expansion of F^ε provides unexpectedly accurate approximations.

The `yuima` package provides functions to construct the functional F^ε , and automatic asymptotic expansion based on Malliavin calculus starting from a `yuima` object.

Overview of the Yuima Project

Overview of the `yuima` package

What contains a `yuima` object ?

What is possible to do with a `yuima` object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

```
> diff.matrix <- matrix( c("x*e"), 1,1)
> model <- setModel(drift = c("x"), diffusion = diff.matrix)
> T <- 1
> xinit <- 1
> f <- list( expression(x/T), expression(0))
> F <- 0
> e <- .3
> yuima <- setYuima(model = model, sampling = setSampling(Terminal=T, n=1000))
> yuima <- setFunctional( yuima, f=f,F=F, xinit=xinit,e=e)
```

setFunctional method

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

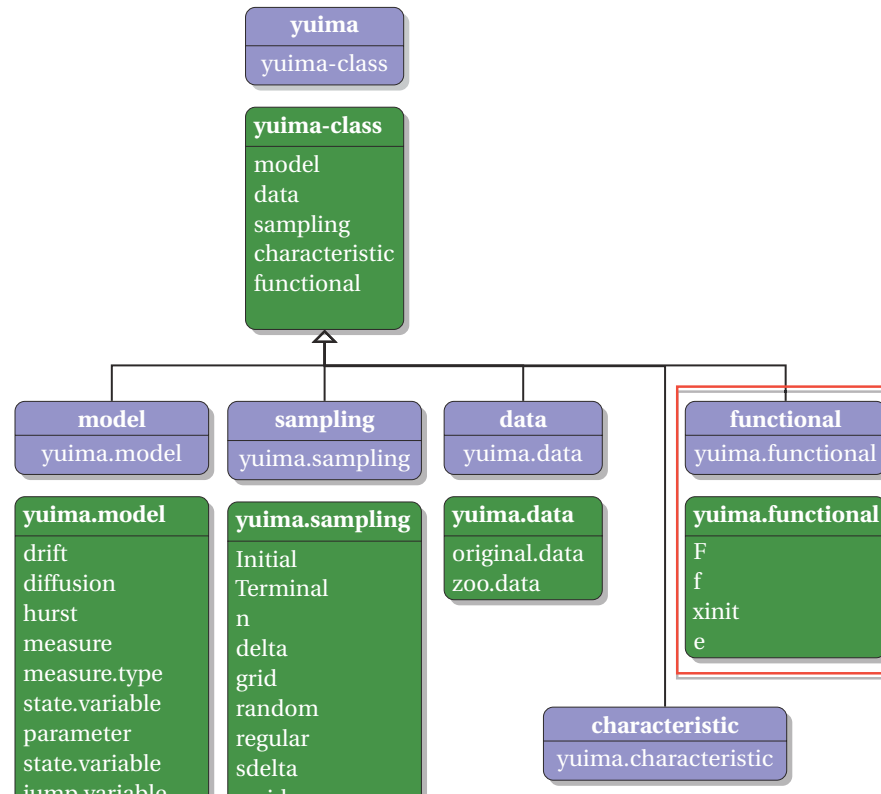
Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

```
> diff.matrix <- matrix( c("x*e"), 1,1)
> model <- setModel(drift = c("x"), diffusion = diff.matrix)
> T <- 1
> xinit <- 1
> f <- list( expression(x/T), expression(0))
> F <- 0
> e <- .3
> yuima <- setYuima(model = model, sampling = setSampling(Terminal=T, n=1000))
> yuima <- setFunctional( yuima, f=f,F=F, xinit=xinit,e=e)
```



Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

```
> diff.matrix <- matrix( c("x*e"), 1,1)
> model <- setModel(drift = c("x"), diffusion = diff.matrix)
> T <- 1
> xinit <- 1
> f <- list( expression(x/T), expression(0))
> F <- 0
> e <- .3
> yuima <- setYuima(model = model, sampling = setSampling(Terminal=T, n=1000))
> yuima <- setFunctional( yuima, f=f,F=F, xinit=xinit,e=e)
```

the definition of the functional is now included in the yuima object (some output dropped)

```
> str(yuima)
Formal class 'yuima' [package "yuima"] with 5 slots
 ..@ data      :Formal class 'yuima.data' [package "yuima"] with 2 slots
 ..@ model     :Formal class 'yuima.model' [package "yuima"] with 16 slots
 ..@ sampling  :Formal class 'yuima.sampling' [package "yuima"] with 11 slots
 ..@ functional:Formal class 'yuima.functional' [package "yuima"] with 4 slots
 .. .. ..@ F   : num 0
 .. .. ..@ f   :List of 2
 .. .. .. ..$ : expression(x/T)
 .. .. .. ..$ : expression(0)
 .. .. ..@ xinit: num 1
 .. .. ..@ e    : num 0.3
```

Estimation of functionals. Example.

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Then, it is as easy as

```
> F0 <- F0(yuima)
> F0
[1] 1.716424
> max(F0-K,0) # asian call option price
[1] 0.7164237
```

Estimation of functionals. Example.

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Then, it is as easy as

```
> F0 <- F0(yuima)
> F0
[1] 1.716424
> max(F0-K,0) # asian call option price
[1] 0.7164237
```

and back to asymptotic expansion, the following script may work

```
> rho <- expression(0)
> get_ge <- function(x,epsilon,K,F0){
+   tmp <- (F0 - K) + (epsilon * x)
+   tmp[(epsilon * x) < (K-F0)] <- 0
+   return( tmp )
+ }
> K <- 1 # strike
> epsilon <- e # noise level
> g <- function(x) {
+   tmp <- (F0 - K) + (epsilon * x)
+   tmp[(epsilon * x) < (K-F0)] <- 0
+   tmp
+ }
```

Add more terms to the expansion

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

The expansion of previous functional gives

```
> asymp <- asymptotic_term(yuima, block=10, rho, g)
calculating d0 ...done
calculating d1 term ...done
> asymp$d0 + e * asymp$d1 # asymp. exp. of asian call price
```

```
[1] 0.7148786
```

```
> library(fExoticOptions) # From RMetrics suite
> TurnbullWakemanAsianApproxOption("c", S = 1, SA = 1, X = 1,
+   Time = 1, time = 1, tau = 0.0, r = 0, b = 1, sigma = e)
Option Price:
```

```
[1] 0.7184944
```

```
> LevyAsianApproxOption("c", S = 1, SA = 1, X = 1,
+   Time = 1, time = 1, r = 0, b = 1, sigma = e)
Option Price:
```

```
[1] 0.7184944
```

```
> X <- sde.sim(drift=expression(x), sigma=expression(e*x), N=1000,M=1000)
> mean(colMeans((X-K)*(X-K>0))) # MC asian call price based on M=1000 repl.
```

```
[1] 0.707046
```


Multivariate Asymptotic Expansion

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Asymptotic expansion is now also available for multidimensional diffusion processes like the Heston model

$$dX_t^{1,\varepsilon} = aX_t^{1,\varepsilon}dt + \varepsilon X_t^{1,\varepsilon} \sqrt{X_t^{2,\varepsilon}} dW_t^1$$

$$dX_t^{2,\varepsilon} = c(d - X_t^{2,\varepsilon})dt + \varepsilon \sqrt{X_t^{2,\varepsilon}} \left(\rho dW_t^1 + \sqrt{1 - \rho^2} dW_t^2 \right)$$

i.e. functionals of the form $F(X^{1,\varepsilon}, X^{2,\varepsilon})$.

Overview of the Yuima Project

Overview of the `yuima` package

What contains a `yuima` object ?

What is possible to do with a `yuima` object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

LASSO estimation & model selection

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

LASSO is nothing but estimation under constraints on the parameters. Usually studied for the least squares estimation method, can be applied here using the QMLE approach for the following diffusion model

$$dX_t = b(\alpha, X_t)dt + \sigma(\beta, X_t)dW_t$$

where $\alpha \in R^p$, $\beta \in R^q$, $p, q \geq 1$

The target function is the minimization of $H_n(\alpha, \beta)$ = minus the log of the approximated likelihood,

$$\min_{\alpha, \beta} H_n(\alpha, \beta) + \sum_{j=1}^p \lambda_{n,j} |\alpha_j| + \sum_{k=1}^q \gamma_{n,k} |\beta_k|$$

Lasso tries to set the maximal number of parameters to 0. In this sense operates model selection jointly with estimation.

Interest rates LASSO estimation examples

LASSO estimation of the U.S. Interest Rates monthly data from 06/1964 to 12/1989. These data have been analyzed by many author including Nowman (1997), Aït-Sahalia (1996), Yu and Phillips (2001) and it is a nice application of LASSO.

Reference	Model	α	β	γ
Merton (1973)	$dX_t = \alpha dt + \sigma dW_t$		0	0
Vasicek (1977)	$dX_t = (\alpha + \beta X_t)dt + \sigma dW_t$			0
Cox, Ingersoll and Ross (1985)	$dX_t = (\alpha + \beta X_t)dt + \sigma \sqrt{X_t}dW_t$			1/2
Dothan (1978)	$dX_t = \sigma X_t dW_t$	0	0	1
Geometric Brownian Motion	$dX_t = \beta X_t dt + \sigma X_t dW_t$	0		1
Brennan and Schwartz (1980)	$dX_t = (\alpha + \beta X_t)dt + \sigma X_t dW_t$			1
Cox, Ingersoll and Ross (1980)	$dX_t = \sigma X_t^{3/2} dW_t$	0	0	3/2
Constant Elasticity Variance	$dX_t = \beta X_t dt + \sigma X_t^\gamma dW_t$	0		
CKLS (1992)	$dX_t = (\alpha + \beta X_t)dt + \sigma X_t^\gamma dW_t$			

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

Interest rates LASSO estimation examples

- Overview of the Yuima Project
- Overview of the yuima package
- What contains a yuima object ?
- What is possible to do with a yuima object in hands?
- How it is supposed to work?
- Inference & Finance
- Quasi Maximum Likelihood Analysis
- Adaptive Bayes Estimation
- Change-point Analysis
- Asymptotic Expansion
- Asynchronous covariance estimation
- LASSO estimation & model selection

Model	Estimation Method	α	β	σ	γ
Vasicek	MLE	4.1889	-0.6072	0.8096	–
CKLS	Nowman	2.4272	-0.3277	0.1741	1.3610
CKLS	Exact Gaussian (Yu & Phillips)	2.0069 (0.5216)	-0.3330 (0.0677)	0.1741	1.3610
CKLS	QMLE	2.0822 (0.9635)	-0.2756 (0.1895)	0.1322 (0.0253)	1.4392 (0.1018)
CKLS	QMLE + LASSO with mild penalization	1.5435 (0.6813)	-0.1687 (0.1340)	0.1306 (0.0179)	1.4452 (0.0720)
CKLS	QMLE + LASSO with strong penalization	0.5412 (0.2076)	0.0001 (0.0054)	0.1178 (0.0179)	1.4944 (0.0720)

LASSO selected: Cox, Ingersoll and Ross (1980) model

$$dX_t = \frac{1}{2}dt + 0.12 \cdot X_t^{3/2} dW_t$$

Example of Lasso estimation

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

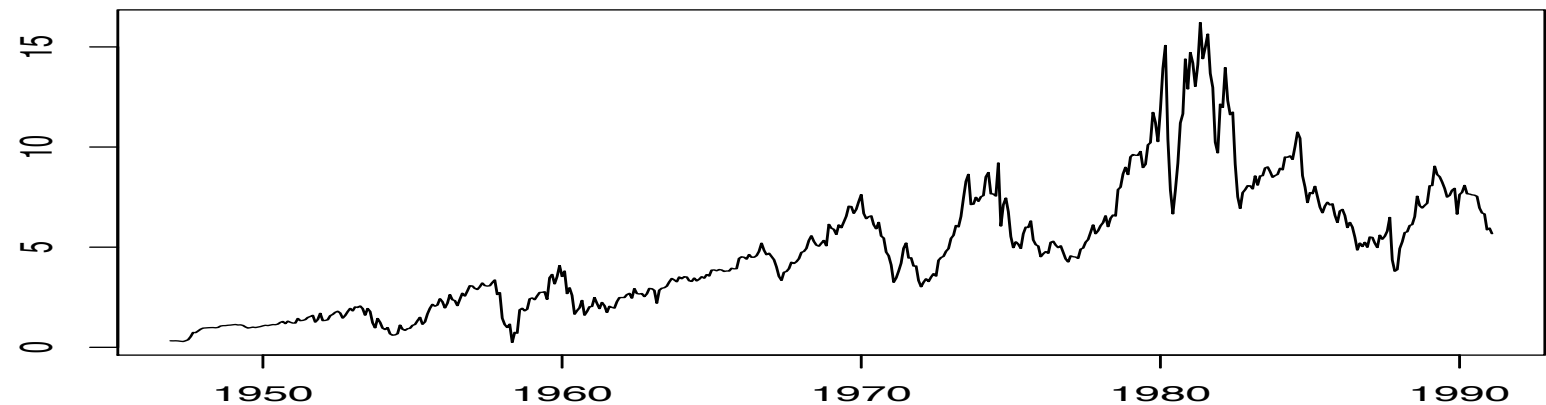
Asynchronous covariance estimation

LASSO estimation & model selection

An example of Lasso use on real data with CKLS model

$$dX_t = (\alpha + \beta X_t)dt + \sigma X_t^\gamma dW_t$$

```
> library(Ecdat)
> data(Irates)
> rates <- Irates[, "r1"]
> plot(rates)
> require(yuima)
> X <- window(rates, start=1964.471, end=1989.333)
> mod <- setModel(drift="alpha+beta*x", diffusion=matrix("sigma*x^gamma", 1, 1))
> yuima <- setYuima(data=setData(X), model=mod)
```



Adaptive sequences: $\lambda_n = \lambda_0 / \tilde{\theta}_n$; $\tilde{\theta}_n = \text{QMLE}$.

Overview of the Yuima Project

Overview of the yuima package

What contains a yuima object ?

What is possible to do with a yuima object in hands?

How it is supposed to work?

Inference & Finance

Quasi Maximum Likelihood Analysis

Adaptive Bayes Estimation

Change-point Analysis

Asymptotic Expansion

Asynchronous covariance estimation

LASSO estimation & model selection

```
> lambda0 <- list(alpha=10, beta =10, sigma =10, gamma =10)
> start <- list(alpha=1, beta =-.1, sigma =.1, gamma =1)
> low <- list(alpha=-5, beta =-5, sigma =-5, gamma =-5)
> upp <- list(alpha=8, beta =8, sigma =8, gamma =8)
> lasso10 <- lasso(yuima, lambda0, start=start, lower=low, upper=upp,
  method="L-BFGS-B")
```

Looking for MLE estimates...

Performing LASSO estimation...

```
> round(lasso10$mle, 3) # QMLE
  sigma  gamma  alpha  beta
0.133  1.443  2.076 -0.263
```

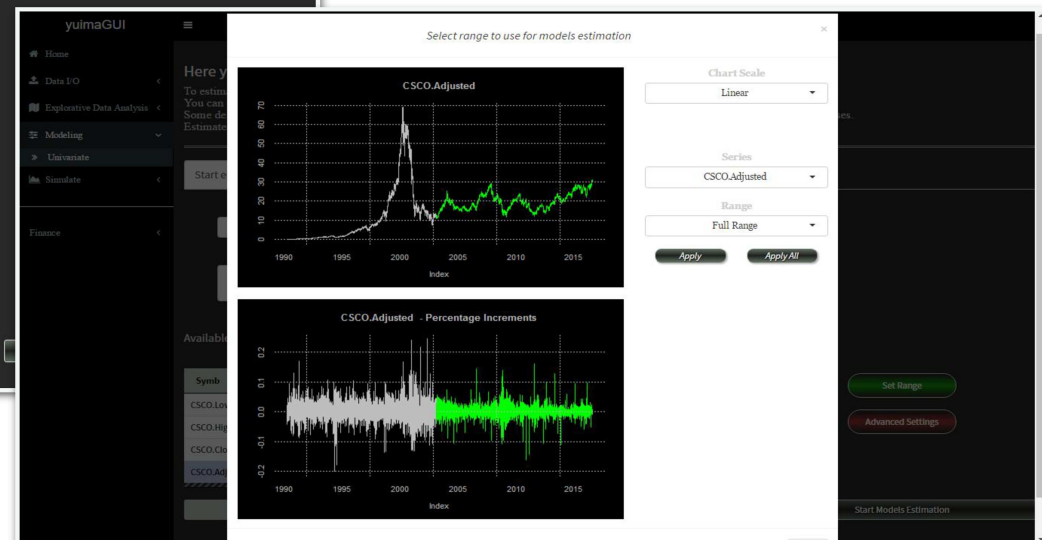
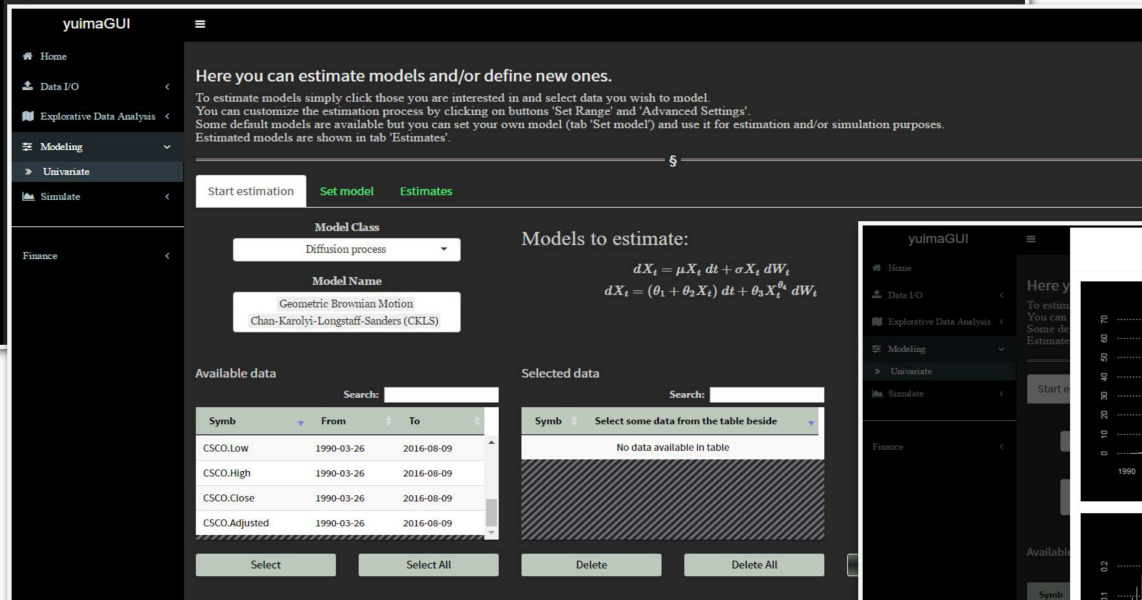
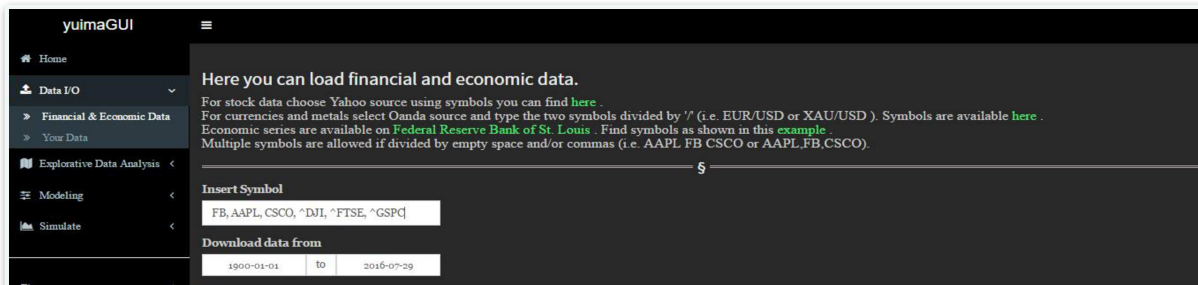
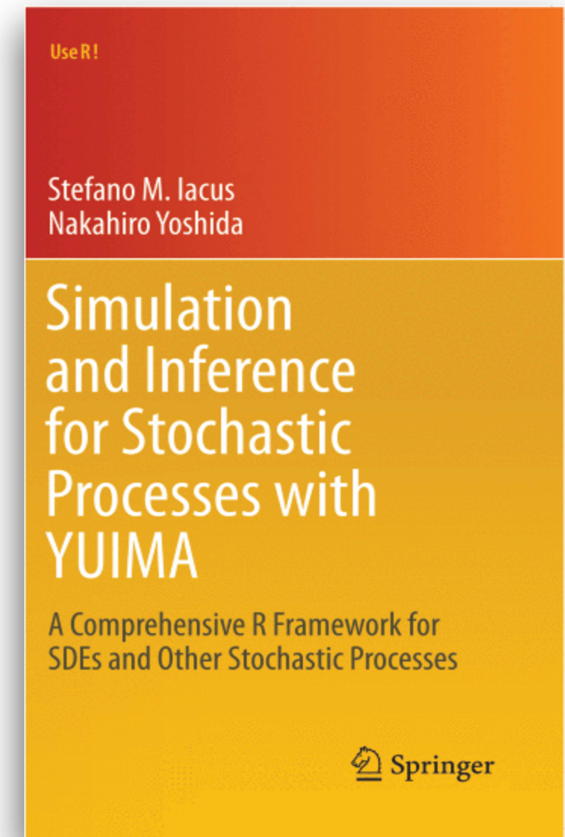
```
> round(lasso10$lasso, 3) # LASSO
  sigma  gamma  alpha  beta
0.117  1.503  0.591  0.000
```

$$dX_t = (\alpha + \beta X_t)dt + \sigma X_t^\gamma dW_t$$

$$dX_t = 0.6dt + 0.12X_t^{\frac{3}{2}}dW_t$$

For further information

<http://www.yuima-project.com>



yuimaGUI is also available!

Emanuele Guidotti

Stefano M. Iacus

Lorenzo Mercuri

yuimaGUI

A graphical user interface for computational finance
based on the **yuima** R package

Complexity Level

Deep scientific knowledge

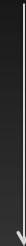


yuima R package
(and others)

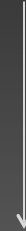


yuimaGUI

Research Level



Programming Level



User-friendly Level

Typical Usage of yuimaGUI

yuimaGUI

Home

Data I/O

Explorative Data Analysis

Modeling

Simulate

Finance

Welcome on yuimaGUI

an amazingly powerful tool for your analysis

Get acquainted with yuimaGUI and learn how to best exploit it in a few simple steps:

Step 1

Load data you wish to analyze (section 'Data I/O').
An easy way to load economic data (i.e. GDP) or financial series (stocks and shares) directly from the Internet is provided. Otherwise you can load data from your own files.
Once data are loaded, you can go and use sections 'Explorative Data Analysis' and 'Modeling'.

Step 2

Model your data in section 'Modeling'.
Here you can fit models to your data choosing between some default options but also defining and using your own model.
Now you are ready to use the estimated models for simulation purposes in section 'Simulate'.

Step 3

Read the short explanation at the beginning of every (sub)section.

Developed by
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Loading Data

Explorative Data Analysis

Modeling

Simulation

Loading Data → Explorative Data Analysis → Modeling → Simulation

Financial & Economic Data

The screenshot shows the 'yuimaGUI' interface. On the left is a navigation sidebar with the following items: Home, Data I/O (expanded), Financial & Economic Data, Your Data, Explorative Data Analysis, Modeling, Simulate, and Finance. The main content area is titled 'Here you can load financial and economic data.' and contains the following text: 'For stock data choose Yahoo source using symbols you can find here . For currencies and metals select Oanda source and type the two symbols divided by '/' (i.e. EUR/USD or XAU/USD). Symbols are available here . Economic series are available on Federal Reserve Bank of St. Louis . Find symbols as shown in this example . Multiple symbols are allowed if divided by empty space and/or commas (i.e. AAPL FB CSCO or AAPL,FB,CSCO).' Below this text is a form with the following fields: 'Insert Symbol' containing 'FB, AAPL, CSCO, ^DJI, ^FTSE, ^GSPC', 'Download data from' with a date range from '1900-01-01' to '2016-07-29', and 'Source' set to 'Yahoo (OHLC data)'. A 'Load data' button is at the bottom of the form.

Loading Data → Explorative Data Analysis → Modeling → Simulation

Financial & Economic Data

yuimaGUI

- Home
- Data I/O
 - Financial & Economic Data
 - Your Data
- Explorative Data Analysis
- Modeling
- Simulate

Finance

Here you can load financial and economic data.

For stock data choose Yahoo source using symbols you can find [here](#) .
For currencies and metals select Oanda source and type the two symbols divided by '/' (i.e. EUR/USD or XAU/USD). Symbols are available [here](#) .
Economic series are available on [Federal Reserve Bank of St. Louis](#) . Find symbols as shown in this [example](#) .
Multiple symbols are allowed if divided by empty space and/or commas (i.e. AAPL FB CSCO or AAPL,FB,CSCO).

All symbols downloaded successfully

Insert Symbol

FB, AAPL, CSCO, ^DJI, ^FTSE, ^GSPC

Download data from

1900-01-01 to 2016-07-29

Source

Yahoo (OHLC data)

Load data

Chart Scale

Linear

Search:

Symbol	From	To
FB.Open	2012-05-18	2016-07-28
FB.High	2012-05-18	2016-07-28
FB.Low	2012-05-18	2016-07-28

Loading Data → Explorative Data Analysis → Modeling → Simulation

Your Data

The screenshot shows the 'yuimaGUI' interface with a sidebar on the left containing navigation items: Home, Data I/O (selected), Financial & Economic Data, Your Data, Explorative Data Analysis, Modeling, Simulate, Finance, and Home. The main content area is titled 'Here you can load data from your own files.' and includes instructions: 'Please upload your file and specify its structure. A preview will be shown below. First, declare if the file contains raw and/or column headers and specify what kind of field separator has to be used to read data. Each column will be uploaded as a different series. So you might want to switch columns with rows if your file is organized differently. Finally specify what column to use to index series and its format.'

Below the instructions is a section titled 'Choose file to upload' with a 'Scegli file' button and the text 'Nessun file selezionato'. A progress indicator shows 50% completion.

Configuration options include:

- Headers: Default
- Field Separator: Space
- Switch rows/columns: No
- Index: Default
- Index Format: Year-Month-Day (yyyy-mm-dd)

Loading Data → Explorative Data Analysis → Modeling → Simulation

Loading Data → Explorative Data Analysis → Modeling → Simulation

Change Point Estimation

yuimaGUI

- Home
- Data I/O
- Explorative Data Analysis
 - Change Point Estimation
 - Clustering
- Modeling
- Simulate
- Finance

Here you can estimate change points.
Select data for which you want to estimate change points from table 'Available Data'.
Then choose the algorithm you want to use for the estimation.
Results will be shown below by plotting series and detected change points.

5

Available data

Search:

Symb	From	To
FB.Open	2012-05-18	2016-07-28
FB.High	2012-05-18	2016-07-28
FB.Low	2012-05-18	2016-07-28
FB.Close	2012-05-18	2016-07-28

Select Select All

Selected data

Search:

Symb	Select some data from the table beside
No data available in table	

Delete Delete All

Method

Least Squares

Start Estimation

Loading Data → Explorative Data Analysis → Modeling → Simulation

Change Point Estimation

yuimaGUI

- Home
- Data I/O
- Explorative Data Analysis
 - Change Point Estimation
 - Clustering
- Modeling
- Simulate
- Finance

Here you can estimate change points.
Select data for which you want to estimate change points from table 'Available Data'.
Then choose the algorithm you want to use for the estimation.
Results will be shown below by plotting series and detected change points.

5

Available data

Search:

Symb	From	To
FB.Adjusted	2012-05-18	2016-07-28
AAPL.Adjusted	1980-12-12	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28
DJIA.Adjusted	1985-01-29	2016-07-28

Select Select All

Selected data

Search:

Symb	From	To
FTSE.Adjusted	1984-01-03	2016-07-06
GSPC.Adjusted	1950-01-03	2016-07-28
DJIA.Adjusted	1985-01-29	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28

Delete Delete All

Method

Kolmogorov - percentage increments

p-value (%)

0 1 2 3 4 5 6 7 8 9 10

Start Estimation

Loading Data → Explorative Data Analysis → Modeling → Simulation

Change Point Estimation



Loading Data → Explorative Data Analysis → Modeling → Simulation

Change Point Estimation

Finance <

FB.Adjusted	2012-05-18	2016-07-28
AAPL.Adjusted	1980-12-12	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28
DJIA.Adjusted	1985-01-29	2016-07-28

FTSE.Adjusted	1984-01-03	2016-07-06
GSPC.Adjusted	1950-01-03	2016-07-28
DJI.Adjusted	1985-01-29	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28

Kolmogorov - percentage increments ▾

p-value (%)

Select Select All Delete Delete All Start Estimation

§
Symbol
FTSE.Adjusted ▾

Scale
Logarithmic (Y) ▾

FTSE.Adjusted

FTSE.Adjusted - Percentage Increments

Loading Data → Explorative Data Analysis → Modeling → Simulation

Clustering

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Change Point Estimation
Clustering
Modeling
Simulate
Finance

Here you can perform clustering.
Select data you want to cluster from table 'Available Data'.
Then choose the distance you are interested in and the kind of linkage for the hierarchical cluster analysis.
Results will be shown below by plotting dendrogram and multidimensional scaling output.

Available data

Symb	From	To
FB.Open	2012-05-18	2016-07-28
FB.High	2012-05-18	2016-07-28
FB.Low	2012-05-18	2016-07-28
FB.Close	2012-05-18	2016-07-28

Select Select All

Selected data

Symb	Select some data from the table beside
No data available in table	

Delete Delete All

Linkage
Complete

Distance
Markov Operator

Start Clustering

Loading Data → Explorative Data Analysis → Modeling → Simulation

Clustering

yuimaGUI

- Home
- Data I/O
- Explorative Data Analysis**
 - Change Point Estimation
 - Clustering**
- Modeling
- Simulate
- Finance

Here you can perform clustering.

Select data you want to cluster from table 'Available Data'. Then choose the distance you are interested in and the kind of linkage for the hierarchical cluster analysis. Results will be shown below by plotting dendrogram and multidimensional scaling output.

5

Available data

Search:

Symb	From	To
FB.Adjusted	2012-05-18	2016-07-28
AAPL.Adjusted	1980-12-12	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28
DJIA.Adjusted	1985-01-29	2016-07-28

Select Select All

Selected data

Search:

Symb	From	To
FTSE.Adjusted	1984-01-03	2016-07-06
GSPC.Adjusted	1950-01-03	2016-07-28
DJIA.Adjusted	1985-01-29	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28

Delete Delete All

Linkage

Complete

Distance

Distribution of Returns

Start Clustering

Loading Data → Explorative Data Analysis → Modeling → Simulation

Clustering

Modeling
Simulate
Finance

Search:

Symb	From	To
FB.Adjusted	2012-05-18	2016-07-28
AAPL.Adjusted	1980-12-12	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28
DJI.Adjusted	1985-01-29	2016-07-28

Select Select All

Search:

Symb	From	To
FTSE.Adjusted	1984-01-03	2016-07-06
GSPC.Adjusted	1950-01-03	2016-07-28
DJI.Adjusted	1985-01-29	2016-07-28
CSCO.Adjusted	1990-03-26	2016-07-28

Delete Delete All

Linkage
Complete

Distance
Distribution of Returns

Start Clustering

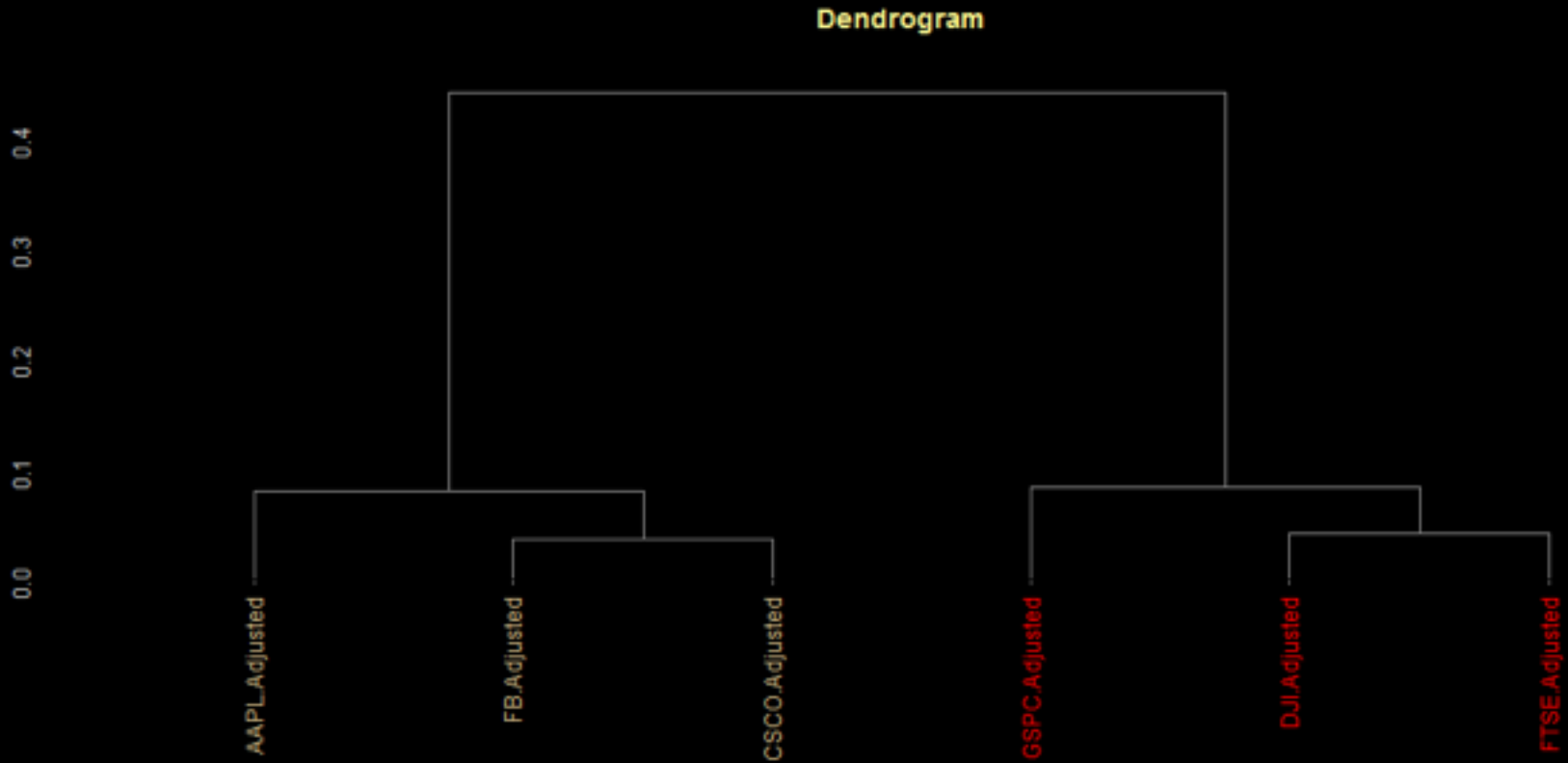
Dendrogram

Multidimensional scaling

Save dendrogram Save chart

Loading Data → Explorative Data Analysis → Modeling → Simulation

Clustering



Loading Data → Explorative Data Analysis → Modeling → Simulation

Loading Data —> Explorative Data Analysis —> Modeling —> Simulation

Univariate Modeling

The screenshot displays the 'yuimaGUI' interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling (selected), Univariate (selected), Simulate, and Finance. The main content area has a header: 'Here you can estimate models and/or define new ones.' Below this is a paragraph: 'To estimate models simply click those you are interested in and select data you wish to model. You can customize the estimation process by clicking on buttons 'Set Range' and 'Advanced Settings'. Some default models are available but you can set your own model (tab 'Set model') and use it for estimation and/or simulation purposes. Estimated models are shown in tab 'Estimates'.'

Below the text are three tabs: 'Start estimation', 'Set model', and 'Estimates'. The 'Set model' tab is active, showing a 'Model Class' dropdown menu with options: 'Diffusion process|', 'Diffusion process', and 'Compound Poisson'. Below this are two data selection tables. The 'Available data' table has a search bar and a table with columns 'Symb', 'From', and 'To'. The 'Selected data' table has a search bar and a table with columns 'Symb' and a dropdown menu. Below the tables are buttons: 'Select', 'Select All', 'Delete', 'Delete All', 'Set Range', 'Advanced Settings', and 'Start Models Estimation'.

Available data

Symb	From	To
FB.Open	2012-05-18	2016-07-28
FB.High	2012-05-18	2016-07-28
FB.Low	2012-05-18	2016-07-28
FB.Close	2012-05-18	2016-07-28

Selected data

Symb	Select some data from the table beside
No data available in table	

Loading Data → Explorative Data Analysis → Modeling → Simulation

Univariate Modeling

The screenshot displays the 'yuimaGUI' interface. On the left, a navigation sidebar includes 'Home', 'Data I/O', 'Explorative Data Analysis', 'Modeling' (selected), 'Univariate' (sub-selected), 'Simulate', and 'Finance'. The main panel features a header with the text: 'Here you can estimate models and/or define new ones. To estimate models simply click those you are interested in and select data you wish to model. You can customize the estimation process by clicking on buttons 'Set Range' and 'Advanced Settings'. Some default models are available but you can set your own model (tab 'Set model') and use it for estimation and/or simulation purposes. Estimated models are shown in tab 'Estimates'.' Below this, there are three tabs: 'Start estimation', 'Set model', and 'Estimates'. The 'Set model' tab is active, showing a 'Model Class' dropdown set to 'Diffusion process' and a 'Model Name' dropdown menu. The menu lists several models: Brownian Motion, Geometric Brownian Motion, Ornstein-Uhlenbeck (OU), Vasicek model (VAS), Constant elasticity of variance (CEV), Cox-Ingersoll-Ross (CIR), and Chan-Karolyi-Longstaff-Sanders (CKLS). Below the menu is a table of available data:

Symb	Start	End
FB.Low	2012-05-18	2016-07-28
FB.Close	2012-05-18	2016-07-28

Buttons for 'Select', 'Select All', 'Delete', and 'Delete All' are located below the table. To the right, a 'Selected data' section shows a search bar and a dropdown menu with the text 'Select some data from the table beside'. Below this, it states 'No data available in table' and shows a shaded area representing the selected data. On the far right, there are two buttons: 'Set Range' (green) and 'Advanced Settings' (red). At the bottom right, a large button labeled 'Start Models Estimation' is visible.

Loading Data → Explorative Data Analysis → Modeling → Simulation

Univariate Modeling

The screenshot shows the 'yuimaGUI' interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling (selected), Univariate (selected), Simulate, and Finance. The main content area has a header: 'Here you can estimate models and/or define new ones.' Below this is a paragraph explaining the estimation process and buttons for 'Start estimation', 'Set model', and 'Estimates'. The 'Set model' button is active. Under 'Model Class', 'Diffusion process' is selected. Under 'Model Name', 'Geometric Brownian Motion' and 'Chan-Karolyi-Longstaff-Sanders (CKLS)' are listed. To the right, under 'Models to estimate:', two stochastic differential equations are shown: $dX_t = \mu X_t dt + \sigma X_t dW_t$ and $dX_t = (\theta_1 + \theta_2 X_t) dt + \theta_3 X_t^{\theta_3} dW_t$. Below are two data tables: 'Available data' and 'Selected data'. The 'Available data' table has columns for 'Symb', 'From', and 'To', with rows for CSCO.Low, CSCO.High, CSCO.Close, and CSCO.Adjusted. The 'Selected data' table is currently empty, showing 'No data available in table'. At the bottom right are buttons for 'Set Range', 'Advanced Settings', and 'Start Models Estimation'.

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Univariate
Simulate
Finance

Here you can estimate models and/or define new ones.

To estimate models simply click those you are interested in and select data you wish to model. You can customize the estimation process by clicking on buttons 'Set Range' and 'Advanced Settings'. Some default models are available but you can set your own model (tab 'Set model') and use it for estimation and/or simulation purposes. Estimated models are shown in tab 'Estimates'.

Start estimation Set model Estimates

Model Class
Diffusion process

Model Name
Geometric Brownian Motion
Chan-Karolyi-Longstaff-Sanders (CKLS)

Models to estimate:

$$dX_t = \mu X_t dt + \sigma X_t dW_t$$
$$dX_t = (\theta_1 + \theta_2 X_t) dt + \theta_3 X_t^{\theta_3} dW_t$$

Available data

Symb	From	To
CSCO.Low	1990-03-26	2016-08-09
CSCO.High	1990-03-26	2016-08-09
CSCO.Close	1990-03-26	2016-08-09
CSCO.Adjusted	1990-03-26	2016-08-09

Select Select All

Selected data

Symb	Select some data from the table beside
No data available in table	

Delete Delete All

Set Range
Advanced Settings
Start Models Estimation

Loading Data → Explorative Data Analysis → Modeling → Simulation

Univariate Modeling

The screenshot shows the 'yuimaGUI' interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling (selected), Univariate (selected), Simulate, and Finance. The main content area has a header: 'Here you can estimate models and/or define new ones.' Below this is a paragraph explaining the estimation process and a progress indicator '5'. There are three tabs: 'Start estimation' (active), 'Set model', and 'Estimates'. Under 'Start estimation', there are two input fields: 'Model Class' (set to 'Diffusion process') and 'Model Name' (set to 'Geometric Brownian Motion' and 'Chan-Karolyi-Longstaff-Sandees (CKLS)'). To the right, under 'Models to estimate:', two stochastic differential equations are shown:
$$dX_t = \mu X_t dt + \sigma X_t dW_t$$
 and
$$dX_t = (\theta_1 + \theta_2 X_t) dt + \theta_3 X_t^{\theta_4} dW_t$$
. Below these are two tables: 'Available data' and 'Selected data'. Both tables have a search bar and columns for 'Symb', 'From', and 'To'. The 'Available data' table lists 'CSCO.Low', 'CSCO.High', 'CSCO.Close', and 'CSCO.Adjusted' with dates from 1990-03-26 to 2016-08-09. The 'Selected data' table shows 'CSCO.Adjusted' with the same dates. Below the tables are buttons for 'Select', 'Select All', 'Delete', and 'Delete All'. On the right side of the interface are buttons for 'Set Range' (green), 'Advanced Settings' (red), and 'Start Models Estimation' (grey).

Loading Data → Explorative Data Analysis → Modeling → Simulation

Univariate Modeling

The screenshot displays the 'yuimaGUI' interface with a central dialog box titled 'Select range to use for models estimation'. The dialog contains two line charts and a control panel. The top chart, 'CSCO.Adjusted', shows a price index from 1990 to 2015, with a sharp peak around 2000. The bottom chart, 'CSCO.Adjusted - Percentage Increments', shows the percentage change in the index over the same period. The control panel on the right includes dropdown menus for 'Chart Scale' (set to 'Linear'), 'Series' (set to 'CSCO.Adjusted'), and 'Range' (set to 'Full Range'). Below these are 'Apply' and 'Apply All' buttons. In the background, the main interface shows a sidebar with navigation options like 'Home', 'Data I/O', 'Explorative Data Analysis', 'Modeling', 'Univariate', 'Simulate', and 'Finance'. A 'Start e' button is visible, and at the bottom right, there are 'Set Range' and 'Advanced Settings' buttons, and a 'Start Models Estimation' button.

Loading Data → Explorative Data Analysis → Modeling → Simulation

Univariate Modeling

The screenshot shows the yuimaGUI interface. On the left is a navigation menu with options: Home, Data I/O, Explorative Data Analysis, Modeling (selected), Univariate (selected), Simulate, and Finance. The main panel displays a header "Here you can estimate models and/or define new ones." followed by instructions. Below this are three tabs: "Start estimation", "Set model", and "Estimates" (active). The active tab shows the model name "CSCO.Adjusted" and a "More info" link. The stochastic differential equation is displayed as $dX_t = \mu X_t dt + \sigma X_t dW_t$. A table shows the estimated parameters:

	sigma	mu
Estimate	0.3	0.11
Std. Error	0.004	0.08

Below the table is a "Base" dropdown menu set to "Yearly". At the bottom, a table lists the estimated models:

	Symb	Class	Model	Jumps	From	To	AIC	BIC
CSCO.Adjusted 1	CSCO.Adjusted	Diffusion process	Geometric Brownian Motion		2003-02-20	2016-08-09	2797.604	2809.862
CSCO.Adjusted 2	CSCO.Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)		2003-02-20	2016-08-09	2608.725	2633.241

Buttons for "Delete" and "Delete All" are located at the bottom right of the table area.

Loading Data → Explorative Data Analysis → Modeling → Simulation

Univariate Modeling

yuimaGUI

- Home
- Data I/O
- Explorative Data Analysis
- Modeling
 - Univariate
 - Simulate
- Finance

Here you can estimate models and/or define new ones.

To estimate models simply click those you are interested in and select data you wish to model. You can customize the estimation process by clicking on buttons 'Set Range' and 'Advanced Settings'. Some default models are available but you can set your own model (tab 'Set model') and use it for estimation and/or simulation purposes. Estimated models are shown in tab 'Estimates'.

5

Start estimation Set model **Estimates**

CSCO.Adjusted

[More Info](#)

$$dX_t = (\theta_1 + \theta_2 X_t) dt + \theta_3 X_t^{\theta_4} dW_t$$

	theta3	theta4	theta1	theta2
Estimate	2.6	0.27	17.1	-0.8
Std. Error	0.4	0.05	7.2	0.4

Base

Yearly

Search:

	Symb	Class	Model	Jumps	From	To	AIC	BIC
CSCO.Adjusted 1	CSCO.Adjusted	Diffusion process	Geometric Brownian Motion		2003-02-20	2016-08-09	2797.604	2809.862
CSCO.Adjusted 2	CSCO.Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)		2003-02-20	2016-08-09	2608.725	2633.241

Delete Delete All

Loading Data → Explorative Data Analysis → Modeling → Simulation

Building your model

The screenshot shows the 'yuimaGUI' interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling (selected), Univariate, Simulate, and Finance. The main panel is titled 'Here you can estimate models and/or define new ones.' and contains instructions: 'To estimate models simply click those you are interested in and select data you wish to model. You can customize the estimation process by clicking on buttons 'Set Range' and 'Advanced Settings'. Some default models are available but you can set your own model (tab 'Set model') and use it for estimation and/or simulation purposes. Estimated models are shown in tab 'Estimates'.'

At the top of the main panel are three tabs: 'Start estimation', 'Set model' (active), and 'Estimates'. Below the tabs are the following fields:

- Model Class:** A dropdown menu currently showing 'Diffusion process'.
- Model Name:** An empty text input field.
- Stochastic Differential Equation:** The equation $dX = a(t, X, \theta) dt + b(t, X, \theta) dW$ is displayed.
- Drift Function:** A text input field labeled $a(t, X, \theta)$.
- Diffusion Function:** A text input field labeled $b(t, X, \theta)$.
- Save Model:** A blue button at the bottom.

Loading Data → Explorative Data Analysis → Modeling → Simulation

Building your model

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Univariate
Simulate
Finance

Here you can estimate models and/or define new ones.

To estimate models simply click those you are interested in and select data you wish to model. You can customize the estimation process by clicking on buttons 'Set Range' and 'Advanced Settings'. Some default models are available but you can set your own model (tab 'Set model') and use it for estimation and/or simulation purposes. Estimated models are shown in tab 'Estimates'.

Model saved successfully

5

Start estimation | Set model | Estimates

Model Class: Diffusion process

Model Name: myMod

Saved Models: myMod

$$dX_t = (\cos(\alpha \cdot t + \beta)) dt + [\sigma] (dW_t)$$

$a(t, X, \theta)$: cos(alpha*t+beta)

$b(t, X, \theta)$: sigma

Save Model

Delete Model(s)

Loading Data → Explorative Data Analysis → Modeling → Simulation

Building your model

The screenshot shows the 'yuimaGUI' interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling (selected), Univariate, Simulate, and Finance. The main content area has a header: 'Here you can estimate models and/or define new ones.' Below this is a paragraph explaining the estimation process and a progress indicator showing '5' out of 5 steps. There are three tabs: 'Start estimation', 'Set model' (active), and 'Estimates'. Under 'Set model', there are input fields for 'Model Class' (set to 'Diffusion process') and 'Model Name' (set to 'myMod'). To the right, the text 'Models to estimate:' is followed by the stochastic differential equation: $(dX_t) = (\cos(\alpha \cdot t + \beta)) dt + [\sigma](dW_t)$. Below this are two data selection tables. The 'Available data' table lists FTSE.Low, FTSE.Close, FTSE.Volume, and FTSE.Adjusted, all with dates from 1984-01-03 to 2016-07-06. The 'Selected data' table shows FTSE.Adjusted with the same date range. To the right of the tables are buttons for 'Set Range' (green), 'Advanced Settings' (red), and 'Start Models Estimation' (grey).

Loading Data → Explorative Data Analysis → Modeling → Simulation

Loading Data —> Explorative Data Analysis —> Modeling —> Simulation

simulate Estimated Model

The screenshot displays the yuimaGUI interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling, Simulate (selected), and Finance. The main content area has a header "Here you can perform simulations." with explanatory text. Below this is a tabbed interface with "Simulate model" (active), "Simulate equation", and "Simulations". The "Available models" section contains a table with columns: Symb, Class, Model, Jumps, From, To, AIC, and BIC. Two rows are visible, both for "CSCO.Adjusted" models. Below the table are "Select" and "Select All" buttons. The "Selected Models" section is currently empty, showing a message "Please select models from the table above" and "No data available in table". To the right of this section are "Set Simulation" and "Advanced Settings" buttons.

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Simulate
Finance

Here you can perform simulations.

To simulate models that have been estimated on data simply select those you are interested in from table 'Available Models'.
If you want to simulate a model that has not been estimated you can specify its parameters values in tab 'Simulate equation' and select it.
You can customize the simulation process by clicking on buttons 'Set Simulation' and 'Advanced Settings'.
Simulations are shown in tab 'Simulations'

5

Simulate model Simulate equation Simulations

Available models

Search:

Symb	Class	Model	Jumps	From	To	AIC	BIC
CSCO.Adjusted 1	CSCO.Adjusted	Diffusion process	Geometric Brownian Motion	2003-02-20	2016-08-09	2797.604	2809.862
CSCO.Adjusted 2	CSCO.Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)	2003-02-20	2016-08-09	2608.725	2633.241

Select Select All

Selected Models

Search:

Symb Please select models from the table above

No data available in table

Set Simulation
Advanced Settings

Loading Data → Explorative Data Analysis → Modeling → Simulation

simulate Estimated Model

The screenshot displays the yuimaGUI interface. On the left is a navigation sidebar with options: Home, Data I/O, Explorative Data Analysis, Modeling, Simulate, and Finance. The 'Simulate' menu is expanded, showing 'Simulate' and 'Simulate' sub-items. The main content area has a header 'Here you can perform simulations.' followed by instructions: 'To simulate models that have been estimated on data simply select those you are interested in from table 'Available Models'. If you want to simulate a model that has not been estimated you can specify its parameters values in tab 'Simulate equation' and select it. You can customize the simulation process by clicking on buttons 'Set Simulation' and 'Advanced Settings'. Simulations are shown in tab 'Simulations'.

Below the instructions are three tabs: 'Simulate model' (active), 'Simulate equation', and 'Simulations'. The 'Available models' section contains a table with columns: Symb, Class, Model, Jumps, From, To, AIC, and BIC. Two rows are visible, both selected. Below the table are 'Select' and 'Select All' buttons. The 'Selected Models' section shows a table with the same columns, containing one selected row. To the right of this table are 'Set Simulation' and 'Advanced Settings' buttons.

Symb	Class	Model	Jumps	From	To	AIC	BIC
CSCO.Adjusted 1	CSCO.Adjusted	Diffusion process	Geometric Brownian Motion	2003-02-20	2016-08-09	2797.604	2809.862
CSCO.Adjusted 2	CSCO.Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)	2003-02-20	2016-08-09	2608.725	2633.241

Symb	Class	Model	Jumps	From	To
CSCO.Adjusted 2	CSCO.Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)	2003-02-20	2016-08-09

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Estimated Model

The screenshot displays the 'yuimaGUI' interface with a 'Set Simulation' dialog box open. The dialog box contains the following fields and controls:

- Simulation ID:** A dropdown menu showing 'CSCO.Adjusted 2'.
- Simulation interval:** Two date input fields: '2015-08-09' and '2017-08-09', with a 'to' separator. Below are 'Apply' and 'Apply All' buttons.
- Initial value:** A text input field containing '30.94'. Below are 'Apply' and 'Apply All' buttons.
- Number of simulations:** A text input field containing '1000'.
- Number of steps per simulation:** An empty text input field.
- Buttons:** 'Apply', 'Apply All', and 'Close' buttons.

The background interface shows the 'Available models' table and the 'Selected Models' table.

Symb	Class
CSCO.Adjusted 1	CSCO.Adjusted
CSCO.Adjusted 2	CSCO.Adjusted

Symb	Class
CSCO.Adjusted 2	CSCO.Adjusted

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Estimated Model

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Simulate
Finance

Here you can perform simulations.

To simulate models that have been estimated on data simply select those you are interested in from table 'Available Models'.
If you want to simulate a model that has not been estimated you can specify its parameters values in tab 'Simulate equation' and select it.
You can customize the simulation process by clicking on buttons 'Set Simulation' and 'Advanced Settings'.
Simulations are shown in tab 'Simulations'

5

Simulate model Simulate equation Simulations

Search:

Symb	Class	Model	Jumps	N sim	Simulated from	Simulated to	Estimated from	Estimated to
CSCO.Adjusted 1	CSCO.Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)	1000	2016-08-09	2017-08-09	2003-02-20	2016-08-09

Show Simulations Delete Delete All

Loading Data → Explorative Data Analysis → Modeling → Simulation

simulate Estimated Model

The screenshot displays the yuimaGUI interface with a sidebar on the left containing navigation options: Home, Data I/O, Explorative Data Analysis, Modeling, Simulate, and Finance. The main window is titled 'Simulation ID' and shows 'CSCO.Adjusted 1' selected in a dropdown menu. Below this, there are two main plots: a 'Trajectory' plot and a 'Histogram' plot. The 'Trajectory' plot shows a dense cloud of blue lines representing the time series data from September to July, with values ranging from approximately 15 to 45. The 'Histogram' plot shows the density distribution of the data, with a peak around 25 and a mean of 17.2682269481192. To the right of the plots, there are controls for 'Chart Scale' (set to 'Linear') and 'Adjust bin width' (set to 20). Below these controls, the 'Mean & Probability' section shows a probability of 5% and a mean of 17.2682269481192. A 'Save' button is located at the bottom right of the simulation results area.

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Equation

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Simulate
Finance

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Simulations are shown in tab 'Simulations'

5

Simulate model Simulate equation Simulations

$$(dX_t) = (\cos(\alpha \cdot t + \beta)) dt + [\sigma] (dW_t)$$

Class: Diffusion process Model Name: myMod Search:

Simulation ID: myMod simulation

Parameter: alpha Parameter value: 3

Save

Class	Model	alpha	beta	sigma	
myModsimulation	Diffusion process	myMod	3	MISSING	MISSING

Select Select All Delete Delete All

Selected Models Search:

Symb
Please select models from the table above
No data available in table

Set Simulation
Advanced Settings

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Equation

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Simulate
Finance

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5

Simulate model Simulate equation Simulations

$$(dX_t) = (\cos(\alpha \cdot t + \beta)) dt + [\sigma] (dW_t)$$

Class: Diffusion process Model Name: myMod Search:

Simulation ID: myMod simulation

Parameter: beta Parameter value: 0

Save

Class	Model	alpha	beta	sigma	
myModsimulation	Diffusion process	myMod	3	0	MISSING

Select Select All Delete Delete All

Selected Models Search:

Symb
Please select models from the table above
No data available in table

Set Simulation
Advanced Settings

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Equation

yuimaGUI

Home
Data I/O
Explorative Data Analysis
Modeling
Simulate
Finance

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Simulations are shown in tab 'Simulations'

5

Simulate model Simulate equation Simulations

$$(dX_t) = (\cos(\alpha \cdot t + \beta)) dt + [\sigma] (dW_t)$$

Class	Model Name	Search:
Diffusion process	myMod	

Simulation ID
myMod simulation

Parameter	Parameter value
sigma	0.25

Save

Class	Model	alpha	beta	sigma	
myModsimulation	Diffusion process	myMod	3	0	0.25

Select Select All Delete Delete All

Selected Models

Search:

Symb	Please select models from the table above
No data available in table	

Set Simulation
Advanced Settings

Loading Data → Explorative Data Analysis → Modeling → Simulation

simulate Equation

You can customize the simulation process by clicking on buttons 'Set Simulation' and 'Advanced Settings'. Simulations are shown in tab 'Simulations'

5

Simulate model Simulate equation Simulations

$$(dX_t) = (\cos(\alpha \cdot t + \beta)) dt + [\sigma](dW_t)$$

Class: Diffusion process Model Name: myMod Search:

Simulation ID: myMod simulation

Parameter: sigma Parameter value: 0.25

Save

Class	Model	alpha	beta	sigma	
myModsimulation	Diffusion process	myMod	3	0	0.25

Select Select All Delete Delete All

Selected Models Search:

Class	Model	alpha	beta	sigma	
myModsimulation	Diffusion process	myMod	3	0	0.25

Delete Delete All

Set Simulation Advanced Settings Start Simulation

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Equation

You can customize the simulation process by clicking on buttons 'Set Simulation' and 'Advanced Settings'. Simulations are shown in tab 'Simulations'

Simulate model Simulate equation Sim

Class
Diffusion process

Simulation ID
myMod simulation

Parameter
sigma

Save

Selected Models

Class	Model	alpha	beta	sigma	
myModsimulation	Diffusion process	myMod	3	0	0.25

Select Select All Delete Delete All

beta sigma

0 0.25

Set Simulation Advanced Settings

Delete Delete All Start Simulation

Set Simulation

Simulation ID
myModsimulation

From To
0 10
Apply Apply All

Initial value
1
Apply Apply All

Number of simulations
1

Number of steps per simulation
Apply Apply All

Close

$dt + [\sigma](dW_t)$

Loading Data → Explorative Data Analysis → Modeling → Simulation

Simulate Equation

yuimaGUI

- Home
- Data I/O
- Explorative Data Analysis
- Modeling
- Simulate**
 - Simulate
- Finance

Here you can perform simulations.

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Simulate model Simulate equation **Simulations**

Search:

	Symb	Class	Model	Jumps	N sim	Simulated from	Simulated to	Estimated from	Estimated to
CSCO Adjusted 1	CSCO Adjusted	Diffusion process	Chan-Karolyi-Longstaff-Sanders (CKLS)		1000	2016-08-09	2017-08-09	2003-02-20	2016-08-09
myModsimulation 1	myModsimulation	Diffusion process	myMod		1	0	10		

Show Simulations Delete Delete All

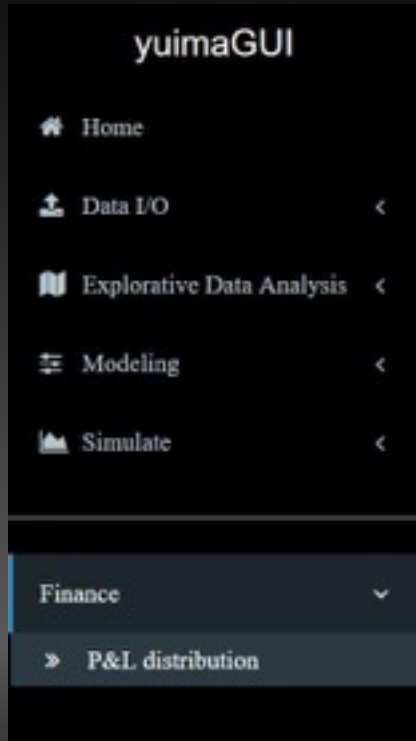
Loading Data → Explorative Data Analysis → Modeling → Simulation

simulate Equation



Loading Data → Explorative Data Analysis → Modeling → Simulation

Task-specific sections

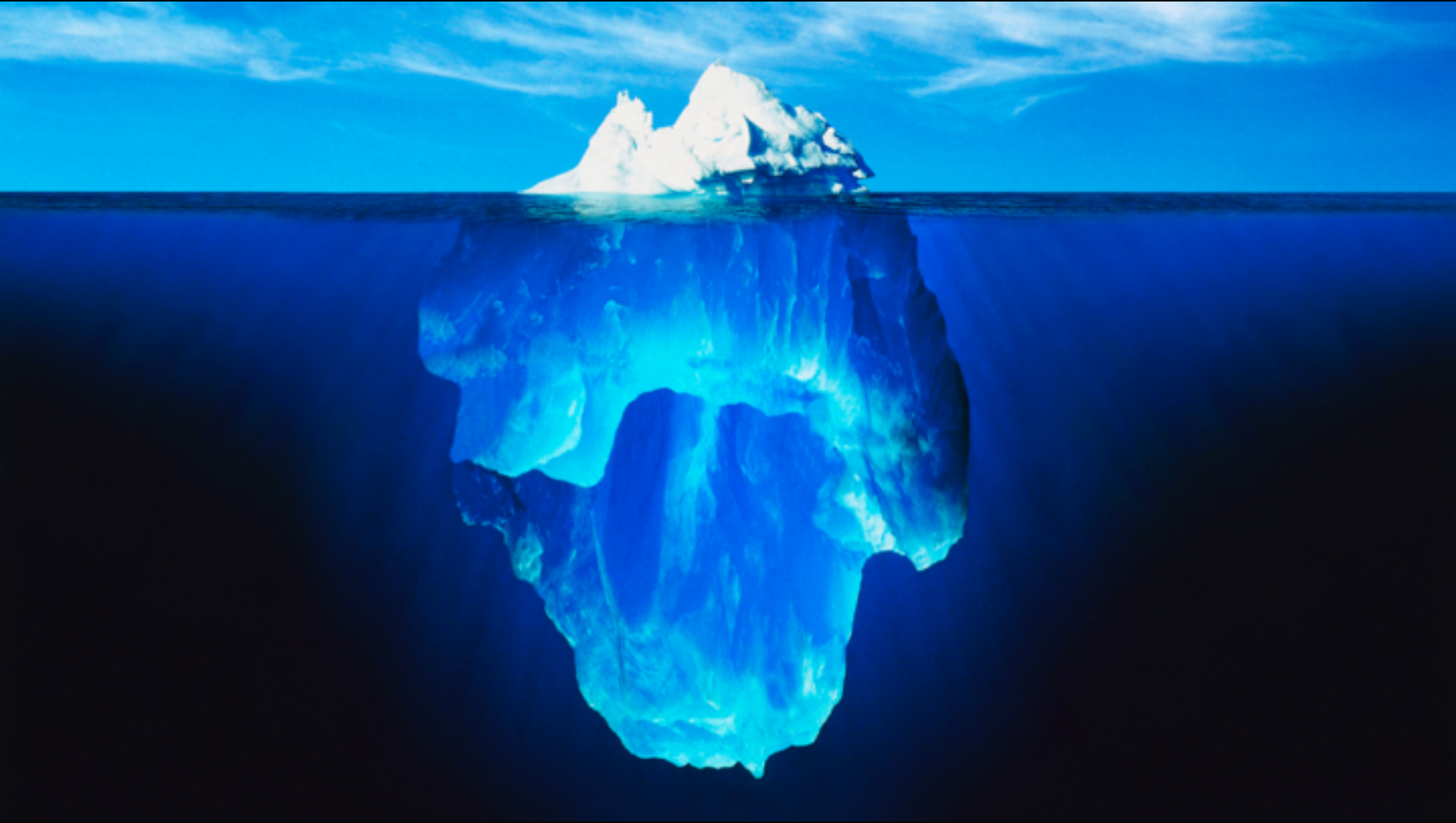


Typical usage of yuimaGUI



Task-specific sections

Just the point of the iceberg



This presentation only shows a little portion of both **yuima** and **yuimaGUI** capabilities

Install `yuimaGUI`!

```
### install dependencies
install.packages("yuima")
install.packages("yuimaGUI")

library(yuima)
library(yuimaGUI)

yuimaGUI() # runs the shiny GUI
```

Thank You



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