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Java Applet for the Pricing of Exotic Options by Monte-Carlo Simulations in a Lèvy market with Stochastic Volatility

by

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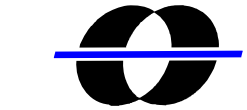

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Java Applet for the Pricing of Exotic Options by Monte-carlo simulations in a Lèvy market with Stochastic Volatility

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"We must accept finite disappointment, but we must never lose infinite hope".
--Dr. Martin Luther King Jr

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Abstract

Most financial models including the famous Black & Scholes model assumes constant volatility. However in recent times modellers at major financial institutions are modelling stock prices based on stochastic volatility models. One such way is when stock prices are assumed to undergo Lévy processes with stochastic volatility.

Based on this, exotic options like the barrier and look back options are priced using Monte-Carlo simulations. The sampling of the processes is based on time changed technique of the Lévy processes involved. A Java applet is developed to price this options and to calculate the standard errors.

Executive summary

In the last couple of years, the size of world's exotic options market has grown considerably. Today a large diversity of such instruments is accessible to investors and they can be used for numerous purposes. Numerous factors can provide a clarification for the recent success of these instruments. One likelihood is their almost boundless flexibility in the sense that they can be personalized to meet the precise needs of any investor. Hence them being sometimes referred to as customer-tailored options or special-purpose options.

These options also play an important hedging role and, thus, they meet the hedgers' needs in gainful ways. Corporations have left buying some form of general protection to designing strategies to meet precise exposures to risk at a given point in time. These strategies can be based on exotic options which are less expensive and much more efficient than standard instruments. Many exotic options have been priced either numerically or analytically.

The approach we adopt for pricing is based on Monte Carlo simulations and it is implemented in Java.

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Introduction

The revolution of financial instruments pricing was escalated with the introduction of the famous continuous time Black-Scholes model. It prices stocks or indices with the assumption that their returns undergo log normal distribution. The price process of the underlying is given by the geometric Brownian motion

$$S_t = S_0 \exp\left(\left(\mu - \frac{\sigma^2}{2}\right)t + \sigma W_t\right),$$

where $\{W_t, t \geq 0\}$ is a standard Brownian motion .With this formula various options can be developed, mainly the plain vanilla options and the exotic options , one of particular interest for this thesis is the pricing of the exotic options(so called path dependent options) of European nature.

The plain vanilla products have standard well-defined properties and trade actively. Their prices or implied volatilities are quoted by exchanges or by brokers on a regular basis. One of the exciting aspects of over-the-counter derivatives market is the number of non-standard (or exotic) products that have been created by financial engineers. Even though the usually make up a very small percentage of a portfolio they are usually much more profitable than the plain vanilla products. Exotic options are created for a number of reasons. Sometimes they meet a genuine hedging need in the market; there could be tax, accounting, legal or regulatory reasons why corporate treasurers find exotic option attractive. They could also be designed to reflect a corporate treasurers perceptions about the future movement of a market variable. However because of its flexible nature they can be made to seem more attractive than it is for an unwary corporate treasurer.

In this paper interest is focused on the so called barrier options and the lookback options to investigate the pricing procedures. Since there exist traditional pricing procedures a method by way of the principles of Lévy processes is adopted. It is also investigated into detailed the idea of stochastic volatility which is incorporated, this is a drawback in the Black-Scholes model which assumes a constant volatility. Hence for any pricing the value is dependent heavily on the choice of the constant volatility estimate. The relaxation of these strong assumption in the Black-Schole world makes modelling much more realistic.

Analytical formulas are available in the BS-world however numerical procedures need incoporated if the Lévy stochastic volatility modelling is to be used. Path-dependent options

are now very popular in the OTC market in these last decades. Examples of exotic type path-dependent options are lookback options and barrier options. The lookback option gives its holder the right but not the obligation to buy (call type lookback) or sell (put type look back) the stock at the minimum or maximum respectively it has attained over the life of the option. The value of barrier option depends on whether the price of the underlying asset crosses a given threshold (the barrier) before maturity. The simplest barrier options are "knock in" options which become alive when the price of the underlying asset touches the barrier and "knock-out" options which goes out of existence (become dead) in the case. E.g. an up-and-out call or put has the same payoff as a regular plain vanilla call or put whiles the price of the underlying assets stays below the barrier during the life of the option but becomes valueless as soon as the price of the underlying asset crosses the barrier. The Black-Scholes framework gives a closed-form option pricing formulae for the above types of barrier and lookback options ([2]). It has been established that the log-returns of most financial assets are asymmetrically distributed and have an actual kurtosis that is higher than that of the Normal distribution. The Black-Scholes model is thus a very poor model for describing stock price dynamics. In real life traders aware that the future probability distribution of an underlying asset may not always be log normal hence they use a volatility smile adjustment. The volatility smile-effect is diminishing with time to maturity. To price a set of European vanilla options, one uses for every strike K and for each maturity T a chosen volatility parameter which is basically wrong since this implies that only one underlying stock/index is modeled by a number of utterly different stochastic processes. What is more,one cannot guarantee that the choice of volatility parameters can be used to price exotic options.

To handle the non-Gaussian nature of the log-returns, in the last two decades several other models, based on more complicated distributions, were proposed. In these models the stock price process where considered to be an exponential of a so-called Lèvy process. As for a Brownian motion, the Lèvy process has stationary and independent increments; however the distribution of the increments must now belong to the class of infinitely divisible laws. Choosing this law is crucial in the modeling and it should reflect the stochastic behavior of the log-returns of the asset.

In [3] (Madan and Seneta) and in [4] (Barndorff-Nielsen) proposed a Lèvy process with Variance Gamma and Normal Inverse Gaussian (NIG) distributions respectively. These models are better at calibration of model prices to market prices than the BS-models, even though this will not be investigated in this paper it is worth mentioning. The models are better

fit to historical data as well. Even with a significant improvement in accuracy with respect to the BS-model by financial modelers, there is still is a discrepancy between model prices and market prices. In using these Lèvy models one need to note the main feature which these models are missing, i.e. the fact that the volatility or more general the environment is varying stochastically over time. Stochastic volatility is a stylized feature of financial time series of log-returns of asset prices.

To deal with this problem, one begins with the Black-Scholes setting and makes the volatility parameter itself stochastic. A variety of choices can be made to describe the stochastic behavior of the volatility. The Cox-Ingersoll-Ross (CIR) square root process was mentioned and used in this case as proposed in [6].

The focus was on the introduction of the stochastic situation through the stochastic time change as proposed in [6]. This technique is not necessarily used starting from the BS-model, but could be used with Lèvy models as well. In these stochastic volatility models the business time (of the Lèvy process) is made stochastic, i.e. in periods with high volatility time is running fast, and in periods with low volatility the time is running slow. For this rate of time process, leads to the choice of the proposal in [6] a classical example of a mean-reverting positive process: the CIR process. Based on these models and the idea of Monte-Carlo simulations a Java applet was developed to price barrier and look back options. Finding explicit formulae for exotic options is very difficult if not impossible in these models. However, once the model is calibrated to a basic set of options, it is easy to price other (exotic) options using Monte-Carlo simulations. With the choice of the time-changing process (ie.in my case CIR) the complexity of the simulation is not made any more difficult than the Lèvy process.

In section 5.0 I performed a number of simulations to compute option prices for both the VG and NIG models. I also did simulations to compute the standard error of the models option prices. It is shown in [1] that the standard error of the simulations can be reduced if the technique of control variates is used however this was not investigated in this paper.

Derivatives pricing

All the way through the text I denote the daily interest rate with r and the dividend yield per year with q unless otherwise stated. Assumption of a fixed forecasting horizon T and a market

with a single riskless asset (one bond) with a price process given by $B = \{B_t = e^{rt}, 0 \le t \le T\}$ and one risky asset (the stock) with price process $S = \{S_t, 0 \le t \le T\}$. Focus is on the European-type derivatives, hence no exercise prior to expiration is possible. For the market model, let $G(\{S_u, 0 \le u \le T\})$ represent the payoff of the derivative at its time of expiry T.

According to the fundamental theorem of asset pricing [15] the arbitrage free price P_t of the derivative at time $t \in [0,T]$ is given by $P_t = E^Q\left[e^{-r(T-t)}G(\{S_u, 0 \le u \le T\}) \middle| f_t\right]$, where the expectation is taken with respect to an equivalent martingale measure Q and $f = \{f_t, 0 \le t \le T\}$ is the natural filtration of the price process $S = \{S_t, 0 \le t \le T\}$. An equivalent martingale measure is a probability measure which is equivalent (.i.e. has the same null-sets) to the given (historical) probability measure and under which the discounted process $\{e^{-r(T-t)}S_t\}$ is a martingale. Models with only one equivalent measures are said to be complete and those with more than one equivalent measures are said to be incomplete.

Vanilla options

Carr and Madan [11] were the first to develop a general pricing method, which is applicable when the characteristic function of a risk-neutral stock price process is known. In [11] it was shown that the price of an European call option C(K,T) with strike K expiration T and α being a positive constant such that the αth moment of the stock price exist is given by

$$C(K,T) = \frac{\exp(-\alpha \log(K))}{\pi}\int_0^{+\infty} \exp(-iv\log(K))\psi(v)dv,$$

where α is a positive constnt ,and the characteristic function

$$\psi(v) = \frac{e^{-rT}E[\exp(i(v-(\alpha+1)i)\log(S_T))]}{\alpha^2+\alpha-v^2+i(2\alpha+1)v}$$

The price of an the corresponding put option can be found using the put-call parity.

Exotic options

Barrier and Lookback options

To explain the valuation of the lookback and barrier options, first consider an option contract that expires at time T, and has a maximum and minimum process respectively. If the process is $Y = \{Y_t, 0 \le t \le T\}$, then let the maximum process be;

$$M_t^Y = \sup\{Y_u; 0 \le u \le t\},$$

and the minimum process being $m_t^Y = \inf\{Y_u; 0 \le u \le t\}, \quad 0 \le t \le T$. Then using the risk-neutral pricing, the price of a lookback call option is given by

$$LC = e^{-rT} E^Q \left[S_T - m_T^s \right],$$

and that of a lookback put option is given by

$$LP = e^{-rT} E^Q \left[M_T^S - S_T \right].$$

For barrier options, specifically the single barrier type options, the following are considered.

Down-and-out barrier option:

This type of barrier option is worthless except if its minimum remains above some level H. Usually this level H is initially set below the initial value of the underlying (stock). If it remains above the barrier H until maturity then it retains the structure of an European call or put with strike K.The initial price at t =0 is

$$DOB_{call} = e^{-rT} E^Q \left[(S_T - K)^+ 1(m_T^S > H) \right]$$

and

$$DOB_{put} = e^{-rT} E^Q \left[(K - S_T)^+ 1(m_T^S > H) \right]$$

for a Call and Put ,respectively.

Down-and-in barrier option:

This type of barrier option is worthless except if its minimum went below some level H. Usually this level H is initially set below the initial value of the underlying asset (stock). If it remains above the barrier H until maturity then it is worthless. However if its minimum goes below the barrier H then it retains the structure of an European call or put with initial price i.e. at t =0, given by;

$DIB_{call} = e^{-rT} E^Q \left[(S_T - K)^+ 1(m_T^S \le H) \right]$ for a call contract and

$$DIB_{put} = e^{-rT} E^{Q}\left[(K - S_T)^{+} 1(m_T^S \le H) \right]$$ for a put contract

Up-and-in barrier option:

This type of barrier option is worthless except if its maximum goes above some level H. Usually this level H is initially set above the initial value of the underlying (stock). If this barrier is crossed during the life of the contract; it retains the structure of an European call or put with strike K. The initial price is therefore given by

$$UIB_{call} = e^{-rT} E^{Q}\left[(S_T - K)^{+} 1(M_T^S \ge H) \right]$$ for a call contract and

$$UIB_{put} = e^{-rT} E^{Q}\left[(K - S_T)^{+} 1(M_T^S \ge H) \right]$$ for a put contract.

Up-and-out barrier option

This type of barrier option is worthless except if its maximum remains below some level H. Usually this level H is initially set above the initial value of the underlying (stock). If this barrier is never crossed during the life of the contract, then it retains the structure of an European call or put with strike K. The initial price, t =0, is therefore given by

$$UOB_{call} = e^{-rT} E^{Q}\left[(S_T - K)^{+} 1(M_T^S < H) \right]$$ for a call contract and

$$UOB_{put} = e^{-rT} E^{Q}\left[(K - S_T)^{+} 1(M_T^S < H) \right]$$ for a put contract .

It can be easily observed that a vanilla option with strike K can be constructed from either a combination of a DIB and DOB options with barrier H and strike K.Likewise a combination of UIB and UOB with same strike K and barrier H will give a corresponding vanilla with strike K. Letting C and P denote call and Put price respectively, then

$$DIB_{call} + DOB_{call} = \exp(-rT)E^{Q}\left[(S_T - K)^{+} \left(1(m_T^S \le H) + 1(m_T^S > H)\right) \right]$$

$$= \exp(-rT)E^{Q}\left[(S_T - K)^{+} \right]$$

$$= C(K,T);$$

$$DIB_{put} + DOB_{put} = \exp(-rT)E^{Q}\left[(K - S_T)^{+} \left(1(m_T^S \le H) + 1(m_T^S > H)\right) \right]$$

$$= \exp(-rT)E^{Q}\left[(K - S_T)^{+} \right]$$

$$= P(K,T);$$

For the up and in barrier options the illustration is as follows;

$$UIB_{call} + UOB_{call} = \exp(-rT)E^{Q}\left[(S_T - K)^{+} \left(1(m_T^S \ge H) + 1(M_T^S < H)\right) \right]$$

$$= \exp(-rT)E^{Q}\left[(S_T - K)^{+} \right]$$

$$= C(K,T);$$

$$UIB_{put} + UOB_{put} = \exp(-rT)E^{Q}\left[(K - S_T)^{+} \left(1(m_T^S \ge H) + 1(M_T^S < H)\right) \right]$$

$$= \exp(-rT)E^{Q}\left[(K - S_T)^{+} \right]$$

$$= P(K,T);$$

Hence it can be concluded that the price of a plain vanilla option is related with that of a corresponding barrier option. The price process of the underlying are in practice usually observed at a close of a trading day to check if a barrier has been crossed, for the above formulation however, observations are assumed to be on a continuous basis. [7] and [8] proposes a ways of adjusting the Black-Scholes setting for the case of discrete observations for a lookback options and barrier options respectively. For barrier H is replaced with $H\exp\left(0.582\sigma\sqrt{T/m}\right)$ for an up-and-in or up-and-out and $H\exp\left(-0.582\sigma\sqrt{T/m}\right)$ for the DIB and DOB options.where m is the number of observations and T/m is the time between

observations.In this paper a year is assumed to be 250 days and observations are assumed to be made at the end of a trading day.

Lévy processes

Any real valued stochastic process ($X_{t\in[0,\infty)}$) on a filtered probability space $\left(\Omega, F_{t\in[0,\infty),} P\right)$ is said to be a Lévy process if

(a) It starts at zero i.e for a stochastic process $X=\{X_t, t\geq 0\}, X_0=0,$ with $P(X_0=0)=1$.

(b) Its increments are independent, i.e. for $0\leq s<s_1<s_2....<s_n<\infty$, $X_{S_1}-X_S$, and $X_{S_2}-X_{S_1}$ ... are independent random variables

(c) Has stationary increments (ie.time homogenous) i.e for $t\geq 0, X_{t+h}-X_t$ has the same distibutions as X_h. It therefore means the distributions of increments does not depend on t but depends on the distance between two time moments.

(d) It is a continuous stochastic process i.e. $\forall \varepsilon>0, \lim_{h\to 0} P\left(\left|X_{t+h}-X_t\right|\geq\varepsilon\right)=0$.

(e) Its sample path (trajectories) is right continuos with left limit almost surely,i.e,

$\forall t\in[0,T),$

$\lim_{s\to t, s>t} X_s = X_{t+}$,

$\lim_{s\to t, s<t} X_s = X_{t-}$

and $X_{t+}=X_t$,

As you can see, the fact that left continuity is not needed allows the process to have jumps.It can be proved that X_t has an infinitely divisible distibution for $\forall t\in[0,T),$.

Let *X* be a random variable with its probability density function $\mathbb{P}\trianglelefteq \not\trianglerighteq$. From[16] a characteristic function $\phi_x(w)$ with $\omega\in\mathbb{R}$ is defined as the Fourier transform of the probability density function $\mathbb{P}\trianglelefteq \not\trianglerighteq$

$$\phi_x(w)\equiv f\left[\mathrm{P}(x)\right]\equiv\int_{-\infty}^{\infty} e^{iwx}\mathrm{P}(x)dx\equiv E\left[e^{iwx}\right]$$

From [16], a real valued random variable *X* with a probability density function P(x) and a characteristic function $\phi_x(w)$ is said to be infinitely divisible if for $\forall t \in [0,T)$, there exist i.i.d random variables $X_1, X_2, ..., X_n$ with a characteristic function $\phi_{X_i}(w)$ such that:

$$\phi_X(w) = \left(\phi_{X_i}(w)\right)^n \text{ .....(1)}$$

or

$$(\phi_X(w))^{1/n} = \phi_{X_i}(w)$$

$\mathbb{P}\trianglelefteq \not\trianglerighteq$ is said to be an infinitely divisible distribution.

In [16] it is proposed and proved that, If $X_{t\in[0,\infty)}$ is a real valued Lévy process on a filtered probability space $(\Omega, F_{t\in[0,\infty),} P)$, then X_t has an infinitely divisible distribution for $\forall t \in [0,T)$. Where $\Phi(w; X_t)$ is the characteristics function of X_t and $\Phi(w; X_{t_i - t_{i-1}})$ be the characteristic function of the i.i.d increments.It is obvious from the property of characteristic functions(ie.for independent random variables the characteristic function of their sum is equal to the product of their characteristic functions).

Hence if $\{X_k, k = 1,2,..n\}$ then

$$\phi_{X_1, X_2, ... X_n}(w) = \prod_{k=1}^{n} \phi_k(w),$$

making equation (1) hold for such a characteristic function $\phi_X(w)$ given for $\forall w \varepsilon R$,

$$\phi_X(w) = \exp(\psi_X(w)).$$

where $\psi_X(w)$ is a log Characteristics function given by [1] as;

$$\psi_X(w) = -\frac{Aw^2}{2} + i\gamma w + \int_{-\infty}^{\infty} \left\{\exp(iwx) - 1 - iwx1_{\{|x|\le 1\}}\right\} L(dx) \text{.....(2)}$$

where A= unique non-negative constant called the Gaussian variance ($ie.\sigma^2$)

γ is a real constant

L is a measure on R satisfying

$L(\{0\}) = 0$, *and*

$$\int_{-\infty}^{\infty} \min\left\{|x|^2, 1\right\} L(dx) < \infty$$

which is a Lévy measure .

From (2), it can be seen that Lévy processes consist of three parts: linear deterministic parts(drift) i.e (iγ w),brownian part (.ie. $-\frac{Aw^2}{2}$) and the pure jump part. This triplets are written as (γ ,A,L(dx)).The Lévy measure dictates how the jumps occur. For A=0, $\int_{-\infty}^{\infty}\{|x|^2,1\}Ldx<\infty$, then from the theory of standard Lévy processes, the process has finite variation. However for A=0, $\int_{-\infty}^{\infty}\{|x|^2,1\}Ldx=\infty$, and the process has infinite variation.

Examples of Lévy processes

The Normal Inverse Gaussian process:

The Normal inverse Gaussian (NIG) distrubution was introduced initially by Barndorff-Nielsen[9] and later work was done by other researchers such as Rydberg ,T(1996)[10]
The density of NIG(α,β,δ) distribution is given as

$$f_{NIG}(x:\alpha,\beta,\delta)=\frac{\alpha\delta}{\pi}\exp(\delta\sqrt{\alpha^2-\beta^2}+\beta x)\frac{K_1(\alpha\sqrt{\delta^2+x^2})}{\sqrt{\delta^2+x^2}}$$

From [9] it is known that the characteristic function of the NIG distribution with parameters $\alpha<0,-\alpha<\beta<\alpha,$ and $\delta>0$,is given by

$$\phi_{NIG}(u;\alpha,\beta,\delta)=\exp(-\delta(\sqrt{\alpha^2-(\beta+iu)^2}-\sqrt{\alpha^2-\beta^2})),$$

clearly it is an infinitely divisible characteristic function.Its Lévy measure is given by [1] as $L_{NIG}(dx)=\frac{\delta\alpha}{\pi}\frac{\exp(\beta x)K_1(|x|)}{|x|}dx$,

Its Lévy triplet is given as [γ_{NIG},0,$L_{NIG}(dx)$] where $\gamma_{NIG}=(\frac{2\delta\alpha}{\pi})\int_0^1\sinh(\beta x)K_1(\alpha x)dx$ and $K_1(x)$ denotes the modified Bessel function of the third kind with index 1(see[14]).

The Variance Gamma process:

The variance gamma (VG) process is defined by evaluating a Brownian motion with drift θ and volatility σ at a gamma time.

$$X_{VG}(t;\sigma,L,\theta)=\theta G_t^L+\sigma W(G_t^L)$$

where

G_t^L = gamma process with mean rate t and variance rate rt

The probability density function of the VG-distrubuted random variable G at time t is

$$f(G) = \frac{G(t/L)^{-1}e^{-G/L}}{L^{t/L}\Gamma(\frac{t}{L})}$$ where L is the Lévy measure

The Characteristic function of the VG process is evaluated as

$$\phi_{VG}(u;\sigma\sqrt{t}, L/t, t\theta) = E\left[e^{iuX_{VG}(t)}\right] = (1 - iu\theta L + \sigma^2 L\frac{u^2}{2})^{-t/L}$$

This distribution is infinitely divisible and defined as the VG-process $X_{VG} = \left\{X_t^{(VG)}, t \geq 0\right\}$, which is a process which starts at zero, has independent and stationary increments and where the increments $X_{s+t}^{VG} - X_s^{VG}$, over the time interval [s,s+t] follows a VG($\sigma, \frac{L}{t}, t\theta$) law. In [5] it was shown by Carr, Chang and Madan that the variance gamma process may also be expressed as the difference of two independent gamma process with one describing the up move and one describing the down moves.This characterisation allows the Lévy measure to be determined:

$$L_{VG}(dx) = \begin{cases} C\exp(Gx)|x|^{-1}dx, x < 0 \\ C\exp(-Mx)x^{-1}dx, x > 0 \end{cases}$$

where

$C = \frac{1}{L} > 0$,

$$G = \left(\sqrt{\frac{\theta^2L^2}{4} + \frac{\sigma^2L}{2}} - \frac{\theta L}{2}\right)^{-1} > 0,$$

and

$$M = \left(\sqrt{\frac{\theta^2L^2}{4} + \frac{\sigma^2L}{2}} + \frac{\theta L}{2}\right) > 0.$$

The parameters C, G and M have various characteristics. C controls the overall activity rate of the process. The parameters G and M govern rate at which arrival rates decline with size of

the move. The average of G and M can be regarded as the measure of the size premium.The difference between G and M is also regarded as directional premium .

Since $\int_{-\infty}^{\infty}\{|x|^2,1\}Ldx<\infty$, a VG-process has infinetely many jumps in any finite time interval.

The VG-process has no Brownian component and its Lévy triplet is given $[\gamma,0,L_{VG}(dx)]$.

The Lévy-stochastic Volatility Modelling

In [4] Carr, Madan, Geman and Yor proposed that one can increase or decrease the level of uncertainty by speeding up or slowing down the rate at which time passes. They also suggested that in order to keep time changes going forward one need to employ a mean reverting positive process as a measure of the local rate of time change. The classical example of a mean reverting positive process is the square root process of Cox, Ingersoll, and Ross(CIR). Hence we define y(t) as the solution to the stochastic differential equation

$$dy = k(\eta - y)dt + \lambda\sqrt{y}dW_t \quad \text{.....(3)}$$

where

W_t is a Brownian motion independent of any process,

λ is the volatility of time change(uncertainty of time change),

k is the rate of mean reversion and

η is the long run mean

The process y(t) is the instantaneous rate of time change and so the new clock is given by its integral ,

$$Y(t)=\int_0^t y(u)du \quad \text{.....(4)}$$

The (risk neutral) price process of the stock $S=\{S_t,0\le t\le T\}$ is now modelled as follows

$$S_t = S_0\frac{\exp((r-q)t)}{E[\exp(Z_t)]}\exp(Z_t)$$

by letting Z_t =X(Y(t)) ,

and where $X=\{X_t,0\le t\le T\}$ is a Lévy process with $E[\exp(iuX_t)]=\exp(t\psi_x(u))$.

By deduction it can easily be derived that

$$S_t = S_0 \exp\left[(r-q)t + X_{Y(t)} - Y_t.\psi_x(-i) \right],$$

where for the VG process

$$\psi_x(-i) = -\frac{1}{L_{VG}} \log\left[1 - \frac{\sigma^2 L_{VG}}{2} - \theta L_{VG} \right]$$

and for the NIG process

$$\psi_x(-i) = \frac{1}{L_{NIG}} - \frac{1}{L_{NIG}} \sqrt{1 - \sigma^2 L_{NIG} - 2\theta L_{NIG}}$$

Monte Carlo simulation of stochastic volatility Lévy processes:

The fundamental principle is to first simulate some number of paths, lets say n paths, of our stock price process and then calculate for every single path the payoff function V_i, i=1,....n. Then by Monte-Carlo the expected payoff is estimated as the mean of all the payoffs from all the paths as the sample mean

$$\overline{V} = \frac{1}{n} \sum_{i=1}^{n} V_i \quad \text{.....(5)}$$

The present value of the payoff is given by discounting the sample mean(5) with the annual risk free rate **r** from expiration time in **T** years as $\exp(-rT)\overline{V}$.
The standard error of the estimate is found as:

$$\sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (\overline{V} - V_i)^2}$$

It can be observed that the standard error decreases with the square root of the number of number of sample paths. Hence one can reduce the standard error by half if four times as many sample paths are generated.
Now the question is how do we even simulate the stock price process as a Lévy process?

First the length of business year is chosen as 250 days.

1. Simulate the rate of time change process using the (3) , the discretize version of the CIR(3) is as follows;

$y = \{y_t, 0 \le t \le T\}$

$\Delta y_t = k(\eta - y_t)\Delta t + \lambda\sqrt{y_t}\Delta W_t$

2. From 1 above the time change $Y = \{Y_t, 0 \le t \le T\}$ is calculated, where $Y_0 = 0$, Y is the stochastic business time.

3. The Lévy process $X = \{X_{Y_t}, Y_0 \le Y_t \le Y_T\}$ is then simulated. This is done over the period $[0, Y_T]$.

4. Then the time changed Lévy process X_{Y_t}, for $t \in [0,T]$ is calculated.

5. Calculate the stock price process $S = \{S_t, 0 \le t \le T\}$.

6. Calculate a significant number n of paths for the stock price $S^i = \{S_t^i, 0 \le t \le T\}$ and for each path i the payoff g: i.e. $g_i = G(\{S_t^i, 0 \le t \le T\})$,where $G(\{S_t^i, 0 \le t \le T\})$ is the payoff function for an European exotic option expiring at time T.

7. Calculate the estimation of the expected payoff by

$$\bar{g} = \frac{1}{n}\left(\sum_{i=1}^{n} g_i\right)$$

8. Then finally calculate the price today,

$$price = \exp(-rT)\bar{g}$$

In simulating a variance Gamma process on our fixed time grid, the following algorithm was used from [12].

Firstly we generate Gamma variables using the algorithms below:

Let

$$a = \frac{Y_t - Y_{t-1}}{v}, \theta = C\left(\frac{1}{M} + \frac{1}{G}\right), \sigma = \sqrt{\frac{2C}{GM}}$$

Then generate i.i.d uniform [0,1] random variables U,V.

Then set $x = U^{1/a}, y = V^{1/(1-a)}$

Until $x + y \le 1$

Secondly generate an exponential random variable E

Return $G = \frac{xE}{x + y}$

Now we simulate the variance Gamma process on a fixed time grid with parameter

$a = \frac{Y_t - Y_{t-1}}{v}$

Set $\Delta G_i = v\Delta G_i$ for all i

Then simulate n i.i.d. N(0,1) random variables $N_1,....N_n$.

Set $\Delta X_t = \sigma N_i \sqrt{\Delta G_i} + \theta \Delta G_i$ for all i,

The discretized trajectory is $X_{Y_t} = \sum_{t=1}^{i} \Delta X_t$

In simulating a Normal inverse Gaussian process on our fixed time grid, the following alorithm was used from [12];

First generate an inverse Gaussian variable.

Generate a normal random variable N,

Set $Y = N^2$, and $x = \mu + \frac{\mu^2 Y}{2\lambda} - \frac{\mu}{2\lambda}\sqrt{4\mu\lambda Y + \mu^2 Y^2}$

Generate a uniform [0,1] random variable U. If $U \le \frac{\mu}{x + \mu}$,

Return x, else return $\frac{\mu^2}{x}$.

Now we simulate the normal inverse Gaussian process on our fixed time grid with parameter

$\lambda_i = \frac{(Y_t - Y_{t-1})^2}{v}$ and $\mu_i = Y_t - Y_{t-1}$.

Then simulate n i.i.d N(0,1) random variables $N_1, N_2 ... N_n$

Set $\Delta X_i = \sigma N_i \sqrt{\Delta x_i} + \theta \Delta x_i$ for all i

The discretised trajectory is $X_{Y_t} = \sum_{k=1}^{i} \Delta X_i$

5.0 The LSVP Java Applet :

This Java aplet is called LSVP that is Lèvy Stochastic Volatility Pricing.

The Concept

The naming was made from the fact that the software price barrier and lookback options under Lèvy process with stochastic volatility. This concept is combined with the notion of Monte-Carlo simulation to arrive at this. The idea was to realise this in Java and to make it applicable as much as possible and user friendly.

Users Manual:

Start of the program:

The following user graphical interface appears when the applet is started.

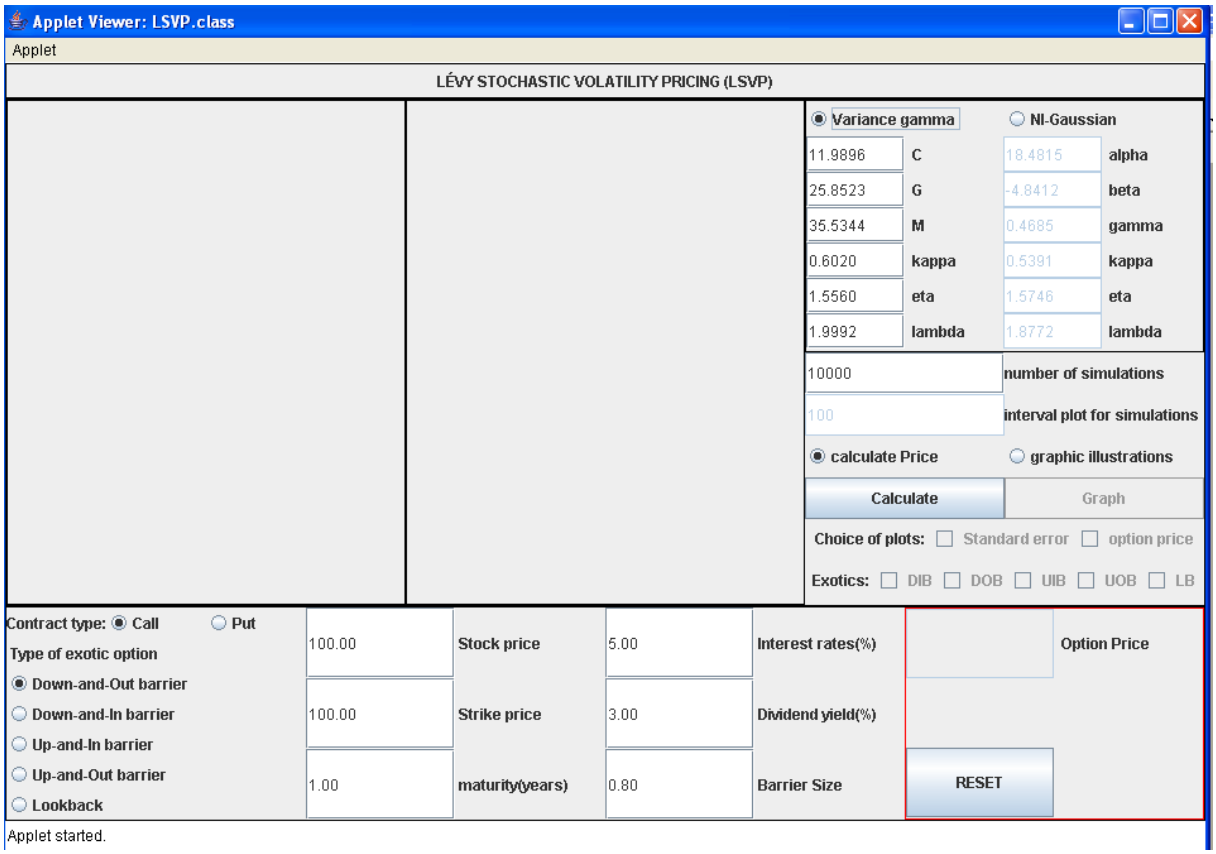

Figure. 1.

Overview of LSVP's user interface

The applet was designed using Java to price Lookback and barrier options. It has the capabilities to evaluate all the standard errors for any chosen number of simulations. It consist mainly of four sections ; The two blank parts which is for graphical illustration of price

changes with increase in number of simulation the other blank part is for a plot of standard deviation with number of simulations.

The right part of the applet is for input of parameters for VG and NIG processes generation. At the bottom of this part is the choice for input of the number of simulations and the choice of intervals for plotting.There are also choices of check boxes for every exotic type option considered,i.e DIB,DOB,UIB,UOB and LB which are down-in- barrier ,down-out-barrier,up-in-barrier ,up-out-barrier and lookback options respectively.The GUI is interactive in such a way as to make it highly user friendly. Then there is the bottom part of the GUI which basically gives the input parameters needed for valuation of the option. The barrier must be chosen appropriately depending on the choice of exotic option under consideration

Description of components

This description does not necessarilly correspond to the panel names used in writing the source codes. These are descriptions for the user on the features on the graphical user interface.

Graphics panel

The figure below is the graphics panel which is where the graph of standard error of the prices are plotted with a corresponding number of simulations (i.e. the left part).The right part of it is where option prices are plotted against the corresponding number of simulations.

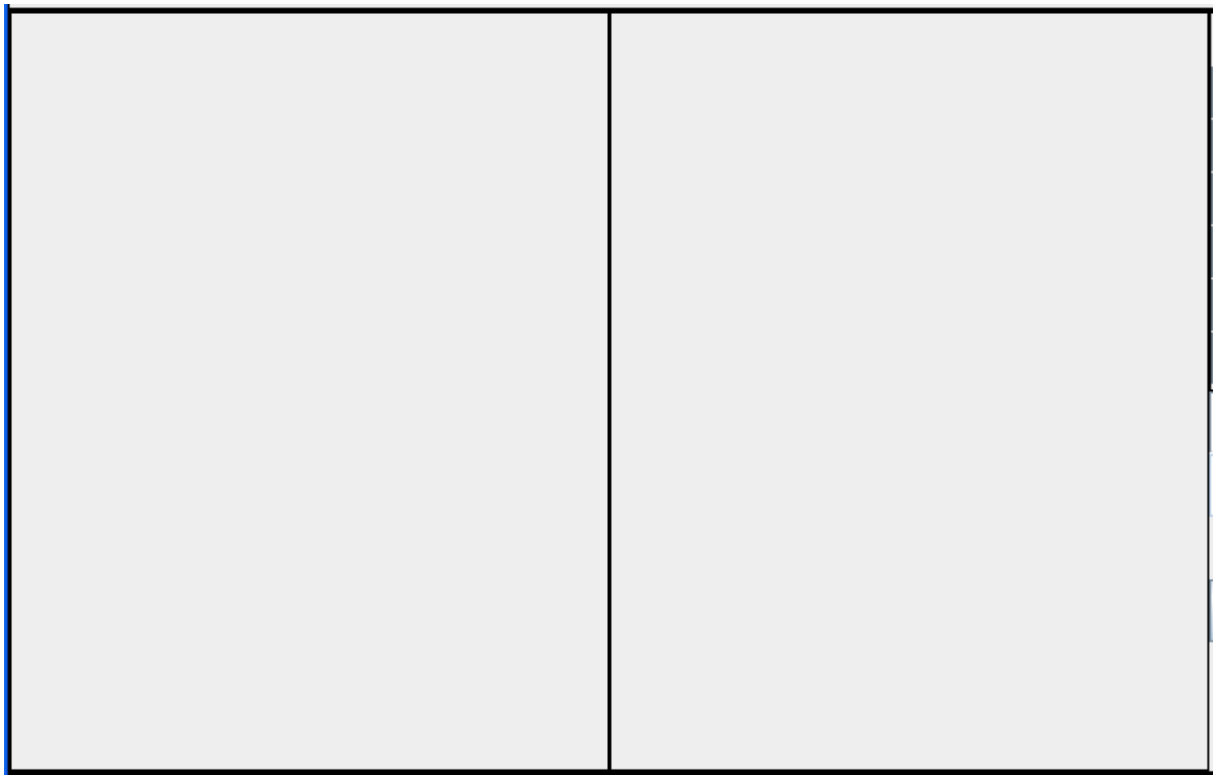

Figure. 2.

process panel:

That is where the normal inverse Gaussian and the variance gamma parameters are input .

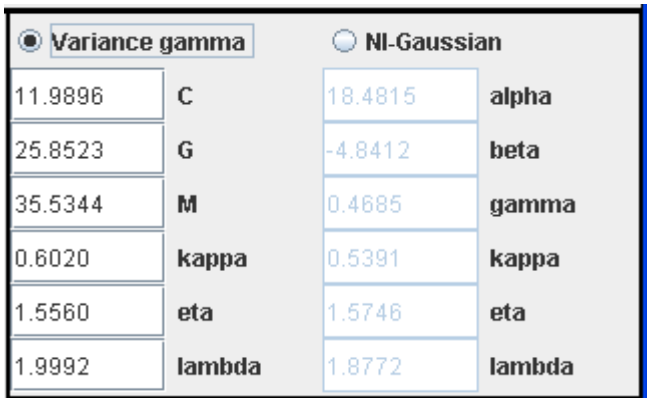

Figure. 3.

The Variance gamma and the NI-gaussian radiobuttons belong to one radio buttons group i.e. when one is clicked the other is subsequently unclicked. When the variance gamma button is clicked as is in Figure 3 the text fields for the parameters C,G,M,kappa,eta and lambda are enabled.This textfields are however enabled by default. If the NI-Gaussian radio button is chosen then alpha,beta,gamma,kappa,eta and lambda text fields for input of the parameters for Normal inverse gaussian are enabled .

The parameters C,G and M should be non-zero positive numbers. Eta ,kappa and lambda are the CIR parameters for both NI-Gaussian and variance gamma which are use for in the Lèvy stochastic volatility modelling as described in the previous sections. In the case of the NI-Gaussian the alpha should be non-zero positive number,beta should be in the range of plus and minus alpha then the gamma which is a non-zero positive number.

Simulations panel

This panel has two text fields ; the number of simulations ,which corresponds to the simulations for calculating the prices and the ”interval plot for simulations”which shows the number of intervals of simulations the user wants prices to be calculated and plotted . If the calculate radio button is clicked then the text field correspnding to the ”number of simulations” is enabled whiles that of ”intervals plots for simulations” is not enabled likewise the vice versa when the graphics illustration button is clicked.

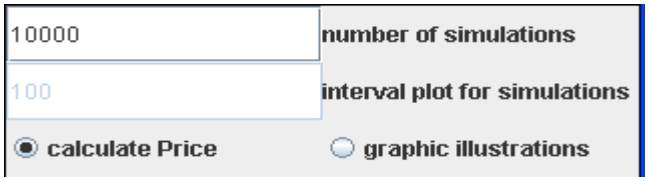

Fig. 4

Action panel

This panel as named has buttons and checkboxes that basically transfer command to the source code to be illicited. When the calculate Price radio button in Figure. 4 is clicked the calculate push button in Figure. 5 is enabled while the graph push button, standard error, option price,DIB,DOB,UIB,UOB,and LB check boxes are unabled the vice versa is the case when the graphic illustrations radio button in Figure. 4 is checked.

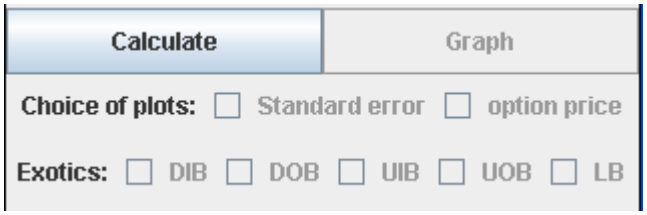

Figure. 5

When the graphics illustration radio button is clicked however the Figure. 5 looks like Figure. 6

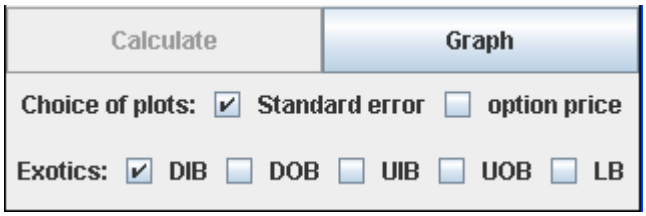

Figure. 6

The standard error checkbox is checked if you want standard error of the price of the corresponding options ,i.e DIB(down-and-in),DOB(down-and-out),UIB(up-and-in),UOB(up-and-out) and LB(lookback) plotted with number simulations. The option price check box also allows for plotting of the prices of the corresponding options ,i.e DIB(down-and-in),DOB(down-and-out),UIB(up-and-in),UOB(up-and-out) and LB(lookback) plotted with number simulations. All this check boxes can be checked at the same time. However by default the standard error and the DIB checkboxes are checked.

Option type panel

This panel has call and put radiobutton groups. These are the choice of contract type. Then are the exotic options type radio buttons which are unabled when the graphics illustration radio button(on figure 4)is clicked and vice versa when the calculate price radio buttons(on figure 4) is clicked.

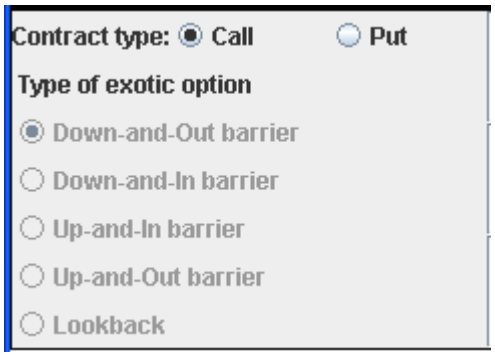

Figure. 7

These radio buttons are choice of the particular type of exotic options price one wants to calculate. Note that when the look back radio button is clicked the textfield corresponding to the strike price and the barrier size is unabled. This is because these parameters are not necessary in the valuation of lookback options.

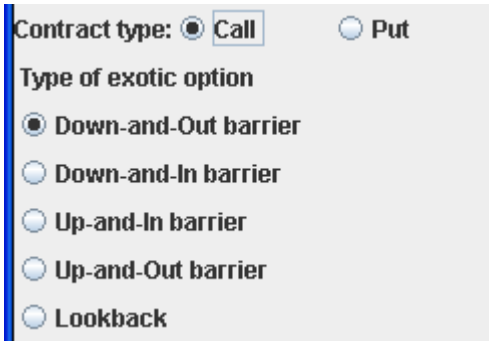

Figure. 8

parameter panel

This has all the text field necessary for input of parameters for the valuation of the options contract. The input parameters in this panel are non-negative numbers.

Figure. 9

output panel

As the name suggest it contains the window where the calculated option price is displayed. Also is the reset push button which is pressed resets all the parameters to numbers by default.

Figure. 10

Some pricing results

For the parameters in table 1 for both the normal inverse gaussian and the variance gamma the applet gave the corresponding results in table 2; The parameters are chosen acording to[1] and used to calculate the prices as inddicated below.

Table 1. Parameter estimates for Lévy SV models

	C	G	M	Kappa	Eta	Lambda
VG-CIR	=11.9896	=25.8523	=35.5344	=0.6020	=1.5560	=1.9992
	Alpha	Beta	Gamma	Kappa	Eta	Lambda
NIG-CIR	=18.4815	=-4.8412	=0.4685	=0.5391	=1.5746	1.8772

And the initial time $y_0 = 0, K = 100, S_0 = 100, T = 1 year(250 days), r = 5\%,$ and the dividend yield $q = 3\%$.

In calculating the barrier options the strike K= S_0 (initial stock price),time to maturity T=1(250days) and the barrier H as $H_{UIB} = 1.1 * S_0$, $H_{UOB} = 1.3 * S_0$, $H_{DIB} == 0.95 * S_0$, $H_{DOB} = 0.8 * S_0$.

n=10000 simulations of paths covering a one year period for all the options. The time is discretised in 250 equally small time steps for the one year period.

The values in table 2 are option prices whiles those in brackets are the standard errors.

Table 2. Exotic Option prices for Call contract

Model	DIB	DOB	UIB	UOB	LB
VG-CIR	0.036667	7.655239	5.708092	5.558471	7.488693
	(0.080530)	(0.145755)	(0.130512)	(0.087452)	(0.119967)
NIG-CIR	0.014966	7.685273	4.682093	5.919467	7.533582
	(0.080798)	(0.120522)	(0.118225)	(0.094543)	(0.117828)

Table 3. Exotic Option prices for Put contract

Model	DIB	DOB	UIB	UOB	LB
VG-CIR	3.051537	4.290505	0.003938	5.728151	5.737173
	(0.075803)	(0.080138)	(0.032185)	(0.108042)	(0.089964)
NIG-CIR	3.639459	4.09589	0.000865	5.93288	5.739952
	(0.081047)	(0.073529)	(0.000909)	(0.112388)	(0.0913711)

Very nice observations can be seen from the graphical results which shows the effect of simulations on the prices and standard errors. The maximum simulations chosen was 5000 with 500 simulations as intervals for the plots. From Figure 11 ,Figure 12 ,Figure 15 and Figure 16 it can observed that the standard error decreases with an increase in simulations. Likewise the prices flactuations decrease as the number of simulations increase as can be seen in Figure 13, Figure 14,Figure 17 and Figure 18. The option prices are much more stable as the number of simulations increase, hence the larger the simulations at which the prices are being calculated the more exact the results.

Call

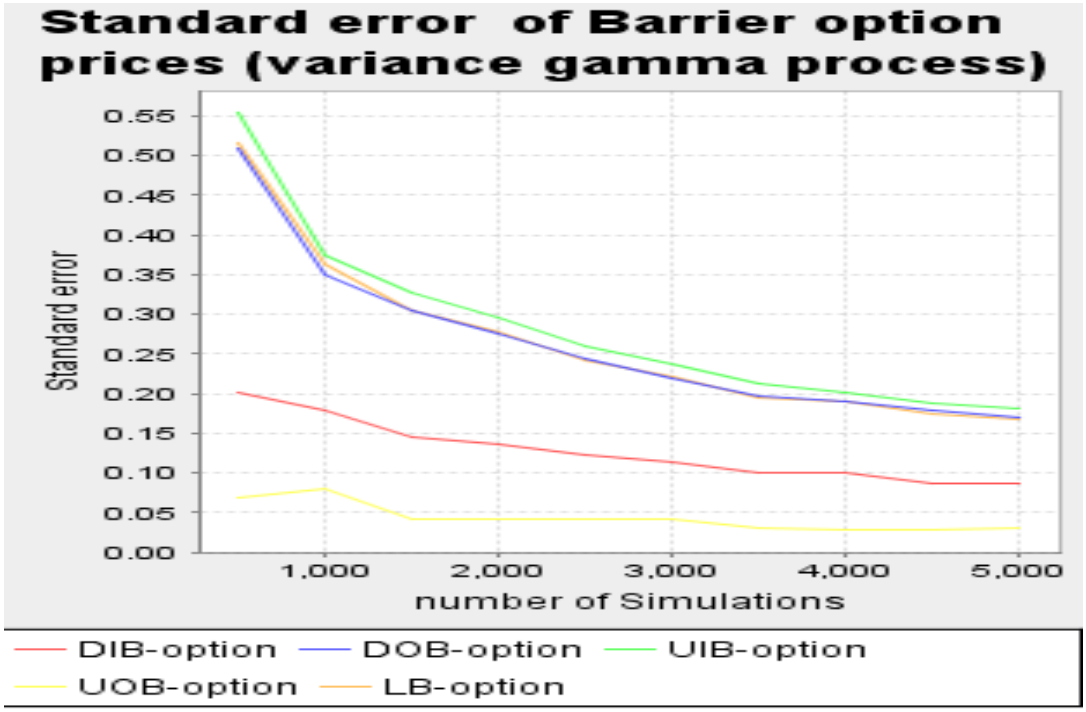

Figure. 11.

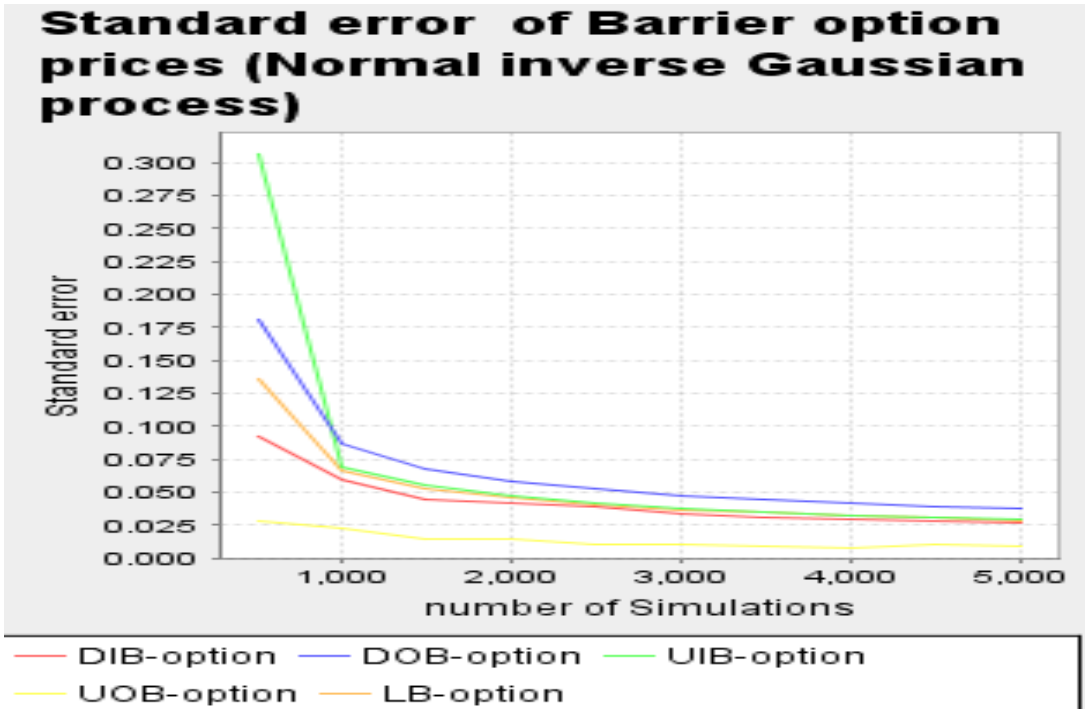

Figure. 12.

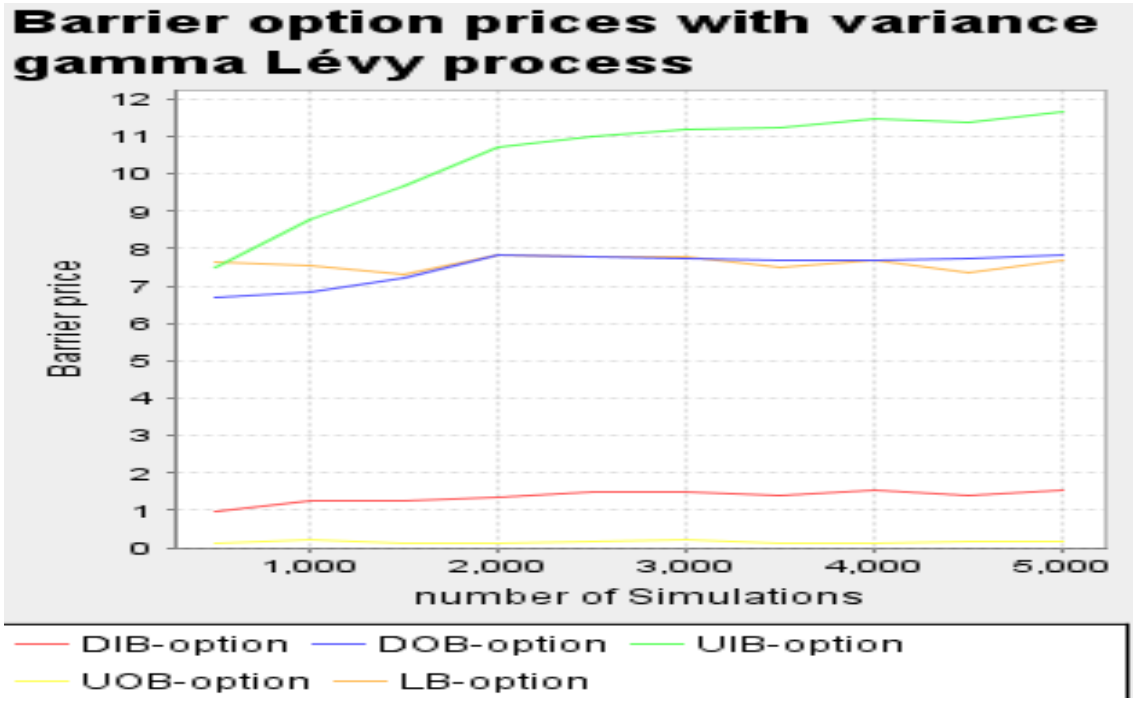

Figure. 13.

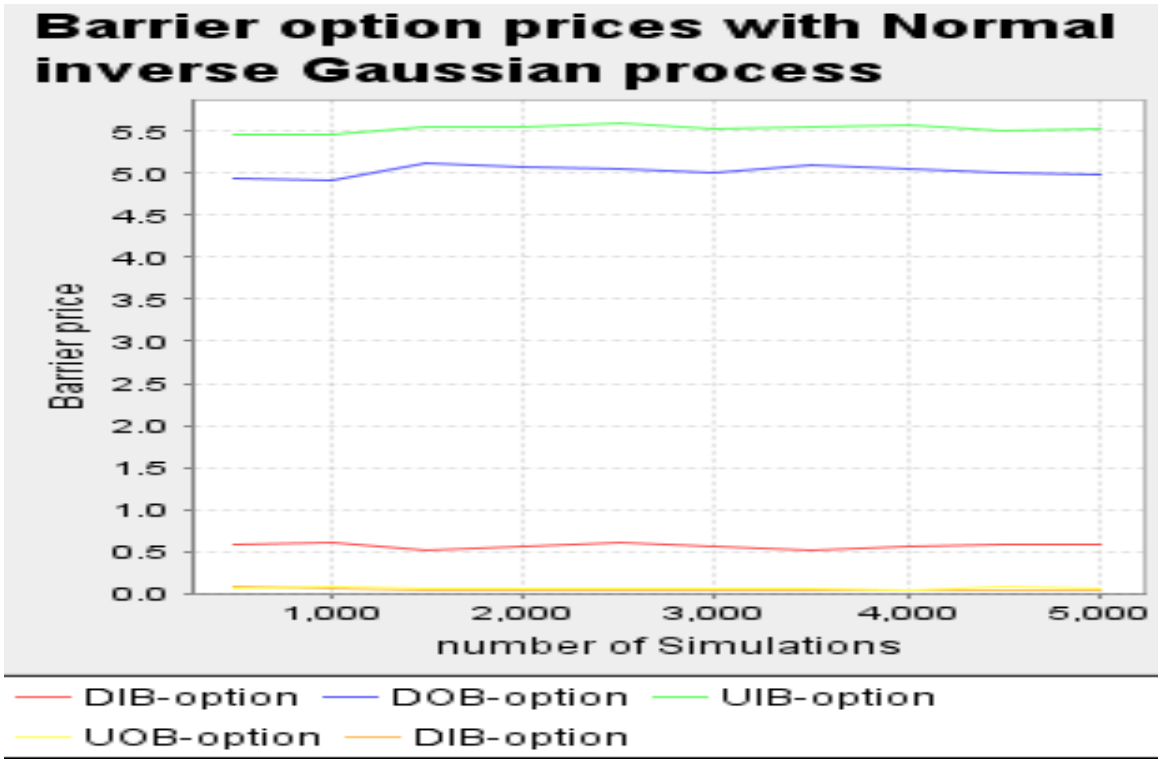

Figure. 14.

Put

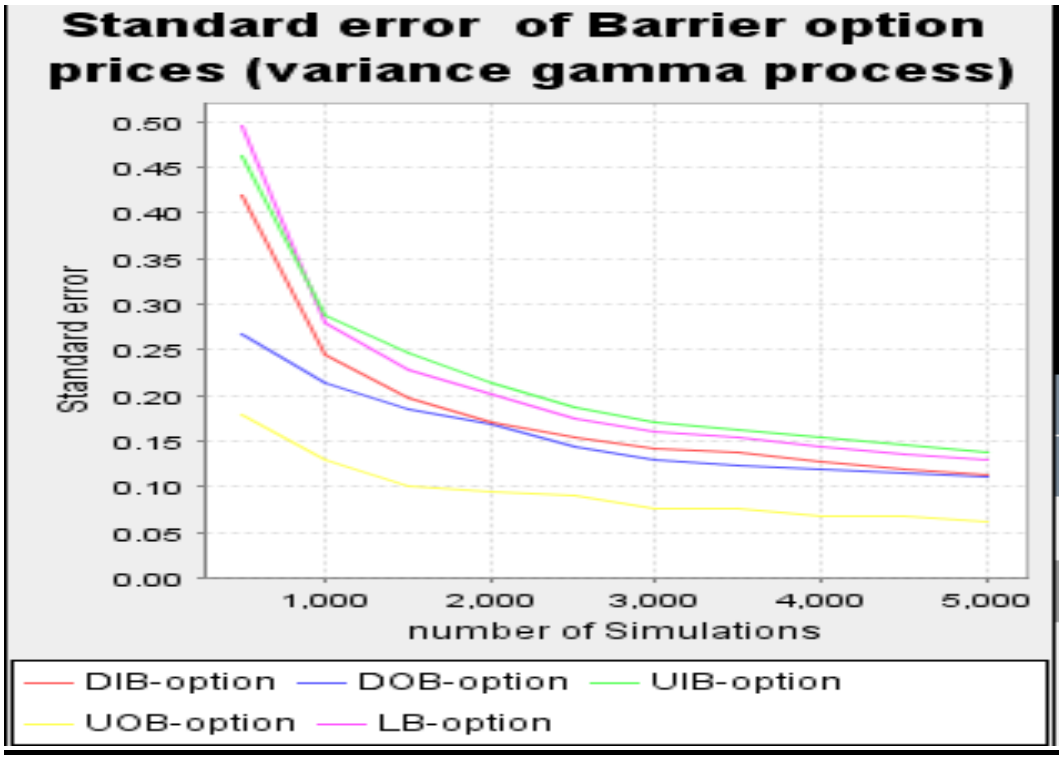

Figure. 15

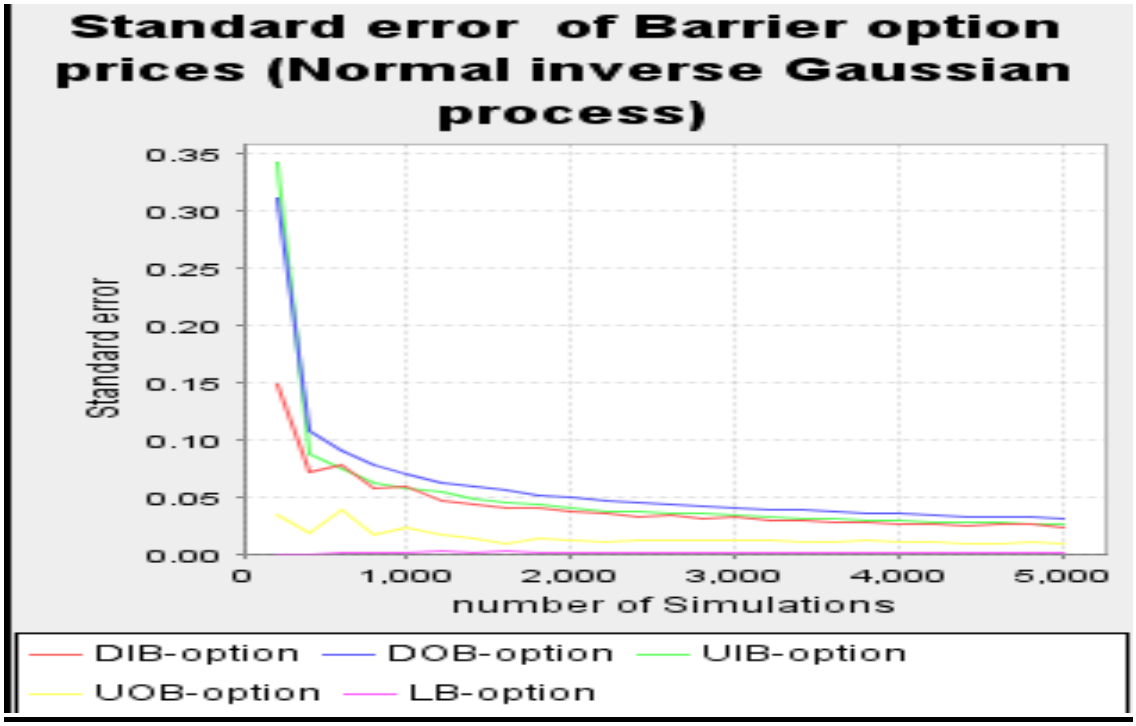

Figure. 16

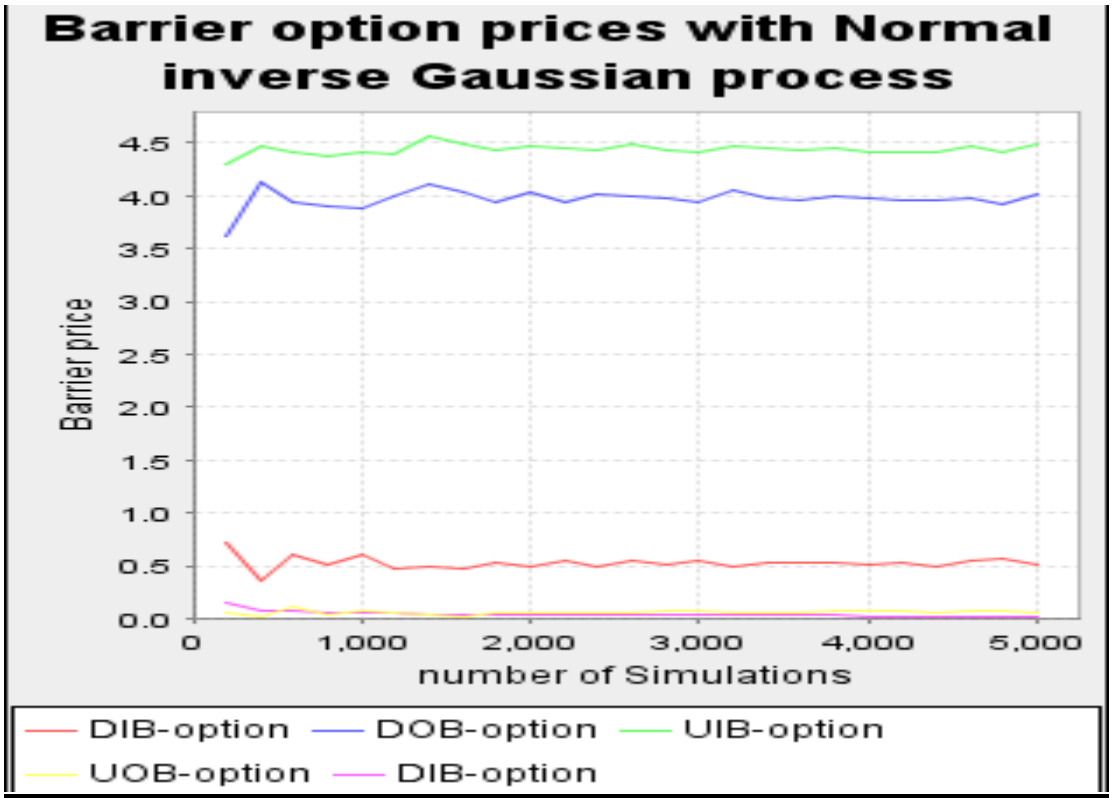

Figure. 17

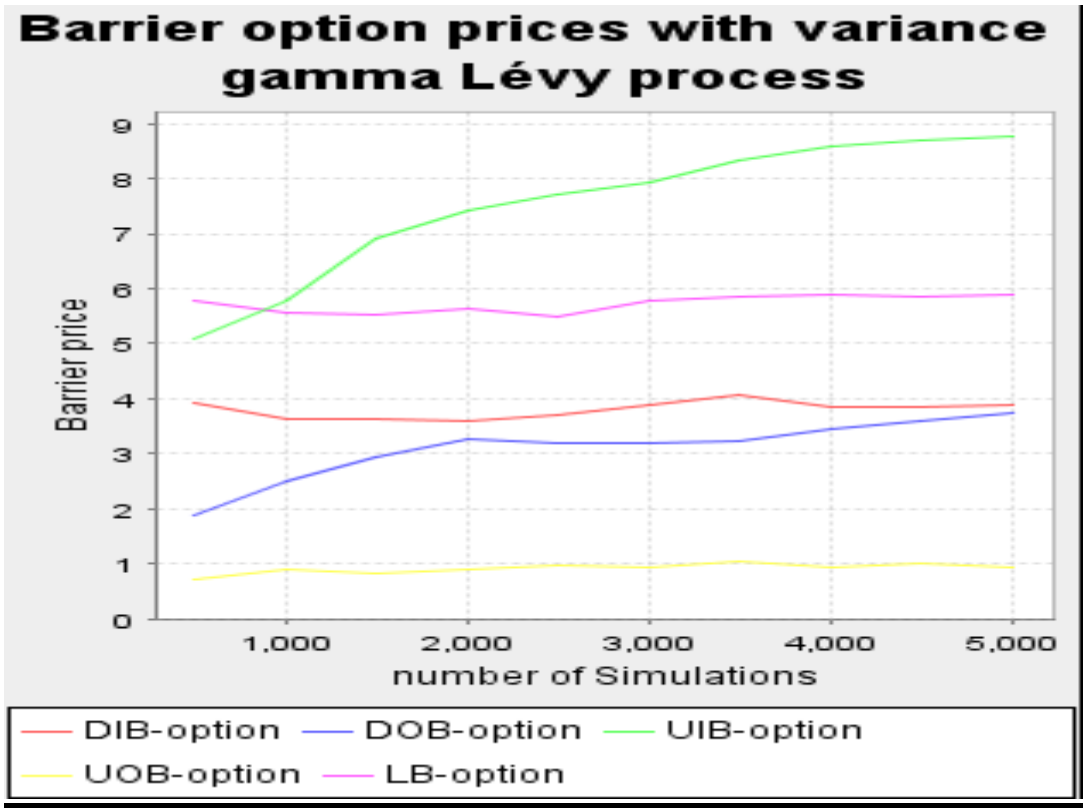

Figure. 18

Conclusion:

From the tables above it is easy to see that this procedure for pricing gives consistent prices with reasonable standard errors. The choice of volatility parameters is not a problem as the model assumes stochastic volatility. These gives it advantage over the Black-Scholes as shown in [1],and other models which demands choice of volatility parameters which poses a problem of what choice is most appropraite. In [1] one can easily see that prices under the Black-Scholes depend heavily on the choice of the volatility parameter making Lèvy-SV models most better for pricing exotic options.In real life we know volatility is stochastic hence the idea of making volatility stochastic fits real life scenarios and there is evidence that the Lévy-SV models are much more reliable;they give much better indication than the BS-model.

"We are what we repeatedly do. Excellence, then, is not an act but a habit".
--Aristotle

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APPENDIX

```
/**
 * @(#) LSVP.java  1.0 05/12/01
 *
 * Copyright (c) 2005 Mälardalen University
 * Högskoleplan Box 883, 721 23 Västerås, Sweden.
 * All Rights Reserved.
 *
 * The copyright to the computer program(s) herein
 * is the property of Isaac Acheampong.
 * The program(s) may be used and/or copied only with
 * the written permission of Isaac Acheampong
 * or in accordance with the terms and conditions
 * stipulated in the agreement/contract under which
 * the program(s) have been supplied.

 * Description: Java Applet for pricing of Barrier and Lookback Oprions
 * using Monte-Carlo Simulations
 * @version 1.0 1 Dec 2005
 * @author Isaac Acheampong
 * Mail: don_squalo@yahoo.com
 */
 import java.awt.*;
 import java.awt.event.*;
 import javax.swing.*;
 import java.text.*;
 import java.util.*;
 import java.lang.*;

 import org.jfree.chart.*;
 import org.jfree.chart.axis.*;
 import org.jfree.chart.plot.*;
 import org.jfree.chart.renderer.category.*;
 import org.jfree.data.category.*;
 import org.jfree.ui.*;
 import org.jfree.data.time.*;
 import org.jfree.data.xy.*;

public class LSVP extends JApplet implements //ItemListener,
                                              ActionListener {
private DecimalFormat  numberFormatter=new DecimalFormat("###.######");
private Container contentPane =null;

  // Panels
   private JPanel titlePanel = null;
   private JPanel converterPanel = null;
```

```
    private JPanel variance_gammaPanel=null;
    private JPanel nigPanel=null;
    private JPanel vg_miniPanel=null;
    private JPanel nig_miniPanel=null;
    private JPanel process_Panel=null;
    private JPanel process_miniPanel=null;
    private JPanel process_1Panel=null;
    private JPanel process_2Panel=null;
    private JPanel barrier_inputPanel=null;
    private JPanel barriermini_Panel=null;
    private ChartPanel graphics1_Panel=null;
    private ChartPanel graphics2_Panel=null;
    private JPanel center_Panel=null;
    private JPanel process_lilminiPanel=null;

    // Group Buttons
    private ButtonGroup processTypeGroup = null;
    private ButtonGroup barrierTypesGroup= null;
    private ButtonGroup callPutTypeGroup=null;
    private ButtonGroup numberofpricesGroup =null;
    private ButtonGroup graph_choiceGroup = null;

    // Radio buttons
    private JRadioButton[] processTypeButtons = null;
    private JRadioButton[] barrierTypesButtons=null;
    private JRadioButton[] callPutTypeButtons=null;
    private JRadioButton[] numberofpricesButtons=null;
    private JRadioButton[] graph_choiceButtons = null;

  // Strings
    private final String EMPTY = "         ";
    private final String CALCULATE = "Calculate";
    private final String NOT_A_NUMBER = "Enter a number";
    private final String NON_POSITIVE = "Enter a positive number";
    private final String NON_ZERO_POSITIVE = "Enter non-zero positive number";
    private final String SAMEOFINPUT_OUTPUT = "The input and output argument are
same";
    private final String NOT_INRANGE ="-3.1416(pi)< beta < 3.1416(pi)";
    private final String HEADER = " LÉVY STOCHASTIC VOLATILITY PRICING (LSVP) ";
    private final String VARIANCE_GAMMA = "VARIANCE GAMMA ";
    private final String  NIG = "NORMAL INVERSE GAUSSIAN PROCESS";
    private final String[] PROCESS_LABEL = {"Variance gamma ","NI-Gaussian" };
    private final String[] GRAPH_CHOICELABEL = {"standard error","option prices " };
    private final String[] BARRIER_TYPE=
```

```
   {"Down-and-Out barrier","Down-and-In barrier","Up-and-In barrier","Up-and-Out
barrier","Lookback"};
   private final String[] NUMBER_OF_PRICEBUTTON={"calculate Price ","graphic
illustrations"};
   private final String PARAMETER_C = "  C ";
   private final String PARAMETER_G = "  G ";
   private final String PARAMETER_M = "  M ";
   private final String PARAMETER_KAPPA = "  kappa ";
   private final String PARAMETER_ETA = "  eta ";
   private final String PARAMETER_LAMBDA = "  lambda ";
   private final String PARAMETER_ALPHA = "  alpha ";
   private final String PARAMETER_BETA = "  beta ";
   private final String PARAMETER_GAMMA = "  gamma ";
   private final String PARAMETER_NUMBEROF_STEPS ="time Steps  ";
   private final String PARAMETER_ALPHACV = "alpha  ";
   private final String PARAMETER_K = " k   ";
   private final String NUMBER_OFSIMULATIONS_1 = "number of simulations";
   private final String INTERVAL= "interval plot for simulations";
   private final String STRIKE_PRICE = " Strike price ";
   private final String STOCK_PRICE = " Stock price ";
   private final String INTERESTRATE = " Interest rates(%) ";
   private final String DIVIDEND = " Dividend yield(%) ";
   private final String TIME_TO_MATURITY = " maturity(years) ";
   private final String BARRIER_SIZE = " Barrier Size  ";
   private final String TYPE_OF_EXOTIC_OPTION = " Type of exotic option ";
   private final String  GRAPH = " Graph ";
   private final String BARRIER_OPTIONPRICE="  Option Price";
   private final String VG_C_ERROR=" INERSE OF LÉVY MEASURE";
   private final String VG_G_ERROR="VARIANCE GAMMA G-Parameter";
   private final String VG_M_ERROR="VARIANCE GAMMA M Parameter";
   private final String VG_KAPPA_ERROR="VARIANCE GAMMA KAPPA Parameter";
   private final String VG_ETA_ERROR="VARIANCE GAMMA ETA Parameter";
   private final String VG_LAMBDA_ERROR="VARIANCE GAMMA LAMBDA Parameter";
   private final String NIG_ALPHA_ERROR="Normal inverse gaussian alpha Parameter";
   private final String NIG_BETA_ERROR="Normal inverse gaussian BETA Parameter";
   private final String NIG_GAMMA_ERROR="Normal inverse gaussian GAMMA  Parameter";
   private final String NIG_KAPPA_ERROR="Normal inverse gaussian KAPPA Parameter";
   private final String NIG_ETA_ERROR="Normal inverse gaussian ETA Parameter";
   private final String NIG_LAMBDA_ERROR="Normal inverse gaussian LAMBDA
Parameter";
   private final String SIMULATIONS_ERROR="NUMBER OF SIMULATIONS";
   private final String RESET=" RESET ";
   private final String NUMBER_LESS_THANMINIMUM =" Number should be Greater than
minimum";
```

```
   private final String NUMBER_MORE_THANMAXIMUM =" Number should be Less than
maximum";
   private final String STANDARD_ERROR="Standard error";
   private final String OPTIONPRICE="option price";
   private final String  DIB="DIB";
   private final String  DOB="DOB";
   private final String  UOB="UOB";
   private final String  UIB="UIB";
   private final String  LB="LB";
   private final String  PLOTS="Choice of plots:";
   private final String  OPTCONSIDERED="Exotics:";
   private final String  TYPE_OF_OPTION="Contract type:";
   private final String[] CALL_PUT ={"Call ","Put "};
   // Labels
   private JLabel emptyLabel = null;
   private JLabel standardErrorLabel=null;
   private JLabel optionPriceLabel=null;
   private JLabel headerLabel = null;
   private JLabel variance_gammaLabel = null;
   private JLabel control_variatesLabel = null;
   private JLabel graph_choiceLabel = null;
   private JLabel optionType_Label =null;

   private JLabel nigLabel = null;
   private JLabel C_Label = null;
   private JLabel G_Label = null;
   private JLabel M_Label = null;
   private JLabel kappa_Label = null;
   private JLabel eta_Label = null;
   private JLabel lambda_Label = null;

   private JLabel alpha_Label = null;
   private JLabel beta_Label = null;
   private JLabel gamma_Label = null;
   private JLabel numberofsimulationsLabel = null;
   private JLabel numberofrunsLabel = null;
   private JLabel  stockprice_Label = null;
   private JLabel  interestrate_Label = null;
   private JLabel  dividentrate_Label = null;
   private JLabel  maturity_Label = null;
   private JLabel  strikeprice_Label = null;
   private JLabel  barriersize_Label = null;
   private JLabel  barrier_Label = null;
   private JLabel  outputprice_Label = null;
   private JLabel numberof_Label=null;
```

```
private JLabel dibLabel=null;
private JLabel dobLabel=null;
private JLabel uibLabel=null;
private JLabel uobLabel=null;
private JLabel LbLabel=null;

private JLabel plotsLabel=null;
private JLabel optconsideredLabel=null;

// Text fields
 private JTextField vg_1Field = null;
 private JTextField vg_2Field = null;
private JTextField vg_3Field = null;
private JTextField vg_4Field = null;
private JTextField vg_5Field = null;
private JTextField vg_6Field = null;
private JTextField variates1Field = null;
private JTextField variates2Field =null;
private JTextField nig_1Field = null;
 private JTextField nig_2Field = null;
private JTextField nig_3Field = null;
private JTextField nig_4Field = null;
private JTextField nig_5Field = null;
private JTextField nig_6Field = null;
private JTextField barrier1Field =null;
private JTextField barrier2Field =null;
private JTextField barrier3Field =null;
private JTextField barrier4Field =null;
private JTextField barrier5Field =null;
private JTextField barrier6Field =null;
private JTextField barrierpriceField =null;
private JTextField interestrate_Field = null;
private JTextField dividentrate_Field = null;
private JTextField maturity_Field = null;
private JTextField strikeprice_Field = null;
private JTextField barriersize_Field = null;

// Check box(es)
 private JCheckBox standardErrorBox=null;
 private JCheckBox optionPriceBox=null;
 private JCheckBox dibBox=null;
 private JCheckBox dobBox=null;
private JCheckBox uibBox=null;
private JCheckBox uobBox=null;
private JCheckBox LbBox=null;
```

```
   private JCheckBox variance_gammaBox = null;

    // Tool tips
    private final String RUNS = " number of runs for estimation of  b   for control
variates";
    private final String K = "number of partitions for compound-Poisson
approximations";
    private final String ALPHA = "constant for estimation of boundaries";
    private final String KAPPA = "Rate of mean reversion ";
    private final String ETA ="Long run rate of time change ";
    private final String LAMBDA="Volatility of time change";

   // Buttons
   private JButton calculateButton = null;
   private JButton graphButton = null;
   private JButton resetButton  =null;

   // Progress bar
   //private JProgressBar progressBar = null;

   // ´Numerical variables
   public int i=0;
   public int j=0;
   private final int NUMBER_OF_STEPS =250;
   int simulations ;
   int interval;

   private double[] y = null;
   private double[] Y = null;
   private double[] X = null;
   private double[] Xg = null;
   private double[] Stockprice=null;
   private double[] ExpX=null;
   private double[] M=null;
   private double[] payout=null;
   private double[] payout1=null;
   private double[] payout2=null;
   private double[] payout3=null;
   private double[] payout4=null;
   private double[] payout5=null;
   private double[] payoutS1=null;
   private double[] payoutS2=null;
   private double[] payoutS3=null;
   private double[] payoutS4=null;
   private double c =11.9896;
```

```
private double g =25.8523;
private double m =35.5344;
private double vgkappa=0.6020;
private double vgeta=1.5560;
private double vglambda=1.9992;
private double deltaTime=0.004 ;
private double interestRate=0.05;
private double dividend=0.03;
private double timetoMaturity=1;
private double nigalpha=18.4815;
private double nigbeta=-4.8412;
private double niggamma=0.4685;
private double nigkappa=0.5391;
private double nigeta=1.5746;
private double niglambda=1.8772;
double mean;
double stddev;
double v;

double w;
double theta;
double sigma;
double initialstockprice;

double ExpectationX;
double Min;
double Max;
double barrier;
double strikeprice;
double b1;
double OptionPrice;
double []OptionPrice1;
double []OptionPrice2;
double []OptionPrice3;
double []OptionPrice4;
double []OptionPrice5;

double Avpayout;
double Avpayout1;
double Avpayout2;
double Avpayout3;
double Avpayout4;
double Avpayout5;
double AvpayoutS1;
double AvpayoutS2;
```

```
 double AvpayoutS3;
 double AvpayoutS4;

 double C_sum;
 double Y_sum;
 double PayoutSum;
 double PayoutSum1;
 double PayoutSum2;
 double PayoutSum3;
 double PayoutSum4;
 double PayoutSum5;


 double PayoutSumS1;
 double PayoutSumS2;
 double PayoutSumS3;
 double PayoutSumS4;


 double StandardError;
 double []StandardError1;
 double []StandardError2;
 double []StandardError3;
 double []StandardError4;
 double []StandardError5;

 double variance;
 double variance1;
 double variance2;
 double variance3;
 double variance4;
 double variance5;

// Generate Random numbers
private final static Random random = new Random();

 // booleans
 private boolean processtypebuttons = false;
 private boolean variateschoicebuttons = false;
 private boolean variateschoice0buttons = false;
 private boolean variateschoice1buttons = false;
 private boolean processtype0buttons = false;
 private boolean processtype1buttons = false;
 private boolean  numberofpricesbuttons = false;
```

```
   // Methods
    public void init() {

      // Get content pane
       contentPane = getContentPane();
       contentPane.setLayout(new BorderLayout());

     //-----------------------TITLE---------------------
       // Add title panel
       titlePanel = new JPanel();
       titlePanel.setBorder(BorderFactory.createLineBorder(
       Color.BLACK, 1));
       contentPane.add(titlePanel,BorderLayout.NORTH);

        // Add title
       headerLabel = new JLabel(HEADER);
        titlePanel.add(headerLabel);

     //---------------Add center_Panel to Left and Right--------------------

       // Add center_Panel to Lévy Monte Carlo
        center_Panel= new JPanel(new GridLayout(1,3));
        center_Panel.setBorder(BorderFactory.createLineBorder(
       Color.BLACK, 1));
       contentPane.add( center_Panel,BorderLayout.CENTER);

    // Add graphics1_Panel to  center_Panel
       graphics1_Panel= new ChartPanel(null);
       graphics1_Panel.setBorder(BorderFactory.createLineBorder(
           Color.BLACK, 1));
        center_Panel.add(graphics1_Panel);

      // Add graphics2_Panel to center Panel
       graphics2_Panel= new ChartPanel(null);
       graphics2_Panel.setBorder(BorderFactory.createLineBorder(
           Color.BLACK, 1));
        center_Panel.add(graphics2_Panel);

       //-------Process Panel to center panel-------------------------------------
---
         // Add process Panel
            process_Panel=new JPanel(new GridLayout(2,1));
            center_Panel.add(process_Panel);
```

```
//------ Add  Process_1Panel to upper half of process panel--------------
     process_1Panel=new JPanel(new GridLayout(7,2));
     process_1Panel.setBorder(BorderFactory.createLineBorder(
  Color.BLACK, 1));
     process_Panel.add(process_1Panel);

    //Add VG and NIG Radio buttons
    process_miniPanel=new JPanel(new GridLayout(1,2));
    process_1Panel.add(process_miniPanel);
    processTypeGroup=new ButtonGroup();
    processTypeButtons=new JRadioButton[2];
      for (int i=0; i<2; i++) {
               processTypeButtons[i] = new JRadioButton(PROCESS_LABEL[i]);
              processTypeGroup.add(processTypeButtons[i]);
              process_miniPanel.add(processTypeButtons[i]);
              processTypeButtons[i].addActionListener(this);
                        }
         processTypeButtons[0].setSelected(true);

    // Add fields for VG and NIG
      //1
      process_miniPanel=new JPanel(new GridLayout(1,4));
      vg_1Field = new JTextField();
      vg_1Field .setText("11.9896");
      C_Label= new JLabel(PARAMETER_C);
      process_miniPanel.add(vg_1Field);
      process_miniPanel.add(C_Label);
      process_1Panel.add(process_miniPanel);
      vg_1Field.setEnabled(true);

      nig_1Field =new JTextField();
      nig_1Field .setText("18.4815");
      process_miniPanel.add(nig_1Field);
      alpha_Label=new JLabel(PARAMETER_ALPHA);
      process_miniPanel.add(nig_1Field);
      process_miniPanel.add(alpha_Label);
     process_1Panel.add(process_miniPanel);
     nig_1Field.setEnabled(false);
     //2
     process_miniPanel=new JPanel(new GridLayout(1,4));
      vg_2Field = new JTextField();
      vg_2Field .setText("25.8523");
      G_Label= new JLabel(PARAMETER_G);
      process_miniPanel.add(vg_2Field);
      process_miniPanel.add(G_Label);
```

```
 process_1Panel.add(process_miniPanel);
 vg_2Field.setEnabled(true);

 nig_2Field = new JTextField();
 nig_2Field .setText("-4.8412");
 process_miniPanel.add(nig_2Field);
 beta_Label=new JLabel(PARAMETER_BETA);
 process_miniPanel.add(nig_2Field);
 process_miniPanel.add(beta_Label);
process_1Panel.add(process_miniPanel);
nig_2Field.setEnabled(false);
//3
process_miniPanel=new JPanel(new GridLayout(1,4));
 vg_3Field = new JTextField();
 vg_3Field .setText("35.5344");
 M_Label= new JLabel(PARAMETER_M);
 process_miniPanel.add(vg_3Field);
 process_miniPanel.add(M_Label);
 process_1Panel.add(process_miniPanel);
 vg_3Field.setEnabled(true);

 nig_3Field = new JTextField();
 nig_3Field .setText("0.4685");
 process_miniPanel.add(nig_3Field);
 gamma_Label=new JLabel(PARAMETER_GAMMA);
 process_miniPanel.add(nig_3Field);
 process_miniPanel.add(gamma_Label);
process_1Panel.add(process_miniPanel);
nig_3Field.setEnabled(false);
//4
process_miniPanel=new JPanel(new GridLayout(1,4));
 vg_4Field = new JTextField();
 vg_4Field .setText("0.6020");
 kappa_Label= new JLabel(PARAMETER_KAPPA);
 process_miniPanel.add(vg_4Field);
 process_miniPanel.add(kappa_Label);
 process_1Panel.add(process_miniPanel);
 vg_4Field.setEnabled(true);
 vg_4Field.setToolTipText(KAPPA);

 nig_4Field = new JTextField();
 nig_4Field .setText("0.5391");
 process_miniPanel.add(nig_4Field);
 kappa_Label=new JLabel(PARAMETER_KAPPA);
 process_miniPanel.add(nig_4Field);
```

```
 process_miniPanel.add(kappa_Label);
process_1Panel.add(process_miniPanel);
nig_4Field.setEnabled(false);
nig_4Field.setToolTipText(KAPPA);

//5
process_miniPanel=new JPanel(new GridLayout(1,4));
 vg_5Field = new JTextField();
 vg_5Field .setText("1.5560");
 eta_Label= new JLabel(PARAMETER_ETA);
 process_miniPanel.add(vg_5Field);
 process_miniPanel.add(eta_Label);
 process_1Panel.add(process_miniPanel);
 vg_5Field.setEnabled(true);
 vg_5Field.setToolTipText(ETA);

 nig_5Field = new JTextField();
 nig_5Field .setText("1.5746");
 process_miniPanel.add(nig_5Field);
 eta_Label=new JLabel(PARAMETER_ETA);
 process_miniPanel.add(nig_5Field);
 process_miniPanel.add(eta_Label);
process_1Panel.add(process_miniPanel);
nig_5Field.setEnabled(false);
nig_5Field.setToolTipText(ETA);

//6
process_miniPanel=new JPanel(new GridLayout(1,4));
 vg_6Field = new JTextField();
 vg_6Field .setText("1.9992");
 lambda_Label= new JLabel(PARAMETER_LAMBDA);
 process_miniPanel.add(vg_6Field);
 process_miniPanel.add(lambda_Label);
 process_1Panel.add(process_miniPanel);
 vg_6Field.setEnabled(true);
vg_6Field.setToolTipText(LAMBDA);

 nig_6Field = new JTextField();
 nig_6Field .setText("1.8772");
 process_miniPanel.add(nig_6Field);
 lambda_Label=new JLabel(PARAMETER_LAMBDA);
 process_miniPanel.add(nig_6Field);
 process_miniPanel.add(lambda_Label);
process_1Panel.add(process_miniPanel);
nig_6Field.setEnabled(false);
```

```
            nig_6Field.setToolTipText(LAMBDA);

        //---Add Process_2Panel to lower part of Process Panel------

            process_2Panel=new JPanel(new GridLayout(6,2));
            process_1Panel.setBorder(BorderFactory.createLineBorder(
         Color.BLACK, 1));
            process_Panel.add(process_2Panel);
            process_miniPanel=new JPanel(new GridLayout(1,2));

            variates1Field =new JTextField();
             variates1Field .setText("10000");
             process_miniPanel.add(variates1Field);
             numberofsimulationsLabel=new JLabel(NUMBER_OFSIMULATIONS_1);
          emptyLabel = new JLabel(EMPTY);
            process_miniPanel.add(variates1Field);
             process_miniPanel.add(numberofsimulationsLabel);
             process_2Panel.add(process_miniPanel);
            variates1Field.setEnabled(true);

             process_miniPanel=new JPanel(new GridLayout(1,2));
             variates2Field =new JTextField();
              variates2Field .setText("100");
              process_miniPanel.add(variates2Field);
              numberofsimulationsLabel=new JLabel(INTERVAL);
              process_miniPanel.add(numberofsimulationsLabel);
              process_2Panel.add(process_miniPanel);
             variates2Field.setEnabled(false);

          //Add calculate price or graphic illustration radio buttons
            process_miniPanel=new JPanel(new GridLayout(1,2));
            process_2Panel.add(process_miniPanel);
            numberofpricesGroup= new ButtonGroup();
            numberofpricesButtons=new JRadioButton[2];

            for (int i=0; i<2; i++) {
                     numberofpricesButtons[i] = new
JRadioButton(NUMBER_OF_PRICEBUTTON[i]);
                    numberofpricesGroup.add(numberofpricesButtons[i]);
                    process_miniPanel.add(numberofpricesButtons[i]);
                    numberofpricesButtons[i].addActionListener(this);
                  }
                  numberofpricesButtons[0].setSelected(true);

        // Add calculate and graph  button
```

```
 process_miniPanel=new JPanel(new GridLayout(1,3));
  emptyLabel = new JLabel(EMPTY);
 calculateButton = new JButton(CALCULATE);
 graphButton = new JButton(GRAPH);
 process_miniPanel.add(calculateButton);
 process_miniPanel.add(emptyLabel);
 process_miniPanel.add(graphButton);
 process_2Panel.add(process_miniPanel);
 graphButton.setEnabled(false);

//Add  checkboxes for type of graph to plot
 process_miniPanel=new JPanel();
 process_2Panel.add(process_miniPanel);
 plotsLabel=new JLabel(PLOTS);
 process_miniPanel.add(plotsLabel);
 standardErrorBox=new JCheckBox();
 process_miniPanel.add(standardErrorBox);
 standardErrorLabel = new JLabel(STANDARD_ERROR);
 process_miniPanel.add(standardErrorLabel);
 standardErrorBox.setEnabled(false);
  standardErrorLabel.setEnabled(false);

 optionPriceBox=new JCheckBox();
 process_miniPanel.add(optionPriceBox);
 optionPriceLabel = new JLabel(OPTIONPRICE);
 process_miniPanel.add(optionPriceLabel);
 optionPriceBox.setEnabled(false);
  optionPriceLabel.setEnabled(false);

 // Adding check boxes for type of
 process_miniPanel=new JPanel();
 process_2Panel.add(process_miniPanel);

 optconsideredLabel=new JLabel(OPTCONSIDERED);
 process_miniPanel.add(optconsideredLabel);

 dibBox= new JCheckBox();
 process_miniPanel.add(dibBox);
 dibLabel=new JLabel(DIB);
 process_miniPanel.add(dibLabel);
 dibLabel.setEnabled(false);
 dibBox.setEnabled(false);

 dobBox= new JCheckBox();
 process_miniPanel.add(dobBox);
```

```
        dobLabel=new JLabel(DOB);
        process_miniPanel.add(dobLabel);
        dobLabel.setEnabled(false);
        dobBox.setEnabled(false);

        uibBox= new JCheckBox();
        process_miniPanel.add(uibBox);
        uibLabel=new JLabel(UIB);
        process_miniPanel.add(uibLabel);
        uibLabel.setEnabled(false);
        uibBox.setEnabled(false);

        uobBox= new JCheckBox();
        process_miniPanel.add(uobBox);
        uobLabel=new JLabel(UOB);
        process_miniPanel.add(uobLabel);
        uobLabel.setEnabled(false);
        uobBox.setEnabled(false);

        LbBox= new JCheckBox();
        process_miniPanel.add(LbBox);
        LbLabel=new JLabel(LB);
        process_miniPanel.add(LbLabel);
        LbLabel.setEnabled(false);
        LbBox.setEnabled(false);

//-----------------------------------------------------------------
//------------Add converter panel(south of Lévy monte carlo)-----------
     converterPanel=new JPanel(new GridLayout(1,4));
     converterPanel.setBorder(BorderFactory.createLineBorder(
      Color.BLACK, 1));
     contentPane.add(converterPanel,BorderLayout.SOUTH);
//-------------barrier inputPanel----------------------

         //Add  barrier inputPanel  converter Panel
                 barrier_inputPanel = new JPanel(new GridLayout(7,1));
                 converterPanel.add(barrier_inputPanel);
                 optionType_Label=new JLabel(TYPE_OF_OPTION);
                 //barrier_inputPanel.add(optionType_Label);
                 barriermini_Panel=new JPanel(new GridLayout(1,3));
                 barriermini_Panel.add(optionType_Label);
                 callPutTypeGroup=new ButtonGroup();
                 callPutTypeButtons=new JRadioButton[2];

                for(int i=0;i<2;i++) {
```

```
            callPutTypeButtons[i]=new JRadioButton(CALL_PUT[i]);
            callPutTypeGroup.add(callPutTypeButtons[i]);
            barriermini_Panel.add(callPutTypeButtons[i]);
            barrier_inputPanel.add(barriermini_Panel);
            callPutTypeButtons[i].addActionListener(this);
            }
          callPutTypeButtons[0].setSelected(true);
          barrier_Label= new JLabel(TYPE_OF_EXOTIC_OPTION);
        barrier_inputPanel.add(barrier_Label);
          barrierTypesGroup=new ButtonGroup();
          barrierTypesButtons =new JRadioButton[5];
        for (int i=0; i<5; i++) {
            barrierTypesButtons[i] = new JRadioButton(BARRIER_TYPE[i]);
            barrierTypesGroup.add(barrierTypesButtons [i]);
            barrier_inputPanel.add( barrierTypesButtons [i]);
            barrierTypesButtons [i].addActionListener(this);
          }
          barrierTypesButtons[0].setSelected(true);

 // Add fields for Options price calculation
    barrier_inputPanel = new JPanel(new GridLayout(3,1));
    converterPanel.add(barrier_inputPanel);

  //Adding field for stockprice and label
   barriermini_Panel= new JPanel(new GridLayout(1,2));
    barrier1Field = new JTextField();
    barrier1Field.setText("100.00");
    stockprice_Label= new JLabel(STOCK_PRICE);
    barriermini_Panel.add(barrier1Field );
    barriermini_Panel.add(stockprice_Label);
    barrier_inputPanel.add( barriermini_Panel);

 //Adding field for strikeprice and label
    barriermini_Panel= new JPanel(new GridLayout(1,2));
    barrier2Field = new JTextField();
    barrier2Field.setText("100.00");
    strikeprice_Label= new JLabel(STRIKE_PRICE);
    barriermini_Panel.add(barrier2Field );
    barriermini_Panel.add(strikeprice_Label);
    barrier_inputPanel.add( barriermini_Panel);

  //Adding field for maturity field and label
    barriermini_Panel= new JPanel(new GridLayout(1,2));
   barrier3Field = new JTextField();
   barrier3Field.setText("1.00");
```

```
    maturity_Label= new JLabel(TIME_TO_MATURITY);
    barriermini_Panel.add(barrier3Field );
    barriermini_Panel.add(maturity_Label);
    barrier_inputPanel.add( barriermini_Panel);


  //Adding field for INTEREST RATE and label
    barrier_inputPanel = new JPanel(new GridLayout(3,1));
     converterPanel.add(barrier_inputPanel);
    barriermini_Panel= new JPanel(new GridLayout(1,2));
    barrier4Field = new JTextField();
    barrier4Field.setText("5.00");
    interestrate_Label= new JLabel(INTERESTRATE);
    barriermini_Panel.add(barrier4Field );
    barriermini_Panel.add(interestrate_Label);
    barrier_inputPanel.add( barriermini_Panel);

  //Adding field for DIVIDEND and label
    barriermini_Panel= new JPanel(new GridLayout(1,2));
    barrier5Field = new JTextField();
    barrier5Field.setText("3.00");
    dividentrate_Label= new JLabel(DIVIDEND);
    barriermini_Panel.add(barrier5Field );
    barriermini_Panel.add(dividentrate_Label);
    barrier_inputPanel.add( barriermini_Panel);

   //Adding field for BARRIER SIZE and label
    barriermini_Panel= new JPanel(new GridLayout(1,2));
   barrier6Field = new JTextField();
   barrier6Field.setText("0.80");
    barriersize_Label= new JLabel(BARRIER_SIZE);
    barriermini_Panel.add(barrier6Field );
    barriermini_Panel.add(barriersize_Label);
    barrier_inputPanel.add( barriermini_Panel);

  // Add fields for Options price output(display of results)
    barrier_inputPanel = new JPanel(new GridLayout(3,1));
     barrier_inputPanel.setBorder(BorderFactory.createLineBorder(
Color.RED, 1));
    converterPanel.add(barrier_inputPanel);

    barriermini_Panel= new JPanel(new GridLayout(1,2));
    barrierpriceField= new JTextField(" ");
    barrierpriceField.setEditable(false);
    outputprice_Label= new JLabel(BARRIER_OPTIONPRICE);
```

```
            barriermini_Panel.add(barrierpriceField );
            barriermini_Panel.add(outputprice_Label);
            barrier_inputPanel.add( barriermini_Panel);

          //Add empty position
            for (int i=0; i<1; i++) {
             barriermini_Panel= new JPanel(new GridLayout(1,2));
            //progressBar = new JProgressBar(JProgressBar.HORIZONTAL);
            //progressBar.setStringPainted(true);
            //progressBar.setForeground(Color.red);
            //progressBar.setIndeterminate(true);
//barriermini_Panel.add(progressBar);
            barrier_inputPanel.add(barriermini_Panel);
            }
          // Add Reset Button
            barriermini_Panel= new JPanel(new GridLayout(1,2));
            resetButton = new JButton(RESET);
           barriermini_Panel.add(resetButton);
           barriermini_Panel.add(emptyLabel);
           barrier_inputPanel.add(barriermini_Panel);

       //--------ADD LISTENERS----------------
          calculateButton.addActionListener(this);
         processTypeButtons[i].addActionListener(this);
         graphButton.addActionListener(this);
         nig_1Field.addActionListener(this);
         nig_2Field.addActionListener(this);
         nig_3Field.addActionListener(this);
         nig_4Field.addActionListener(this);
         nig_5Field.addActionListener(this);
         nig_6Field.addActionListener(this);
         vg_1Field.addActionListener(this);
         vg_2Field.addActionListener(this);
         vg_3Field.addActionListener(this);
         vg_4Field.addActionListener(this);
         vg_5Field.addActionListener(this);
         vg_6Field.addActionListener(this);
         variates1Field.addActionListener(this);
         variates2Field.addActionListener(this);
         barrier1Field.addActionListener(this);
         barrier2Field.addActionListener(this);
         barrier3Field.addActionListener(this);
         barrier4Field.addActionListener(this);
         barrier5Field.addActionListener(this);
         barrier6Field.addActionListener(this);
```

```
      resetButton.addActionListener(this);

}


 public void actionPerformed (ActionEvent event) {
      double tempValue = 1;
   Object source = event.getSource();
    if (source == vg_1Field){
                try {
                    tempValue = Double.parseDouble(vg_1Field.getText());
                }
                catch (NumberFormatException e) {
                    JOptionPane.showMessageDialog(null,
                                                  NOT_A_NUMBER,
                                                     VG_C_ERROR,
                                                     JOptionPane.ERROR_MESSAGE);
                 vg_1Field .setText("11.9896");
                }
                if (tempValue <= 0) {
                 JOptionPane.showMessageDialog(null,
                                                  NON_POSITIVE,
                                                     VG_C_ERROR,
                                                     JOptionPane.ERROR_MESSAGE);
                    vg_1Field .setText("11.9896");
             return ;
                }

            }
             if (source == vg_2Field){
                try {
                    tempValue = Double.parseDouble(vg_2Field.getText());
                      }
                 catch (NumberFormatException e) {
                    JOptionPane.showMessageDialog(null,
                                                  NOT_A_NUMBER,
                                                     VG_G_ERROR,
                                                  JOptionPane.ERROR_MESSAGE);
                    vg_2Field .setText("25.8523");
                                    }
                if (tempValue <= 0) {
                 JOptionPane.showMessageDialog(null,
                                                  NON_POSITIVE,
                                                     VG_G_ERROR,
                            JOptionPane.ERROR_MESSAGE);
```

```
                                vg_2Field .setText("25.8523");
                                  return ;
                                    }

                                 }
                        if (source == vg_3Field){
                         try {
                             tempValue = Double.parseDouble(vg_3Field.getText());
                           }
                         catch (NumberFormatException e) {
                             JOptionPane.showMessageDialog(null,
                                                     NOT_A_NUMBER,
                                                        VG_M_ERROR,
JOptionPane.ERROR_MESSAGE);
                         vg_3Field .setText("35.5344");
                         }
                         if (tempValue <= 0) {
                         JOptionPane.showMessageDialog(null,
                                                     NON_POSITIVE,
                                                        VG_M_ERROR,
                                        JOptionPane.ERROR_MESSAGE);
                                         vg_3Field .setText("35.5344");
                           return ;
                           }
                           }
                        if (source == vg_4Field){
                         try {
                             tempValue = Double.parseDouble(vg_4Field.getText());
                              }
                         catch (NumberFormatException e) {
                             JOptionPane.showMessageDialog(null,
                                                     NOT_A_NUMBER,
                                                        VG_KAPPA_ERROR,
                                                        JOptionPane.ERROR_MESSAGE);
                             vg_4Field .setText("0.6020");
                              }
                         if (tempValue <= 0) {
                         JOptionPane.showMessageDialog(null,
                                                     NON_POSITIVE,
                                                        VG_KAPPA_ERROR,
                                                        JOptionPane.ERROR_MESSAGE);
                                vg_4Field .setText("0.6020");
                                   return  ;
                                   }
```

```
                    }
                if (source == vg_5Field){
                  try {
                      tempValue = Double.parseDouble(vg_5Field.getText());
                       }
                   catch (NumberFormatException e) {
                      JOptionPane.showMessageDialog(null,
                                                    NOT_A_NUMBER,
                                                       VG_ETA_ERROR,

JOptionPane.ERROR_MESSAGE);
                         vg_5Field .setText("1.5560");
                          }
                     if (tempValue <= 0) {
                      JOptionPane.showMessageDialog(null,
                                                    NON_POSITIVE,
                                                       VG_ETA_ERROR,
                                                       JOptionPane.ERROR_MESSAGE);
                      vg_5Field .setText("1.5560");
                       return ;
                     }
                     }
                if (source == vg_6Field){
                   try {
                      tempValue = Double.parseDouble(vg_3Field.getText());
                        }
                   catch (NumberFormatException e) {
                      JOptionPane.showMessageDialog(null,
                                                    NOT_A_NUMBER,
                                                       VG_LAMBDA_ERROR,
                                                       JOptionPane.ERROR_MESSAGE);
                   vg_6Field .setText("1.9992");
                   }
                   if (tempValue <= 0) {
                    JOptionPane.showMessageDialog(null,
                                                    NON_POSITIVE,
                                                       VG_LAMBDA_ERROR,
                                                       JOptionPane.ERROR_MESSAGE);
                    vg_6Field .setText("1.9992");
                     return ;
                       }
                    }
                if (source == nig_1Field)   {

                  try {
```

```
                tempValue = Double.parseDouble(nig_1Field.getText());
            }
            catch (NumberFormatException e) {
                JOptionPane.showMessageDialog(null,
                                              NOT_A_NUMBER,
                                                  NIG_ALPHA_ERROR,
                                                  JOptionPane.ERROR_MESSAGE);

             nig_1Field .setText("18.4815");
            }
            if (tempValue <= 0) {
             JOptionPane.showMessageDialog(null,
                                              NON_POSITIVE,
                                                  NIG_ALPHA_ERROR,
                                              JOptionPane.ERROR_MESSAGE);
            nig_1Field .setText("18.4815");
              return;
              }

           }



if (source == nig_2Field)
      {
          try {
              tempValue = Double.parseDouble(nig_2Field.getText());
           }
           catch (NumberFormatException e) {
              JOptionPane.showMessageDialog(null,
                                              NOT_INRANGE,
                                                  NIG_BETA_ERROR,
                                                  JOptionPane.ERROR_MESSAGE);
             nig_2Field .setText("-4.8412");
             }
           if (tempValue < -3.1416) {
           JOptionPane.showMessageDialog(null,
                                              NOT_INRANGE,
                                                  NIG_BETA_ERROR,
                                                  JOptionPane.ERROR_MESSAGE);

                nig_2Field .setText("-4.8412");
                 }
                 if (tempValue >3.1416) {
           JOptionPane.showMessageDialog(null,
```

```
                                        NOT_INRANGE,
                                            NIG_BETA_ERROR,
                                            JOptionPane.ERROR_MESSAGE);

            nig_2Field .setText("-4.8412");
            return;
           }
         }
if (source == nig_3Field)  {

 try {
     tempValue = Double.parseDouble(nig_4Field.getText());
 }
 catch (NumberFormatException e) {
     JOptionPane.showMessageDialog(null,
                                        NOT_A_NUMBER,
                                            NIG_GAMMA_ERROR,
                                            JOptionPane.ERROR_MESSAGE);
 nig_3Field .setText("0.4685");
 }
 if (tempValue <= 0) {
  JOptionPane.showMessageDialog(null,
                                        NON_POSITIVE,
                                            NIG_GAMMA_ERROR,
                                            JOptionPane.ERROR_MESSAGE);
 nig_3Field .setText("0.4685");
 return;
 }
}
if (source == nig_4Field)       {

 try {
     tempValue = Double.parseDouble(nig_4Field.getText());
 }
 catch (NumberFormatException e) {
     JOptionPane.showMessageDialog(null,
                                        NOT_A_NUMBER,
                                            NIG_KAPPA_ERROR,
                                            JOptionPane.ERROR_MESSAGE);

 nig_4Field .setText("0.5391");
 }
 if (tempValue <= 0) {
  JOptionPane.showMessageDialog(null,
                                        NON_POSITIVE,
```

```
                                        NIG_KAPPA_ERROR,
                                        JOptionPane.ERROR_MESSAGE);

    nig_4Field .setText("0.5391");
    return;
    }
   }

  if (source == nig_5Field)       {

    try {
        tempValue = Double.parseDouble(nig_5Field.getText());
     }
     catch (NumberFormatException e) {
        JOptionPane.showMessageDialog(null,
                                      NOT_A_NUMBER,
                                        NIG_ETA_ERROR,
                                        JOptionPane.ERROR_MESSAGE);
     nig_5Field .setText("1.5746");
    }
    if (tempValue <= 0) {
     JOptionPane.showMessageDialog(null,
                                      NON_POSITIVE,
                                        NIG_ETA_ERROR,
                                        JOptionPane.ERROR_MESSAGE);

     nig_5Field .setText("1.5746");
    return;
   }
  }
 if (source == nig_6Field)       {
    try {
        tempValue = Double.parseDouble(nig_3Field.getText());
     }
     catch (NumberFormatException e) {
        JOptionPane.showMessageDialog(null,
                                      NOT_A_NUMBER,
                                        NIG_LAMBDA_ERROR,
                                        JOptionPane.ERROR_MESSAGE);
    nig_6Field .setText("1.8772");
    }
    if (tempValue <= 0) {
     JOptionPane.showMessageDialog(null,
                                      NON_POSITIVE,
                                        NIG_LAMBDA_ERROR,
```

```
                                                JOptionPane.ERROR_MESSAGE);
      nig_6Field .setText("1.8772");
      return;
     }
    }


// Adding numbers to control variates
     if (source == variates1Field)       {
      try {
          tempValue = Double.parseDouble(variates1Field.getText());
       }
       catch (NumberFormatException e) {
          JOptionPane.showMessageDialog(null,
                                        NOT_A_NUMBER,
                                           SIMULATIONS_ERROR,
                                           JOptionPane.ERROR_MESSAGE);
      variates1Field .setText("10000");
      }
      if (tempValue <=0) {
       JOptionPane.showMessageDialog(null,
                                        NON_POSITIVE,
                                           SIMULATIONS_ERROR,
                                           JOptionPane.ERROR_MESSAGE);
      variates1Field .setText("10000");
      }
      if ( numberofpricesButtons[1].isSelected()) {
             numberofpricesbuttons = false;
          if (tempValue <=
                Double.parseDouble(variates2Field.getText())) {
              JOptionPane.showMessageDialog(null,

                                              NUMBER_MORE_THANMAXIMUM,
                                                   SIMULATIONS_ERROR,


                JOptionPane.ERROR_MESSAGE);
                    variates1Field .setText("10000");
                    variates2Field .setText("100");
                       return;
                                  }
                     }
                    }
    if (source == variates2Field)  {
      try {
          tempValue = Double.parseDouble(variates2Field.getText());
```

```
        }
        catch (NumberFormatException e) {
            JOptionPane.showMessageDialog(null,
                                          NOT_A_NUMBER,
                                              SIMULATIONS_ERROR,
                                              JOptionPane.ERROR_MESSAGE);
       variates2Field .setText("100");
        }
        if (tempValue <= 0) {
         JOptionPane.showMessageDialog(null,
                                          NON_POSITIVE,
                                              SIMULATIONS_ERROR,
                                              JOptionPane.ERROR_MESSAGE);
            variates2Field .setText("100");

        }
         if (tempValue >= Double.parseDouble(variates1Field.getText())){
         JOptionPane.showMessageDialog(null,
                                          NUMBER_LESS_THANMINIMUM,
                                              SIMULATIONS_ERROR,
                                              JOptionPane.ERROR_MESSAGE);
         variates1Field .setText("10000");
         variates2Field .setText("100");
               return;
          }
         }
    if (source == barrier1Field) {

        try {
            tempValue = Double.parseDouble(barrier1Field.getText());
               }
                               catch (NumberFormatException e) {
            JOptionPane.showMessageDialog(null,
                                          NOT_A_NUMBER,
                                              STOCK_PRICE,
                                              JOptionPane.ERROR_MESSAGE);
         barrier1Field.setText("100.00");
        //return;

        }
        if (tempValue <= 0) {
         JOptionPane.showMessageDialog(null,
                                          NON_POSITIVE,
                                              STOCK_PRICE,
                                              JOptionPane.ERROR_MESSAGE);
```

```
  barrier1Field.setText("100.00");
  return;
 }
}

 if (source == barrier2Field)       {
  try {
      tempValue = Double.parseDouble(barrier2Field.getText());
      }
   catch (NumberFormatException e) {
      JOptionPane.showMessageDialog(null,
                                    NOT_A_NUMBER,
                                       STRIKE_PRICE,
                                       JOptionPane.ERROR_MESSAGE);
  barrier2Field.setText("100.00");
  }
  if (tempValue < 0) {
   JOptionPane.showMessageDialog(null,
                                    NON_POSITIVE,
                                       STRIKE_PRICE,
                                       JOptionPane.ERROR_MESSAGE);
  barrier2Field.setText("100.00");
  return;
 }
}
 if (source == barrier3Field)  {
  try {
      tempValue = Double.parseDouble(barrier3Field.getText());
     }
   catch (NumberFormatException e) {
      JOptionPane.showMessageDialog(null,
                                    NOT_A_NUMBER,
                                       TIME_TO_MATURITY,
                                    JOptionPane.ERROR_MESSAGE);
    barrier3Field.setText("1.00");

    }

  if (tempValue <= 0) {
   JOptionPane.showMessageDialog(null,
                                    NON_POSITIVE,
                                       TIME_TO_MATURITY,
                                       JOptionPane.ERROR_MESSAGE);
  barrier3Field.setText("1.00");
  return;
```

```
            }
           }
    if (source == barrier4Field) {
         try {
             tempValue = Double.parseDouble(barrier4Field.getText());
          }
          catch (NumberFormatException e) {
             JOptionPane.showMessageDialog(null,
                                           NOT_A_NUMBER,
                                              INTERESTRATE,
                                              JOptionPane.ERROR_MESSAGE);
         barrier4Field.setText("5.00");
         }
         if (tempValue < 0) {
          JOptionPane.showMessageDialog(null,
                                           NON_POSITIVE,
                                              INTERESTRATE,
                                              JOptionPane.ERROR_MESSAGE);
         barrier4Field.setText("5.00");
         return;
        }
       }
          if (source == barrier5Field)       {

         try {
             tempValue = Double.parseDouble(barrier5Field.getText());
          }
          catch (NumberFormatException e) {
             JOptionPane.showMessageDialog(null,
                                           NOT_A_NUMBER,
                                               DIVIDEND,
                                              JOptionPane.ERROR_MESSAGE);
         barrier5Field.setText("3.00");
         }
         if (tempValue < 0) {
          JOptionPane.showMessageDialog(null,
                                           NON_POSITIVE,
                                               DIVIDEND,
                                              JOptionPane.ERROR_MESSAGE);
        barrier5Field.setText("3.00");
         return;
        }
       }

       if (source == barrier6Field)       {
```

```
        try {
            tempValue = Double.parseDouble(barrier6Field.getText());
        }
        catch (NumberFormatException e) {
            JOptionPane.showMessageDialog(null,
                                          NOT_A_NUMBER,
                                              BARRIER_SIZE,
                                              JOptionPane.ERROR_MESSAGE);
          barrier6Field.setText("0.80");
            }
        if (tempValue < 0) {
        JOptionPane.showMessageDialog(null,
                                          NON_POSITIVE,
                                              BARRIER_SIZE,
                                              JOptionPane.ERROR_MESSAGE);
        barrier6Field.setText("0.80");
        return;
        }
       }


// If Reset Button is Pressed
 if (source == resetButton){
    vg_1Field .setText("11.9896");
    vg_2Field .setText("25.8523");
    vg_3Field .setText("35.5344");
    vg_4Field .setText("0.6020");
    vg_5Field .setText("1.5560");
    vg_6Field .setText("1.9992");
    nig_1Field .setText("18.4815");
    nig_2Field .setText("-4.8412");
    nig_3Field .setText("0.4685");
    nig_4Field .setText("0.5391");
    nig_5Field .setText("1.5746");
    nig_6Field .setText("1.8772");
    variates1Field .setText("10000");
    variates2Field .setText("100");
    barrier1Field.setText("100.00");
    barrier2Field.setText("100.00");
    barrier3Field.setText("1.00");
    barrier4Field.setText("5.00");
      barrier5Field.setText("3.00");
    barrier6Field.setText("0.80");
    barrierpriceField.setText("  ");
```

```
        barrierTypesButtons[0].setSelected(true);
        standardErrorBox.setSelected(true);
         optionPriceBox.setSelected(false);
         dibBox.setSelected(true);
         dobBox.setSelected(false);
        uibBox.setSelected(false);
        uobBox.setSelected(false);
        LbBox.setSelected(false);


        }


     //Add default barrier sizes  to choice of  barrier
   if (source ==   barrierTypesButtons[0]) {
     if (  barrierTypesButtons[0].isSelected()) {
       barrier6Field.setText("0.80");
        }
     }
  if (source ==   barrierTypesButtons[1]) {
    if (  barrierTypesButtons[1].isSelected()) {
       barrier6Field.setText("0.95");
        }
     }
     if (source ==   barrierTypesButtons[2]) {
    if (  barrierTypesButtons[2].isSelected()) {
       barrier6Field.setText("1.10");
        }
     }
  if (source ==   barrierTypesButtons[3]) {
    if (  barrierTypesButtons[3].isSelected()) {
       barrier6Field.setText("1.30");
        }
     }
     if ( barrierTypesButtons[4].isSelected()) {
          //barrier6Field.setText(" ");
          barrier2Field.setEnabled(false);
          barrier6Field.setEnabled(false);
        }
   else{
       barrier2Field.setEnabled(true);
      barrier6Field.setEnabled(true);
      }
```

```
        if(source == calculateButton){
              simulations=(int)(Double.parseDouble(variates1Field.getText()));
              int yLength = (int)(NUMBER_OF_STEPS*timetoMaturity)+1;

initialstockprice=(double)(Double.parseDouble(barrier1Field.getText()));

interestRate=((double)(Double.parseDouble(barrier4Field.getText())))/100;
             dividend =((double)(Double.parseDouble(barrier5Field.getText())))/100;
             double barrier=(double)(Double.parseDouble(barrier6Field.getText()));
             strikeprice=(double)(Double.parseDouble(barrier2Field.getText()));
             b1= barrier*initialstockprice;
              timetoMaturity=(double)(Double.parseDouble(barrier3Field.getText()));
              nigalpha=(double)(Double.parseDouble(nig_1Field.getText()));
             nigbeta=(double)(Double.parseDouble(nig_2Field.getText()));
             niggamma=(double)(Double.parseDouble(nig_3Field.getText()));
             nigkappa=(double)(Double.parseDouble(nig_4Field.getText()));
             nigeta=(double)(Double.parseDouble(nig_5Field.getText()));
             niglambda=(double)(Double.parseDouble(nig_6Field.getText()));

             double kap=1/(niggamma*Math.sqrt(Math.pow(nigalpha,2)-
Math.pow(nigbeta,2)));
             double sig=1/Math.sqrt(kap*(Math.pow(nigalpha,2)-Math.pow(nigbeta,2)));
             //1/Math.sqrt(nigkappa*(Math.pow(nigalpha,2)-Math.pow(nigbeta,2)));
             double thet=Math.pow(sig,2)*nigbeta;//Math.pow(niggamma,2)*nigbeta;
             double nigX1;
             y = new double[yLength];
             Y = new double[yLength];
             X = new double[yLength];
             Stockprice= new double[yLength];
             payout=new double[simulations];
             variance=0;
             PayoutSum =0;

             y[0]=1;
             Y[0]=0;
             X[0]=0;
             deltaTime = 0.004;

          if(processTypeButtons[0].isSelected()){

             Xg =new double[yLength];
             //Xg[0]=0;
             mean=0;
             stddev=1/(NUMBER_OF_STEPS*timetoMaturity);
             c =(double)(Double.parseDouble(vg_1Field.getText()));
```

```
     g =(double)((Double.parseDouble(vg_2Field.getText())));
     m =(double)((Double.parseDouble(vg_3Field.getText())));
     theta=c*((1/m)-(1/g));
     sigma=Math.sqrt((2*c)/(g*m));
     vgkappa=(double)((Double.parseDouble(vg_4Field.getText())));
     vgeta=(double)((Double.parseDouble(vg_5Field.getText())));
     vglambda=(double)((Double.parseDouble(vg_6Field.getText())));
      v=1/c;

   double d=1-(sigma*sigma*v)/2-theta*v;
     //progressBar.setMaximum(simulations);
     //progressBar.setValue(0);
     //progressBar.setIndeterminate(false);
for(int i=0;i<simulations;i++){
    //progressBar.setValue(i+1);

        // Simulate y and Y, i.e. time grid
    for(int j=1;j<yLength;j++){
      y[j]=y[j-1]+vgkappa*(vgeta-y[j-1])*deltaTime
             +vglambda*Math.sqrt(y[j-1])
             *((random.nextGaussian())*stddev);
     //-(2)--calculate from (1)the rate of time change Y
             Y[j]=Y[j-1]+y[j]*deltaTime;
             }
       //-simulate the Lévy process X(.ie.the Variance Gamma Process)-
           //X[0] = 0;
         for(int j=1;j<yLength;j++){
            double p = (Y[j]-Y[j-1])/v;
              //u1 = Math.pow(random.nextDouble(),1/p);
            //u2 = Math.pow(random.nextDouble(),1/(1-p));
            double u1 = 1;
           double u2 = 1;
            while ((u1+u2)>1) {
            u1 = Math.pow(random.nextDouble(),1/p);
            u2 = Math.pow(random.nextDouble(),1/(1-p));
              }

      //--generate an exponential random variable z
          double z = -Math.log(random.nextDouble());
             double G=(z*u1)/(u1+u2) ;
       //- multiply by kappa
                G = G*v;
            w=random.nextGaussian();
       //--generating Xt as by wim
         double Xg;
```

```
   Xg=theta*G+sigma*Math.sqrt(G)*w;
// Generating Xyt as in wims paper
        X[j] = X[j-1]+Xg;
// Generating of stock prices

Stockprice[j]=initialstockprice
      *Math.exp((interestRate-
         dividend)*j*deltaTime+X[j])*Math.pow(d,Y[j]/v);
               }
// Calculating Barrier prices--
        Min=Stockprice[1];
        Max=Stockprice[1];
    for(int j=1;j<yLength;j++){
          if(Stockprice[j]>Max){
              Max=Stockprice[j];
                    }
          else{
                 Max=Stockprice[1];
                 }
              }
     for(int j=1;j<yLength;j++){
          if(Stockprice[j]<Min){
               Min=Stockprice[j];
                    }
              else{
                 Min=Stockprice[1];
                 }
              }
  if(callPutTypeButtons[0].isSelected()){
    //---Calculating DOB Options price for a VG-process-
  if (barrierTypesButtons[0].isSelected()) {
            if(Min>b1){
              if(Stockprice[yLength-1]>strikeprice){
              payout[i]=(Stockprice[yLength-1]-strikeprice);
                   }
                 }
              else{
                  payout[i]=0;
                  }
                }
     //---Calculating DIB Options price for a VG-process-
    if (barrierTypesButtons[1].isSelected()) {
           if(Min<=b1){
               if(Stockprice[yLength-1]>strikeprice){
                payout[i]=(Stockprice[yLength-1]-strikeprice);
```

```
                    }
                  }
               else{
                   payout[i]=0;
                   }
                }
          //---Calculating UIB Options price for a VG-process-
           if (barrierTypesButtons[2].isSelected()) {
                 if(Max>=b1){
                    if(Stockprice[yLength-1]>strikeprice){
                       payout[i]=(Stockprice[yLength-1]-strikeprice);
                        }
                    }
                  else{
                       payout[i]=0;
                       }
                 }
            //---Calculating UOB Options price for a VG-process-
               if (barrierTypesButtons[3].isSelected()) {
                 if(Max<b1){
                     if(Stockprice[yLength-1]>strikeprice){
                       payout[i]=(Stockprice[yLength-1]-strikeprice);
                         }
                     }
                  else{
                       payout[i]=0;
                       }
                 }
             //---Calculating LookBack Options price for a VG-process-
               if (barrierTypesButtons[4].isSelected()) {
                     if(Stockprice[yLength-1]>Min){
                       payout[i]=(Stockprice[yLength-1]-Min);
                         }
                  else{
                       payout[i]=0;
                       }
                 }
                }
          else{

            //---Calculating DOB Options price for a VG-process-
         if (barrierTypesButtons[0].isSelected()) {
                 if(Min>b1){
                   if(strikeprice>Stockprice[yLength-1]){
                   payout[i]=(strikeprice-Stockprice[yLength-1]);
```

```
                }
              }
            else{
                payout[i]=0;
                }
              }
 //---Calculating DIB Options price for a VG-process-
if (barrierTypesButtons[1].isSelected()) {
       if(Min<=b1){
           if(strikeprice>Stockprice[yLength-1]){
            payout[i]=(strikeprice-Stockprice[yLength-1]);
               }
            }
          else{
              payout[i]=0;
              }
           }
//---Calculating UIB Options price for a VG-process-
 if (barrierTypesButtons[2].isSelected()) {
       if(Max>=b1){
          if(strikeprice>Stockprice[yLength-1]){
            payout[i]=(strikeprice-Stockprice[yLength-1]);
             }
            }
          else{
              payout[i]=0;
              }
         }
  //---Calculating UOB Options price for a VG-process-
     if (barrierTypesButtons[3].isSelected()) {
       if(Max<b1){
           if(strikeprice>Stockprice[yLength-1]){
             payout[i]=(strikeprice-Stockprice[yLength-1]);
               }
            }
          else{
              payout[i]=0;
              }
        }
 //---Calculating LookBack Options price for a VG-process-
     if (barrierTypesButtons[4].isSelected()) {
           if(Max>Stockprice[yLength-1]){
             payout[i]=(Max-Stockprice[yLength-1]);
               }
          else{
```

```
                    payout[i]=0;
                    }
                  }
                 }

                   PayoutSum +=payout[i];
                   variance+=Math.pow((Avpayout-payout[i]),2);
                 //progressBar.setValue(i+1);
                 }  //end of i simulation loop
               }// end of process[0] loop



          //----------NORMAL INVERSE GAUSSIAN PROCESSS ---------
            if(processTypeButtons[1].isSelected()){
               //progressBar.setMaximum(simulations);
                for(int i=0;i<simulations;i++){

              // Simulate y and Y, i.e. time grid
                   for(int j=1;j<yLength;j++){
                   y[j]=y[j-1]+vgkappa*(vgeta-y[j-1])*deltaTime
                             +vglambda*Math.sqrt(y[j-1])
                             *((random.nextGaussian())*stddev);

            //-(2)--calculate from (1)the rate of time change Y
                  Y[j]=Y[j-1]+y[j]*deltaTime;
                              }
//-simulate the Lévy process X(.ie.the Normal inverse Gaussian Process)-
               for(int j=1;j<yLength;j++){

            // Generate a standard normal random variable
                        w=random.nextGaussian();
                       double u = (Y[j]-Y[j-1]);
                       double nigY=Math.pow(w,2);
                       double niglamb=Math.pow((Y[j]-Y[j-1]),2)/kap;
                      // double b=


// simulation of ylength number of independent standard normal random variable
          double nigX=u+(u*u*nigY)/(2*niglamb)-((u/(2*niglamb))*
Math.sqrt((4*u*niglamb*nigY)+u*u*nigY*nigY));

                   //Generate a uniform random variable
                        double nigU=random.nextDouble();
```

```
                        if(nigU<=(u/(nigX+u))){

                              nigX1=nigX;
                            }
                          else{

                              nigX1=(u*u)/nigX;
                              }
                  //   Simulate normal inverse Gaussian random variable..
                              double w1=random.nextGaussian();
                              double Xn=sig*w1*Math.sqrt(nigX1)+thet*nigX1;
                              X[j]=X[j-1]+Xn;
                    //    Generating of stock prices
Stockprice[j]=initialstockprice*Math.exp((interestRate-dividend)*j*deltaTime+X[j]
                   -(Y[j]/kap)+(Y[j]/kap)*Math.sqrt(1-(sig*sig*kap)-(2*thet*kap)));
                                    }
                  // Calculating Barrier prices--
                            Min=Stockprice[1];
                           Max=Stockprice[1];

                      for(int j=1;j<yLength;j++){
                          if(Stockprice[j]>Max){
                               Max=Stockprice[j];
                                   }
                             else{
                                Max=Stockprice[1];
                                    }
                                }
                     for(int j=1;j<yLength;j++){
                            if(Stockprice[j]<Min){
                                 Min=Stockprice[j];
                                    }
                               else{
                                Min=Stockprice[1];
                                   }
                                }

                   if(callPutTypeButtons[0].isSelected()){
                    //---Calculating DOB Options price for a NIG-process-
                  if (barrierTypesButtons[0].isSelected()) {
                           if(Min>b1){
                             if(Stockprice[yLength-1]>strikeprice){
                             payout[i]=(Stockprice[yLength-1]-strikeprice);
                                  }
                                }
```

```
            else{
                payout[i]=0;
                }
              }
 //---Calculating DIB Options price for a NIG-process-
 if (barrierTypesButtons[1].isSelected()) {
       if(Min<=b1){
           if(Stockprice[yLength-1]>strikeprice){
            payout[i]=(Stockprice[yLength-1]-strikeprice);
               }
             }
           else{
                payout[i]=0;
                }
            }
//---Calculating UIB Options price for a NIG-process-
 if (barrierTypesButtons[2].isSelected()) {
       if(Max>=b1){
          if(Stockprice[yLength-1]>strikeprice){
             payout[i]=(Stockprice[yLength-1]-strikeprice);
              }
             }
           else{
                payout[i]=0;
                }
         }
  //---Calculating UOB Options price for a NIG-process-
     if (barrierTypesButtons[3].isSelected()) {
       if(Max<b1){
           if(Stockprice[yLength-1]>strikeprice){
             payout[i]=(Stockprice[yLength-1]-strikeprice);
               }
             }
           else{
                payout[i]=0;
                }
        }
 //---Calculating LookBack Options price for a NIG-process-
     if (barrierTypesButtons[4].isSelected()) {
           if(Stockprice[yLength-1]>Min){
             payout[i]=(Stockprice[yLength-1]-Min);
               }
           else{
                payout[i]=0;
                }
```

```
            }
           }
    else{

     //---Calculating DOB Options price for a NIG-process-
  if (barrierTypesButtons[0].isSelected()) {
          if(Min>b1){
            if(strikeprice>Stockprice[yLength-1]){
            payout[i]=(strikeprice-Stockprice[yLength-1]);
                 }
               }
            else{
                 payout[i]=0;
                 }
              }
     //---Calculating DIB Options price for a NIG-process-
     if (barrierTypesButtons[1].isSelected()) {
          if(Min<=b1){
              if(strikeprice>Stockprice[yLength-1]){
               payout[i]=(strikeprice-Stockprice[yLength-1]);
                   }
                 }
            else{
                 payout[i]=0;
                 }
             }
    //---Calculating UIB Options price for a NIG-process-
     if (barrierTypesButtons[2].isSelected()) {
          if(Max>=b1){
             if(strikeprice>Stockprice[yLength-1]){
               payout[i]=(strikeprice-Stockprice[yLength-1]);
                 }
               }
            else{
                 payout[i]=0;
                 }
           }
      //---Calculating UOB Options price for a NIG-process-
          if (barrierTypesButtons[3].isSelected()) {
           if(Max<b1){
              if(strikeprice>Stockprice[yLength-1]){
                payout[i]=(strikeprice-Stockprice[yLength-1]);
                  }
               }
            else{
```

```
                    payout[i]=0;
                    }
                }
            //---Calculating LookBack Options price for a NIG-process-
                if (barrierTypesButtons[4].isSelected()) {
                    if(Max>Stockprice[yLength-1]){
                      payout[i]=(Max-Stockprice[yLength-1]);
                        }
                  else{
                      payout[i]=0;
                      }
                   }
                  }

                // adding up all the payouts for i simulations
                     PayoutSum +=payout[i];
                // adding up  vaiance for  i number of simulations
                     variance+=Math.pow((Avpayout-payout[i]),2);
                     //progressBar.setValue(i+1);
                  }   // end of i loop
                  //progressBar.setValue(0);

                  }  // end of process[1] loop

             //finding average for all i simulations
               Avpayout =PayoutSum/simulations;

            //standard error calculation for i simulations
               StandardError=Math.sqrt((1/Math.pow(simulations-1,2))
                             *variance);
               System.out.println(" StandardError="+StandardError);

            // option price calculation
            OptionPrice=Avpayout*Math.exp(-(interestRate*timetoMaturity));
// setting text field to price (to show on gui)
     barrierpriceField.setText(numberFormatter.format(OptionPrice));
           }

      //-------------GRAPHIC ILLUSTRATIONS--------------
       if(source==graphButton){
          simulations=(int)(Double.parseDouble(variates1Field.getText()));
          interval=(int)(Double.parseDouble(variates2Field.getText()));
          int s=simulations/100;
          int yLength = (int)(NUMBER_OF_STEPS*timetoMaturity)+1;
```

```
initialstockprice=(double)(Double.parseDouble(barrier1Field.getText()));

interestRate=((double)(Double.parseDouble(barrier4Field.getText())))/100;
dividend =((double)(Double.parseDouble(barrier5Field.getText())))/100;
                  double
barrier=(double)(Double.parseDouble(barrier6Field.getText()));
                  b1= barrier*initialstockprice;

timetoMaturity=(double)(Double.parseDouble(barrier3Field.getText()));
                 nigalpha=(double)(Double.parseDouble(nig_1Field.getText()));
                 nigbeta=(double)(Double.parseDouble(nig_2Field.getText()));
                 niggamma=(double)(Double.parseDouble(nig_3Field.getText()));
                 nigkappa=(double)(Double.parseDouble(nig_4Field.getText()));
                 nigeta=(double)(Double.parseDouble(nig_5Field.getText()));
                 niglambda=(double)(Double.parseDouble(nig_6Field.getText()));

strikeprice=(double)(Double.parseDouble(barrier2Field.getText()));

                 double kap=1/(niggamma*Math.sqrt(Math.pow(nigalpha,2)-
Math.pow(nigbeta,2)));
                  double sig=1/Math.sqrt(kap*(Math.pow(nigalpha,2)-
Math.pow(nigbeta,2)));
                   //1/Math.sqrt(nigkappa*(Math.pow(nigalpha,2)-
Math.pow(nigbeta,2)));
                  double thet=Math.pow(sig,2)*nigbeta;
//Math.pow(niggamma,2)*nigbeta;
                 double nigX1;
                 y = new double[yLength];
                 Y = new double[yLength];
                 X = new double[yLength];
                    Stockprice= new double[yLength];

                 payout1=new double[simulations];
                   payout2=new double[simulations];
                  payout3=new double[simulations];
                  payout4=new double[simulations];
                  payout5=new double[simulations];

                  payoutS1=new double[simulations];
                   payoutS2=new double[simulations];
                  payoutS3=new double[simulations];
                  payoutS4=new double[simulations];

                 variance=0;
```

```
            variance1=0;
            variance2=0;
            variance3=0;
            variance4=0;
            variance5=0;

          PayoutSum1 =0;
            PayoutSum2=0;
           PayoutSum3=0;
           PayoutSum4=0;
           PayoutSum5=0;

           StandardError1=new double[simulations];
           StandardError2=new double[simulations];
           StandardError3=new double[simulations];
           StandardError4=new double[simulations];
           StandardError5=new double[simulations];

           OptionPrice1=new double[simulations];
           OptionPrice2=new double[simulations];
           OptionPrice3=new double[simulations];
           OptionPrice4=new double[simulations];
           OptionPrice5=new double[simulations];

           XYSeriesCollection dataset = new XYSeriesCollection();
              XYSeries series1 = new XYSeries("DIB-option");
              XYSeries series2 = new XYSeries("DOB-option");
              XYSeries series3 = new XYSeries("UIB-option");
             XYSeries series4 = new XYSeries("UOB-option");
             XYSeries series4L = new XYSeries("LB-option");

           XYSeriesCollection dataset1 = new XYSeriesCollection();
            XYSeries series5 = new XYSeries("DIB-option");
             XYSeries series6 = new XYSeries("DOB-option");
             XYSeries series7 = new XYSeries("UIB-option");
            XYSeries series8 = new XYSeries("UOB-option");
            XYSeries series8L = new XYSeries("LB-option");

              y[0]=1;
          Y[0]=0;
              X[0]=0;
          deltaTime = 0.004; //unit of  bussiness time in years

    if(processTypeButtons[0].isSelected()){
       Xg =new double[yLength];
```

```
mean=0;
stddev=1/(NUMBER_OF_STEPS*timetoMaturity);
c =(double)(Double.parseDouble(vg_1Field.getText()));
g =(double)((Double.parseDouble(vg_2Field.getText())));
m =(double)((Double.parseDouble(vg_3Field.getText())));
theta=c*((1/m)-(1/g));
sigma=Math.sqrt((2*c)/(g*m));
vgkappa=(double)((Double.parseDouble(vg_4Field.getText())));
vgeta=(double)((Double.parseDouble(vg_5Field.getText())));
vglambda=(double)((Double.parseDouble(vg_6Field.getText())));
v=1/c;
double d=1-(sigma*sigma*v)/2-theta*v;

  //for (s=(simulations/interval);s>0;s--){
for (s=1;s<(simulations/interval)+1;s++){
        variance1=0;
         variance2=0;
         variance3=0;
         variance4=0;
         variance5=0;

         PayoutSum1 =0;
         PayoutSum2=0;
        PayoutSum3=0;
        PayoutSum4=0;
        PayoutSum5=0;

        StandardError1[s]=0;
        StandardError2[s]=0;
        StandardError3[s]=0;
        StandardError4[s]=0;
        StandardError5[s]=0;
   for(int i=0;i<(s*interval);i++){
        // Simulate y and Y, i.e. time grid
    for(int j=1;j<yLength;j++){
      y[j]=y[j-1]+vgkappa*(vgeta-y[j-1])*deltaTime
             +vglambda*Math.sqrt(y[j-1])
             *((random.nextGaussian())*stddev);
     //-(2)--calculate from (1)the rate of time change Y
             Y[j]=Y[j-1]+y[j]*deltaTime;
             }
      //-simulate the Lévy process X(.ie.the Variance Gamma Process)-
          //X[0] = 0;
        for(int j=1;j<yLength;j++){
           double p = (Y[j]-Y[j-1])/v;
```

```
                    //u1 = Math.pow(random.nextDouble(),1/p);
                   //u2 = Math.pow(random.nextDouble(),1/(1-p));
                   double u1 = 1;
                  double u2 = 1;
                   while ((u1+u2)>1) {
                   u1 = Math.pow(random.nextDouble(),1/p);
                   u2 = Math.pow(random.nextDouble(),1/(1-p));
                     }

               //--generate an exponential random variable z
                   double z = -Math.log(random.nextDouble());
                      double G=(z*u1)/(u1+u2) ;
                //- multiply by kappa
                         G = G*v;
                      w=random.nextGaussian();
                //--generating Xt as by wim
                  double Xg;
                  Xg=theta*G+sigma*Math.sqrt(G)*w;
               // Generating Xyt as in wims paper
                        X[j] = X[j-1]+Xg;
               // Generating of stock prices
 Stockprice[j]=initialstockprice*Math.exp((interestRate-
dividend)*j*deltaTime+X[j])*Math.pow(d,Y[j]/v);
                              }
             // Calculating Barrier prices--
                       Min=Stockprice[1];
                       Max=Stockprice[1];
                   for(int j=1;j<yLength;j++){
                         if(Stockprice[j]>Max){
                             Max=Stockprice[j];
                                    }
                         else{
                                Max=Stockprice[1];
                                }
                             }
                    for(int j=1;j<yLength;j++){
                         if(Stockprice[j]<Min){
                               Min=Stockprice[j];
                                    }
                             else{
                                Min=Stockprice[1];
                                }
                             }
             if(callPutTypeButtons[0].isSelected()){
              //---Calculating DIB Options price for a VG-process-
```

```
  if (dibBox.isSelected()) {
        if(Min<=b1){
            if(Stockprice[yLength-1]>strikeprice){
             payout1[i]=(Stockprice[yLength-1]-strikeprice);
                }
              }
          else{
              payout1[i]=0;
              }
           }
  //---Calculating DOB Options price for a VG-process-
if (dobBox.isSelected()) {
        if(Min>b1){
          if(Stockprice[yLength-1]>strikeprice){
          payout2[i]=(Stockprice[yLength-1]-strikeprice);
               }
            }
          else{
              payout2[i]=0;
              }
            }

  //---Calculating UIB Options price for a VG-process-
   if (uibBox.isSelected()) {
        if(Max>=b1){
           if(Stockprice[yLength-1]>strikeprice){
             payout3[i]=(Stockprice[yLength-1]-strikeprice);
               }
             }
          else{
              payout3[i]=0;
              }
          }
    //---Calculating UOB Options price for a VG-process-
       if (uobBox.isSelected()) {
        if(Max<b1){
            if(Stockprice[yLength-1]>strikeprice){
              payout4[i]=(Stockprice[yLength-1]-strikeprice);
                }
              }
          else{
              payout4[i]=0;
              }
          }
     //---Calculating LookBack Options price for a VG-process-
```

```
            if (LbBox.isSelected()) {
                if(Stockprice[yLength-1]>Min){
                    payout5[i]=(Stockprice[yLength-1]-Min);
                       }
                else{
                     payout5[i]=0;
                     }
                 }
               }// end of if  callPutTypeButtons[0].isSelected()
 else{ // ie. if callPutTypeButtons[1].isSelected()

//---Calculating DIB Options price for a VG-process-
    if (dibBox.isSelected()) {
           if(Min<=b1){
               if(strikeprice>Stockprice[yLength-1]){
                payout1[i]=(strikeprice-Stockprice[yLength-1]);
                    }
                }
              else{
                  payout1[i]=0;
                  }
               }
  //---Calculating DOB Options price for a VG-process-
 if (dobBox.isSelected()) {
           if(Min>b1){
              if(strikeprice>Stockprice[yLength-1]){
              payout2[i]=(strikeprice-Stockprice[yLength-1]);
                   }
                }
              else{
                  payout2[i]=0;
                  }
                }
  //---Calculating UIB Options price for a VG-process-
    if (uibBox.isSelected()) {
           if(Max>=b1){
              if(strikeprice>Stockprice[yLength-1]){
                 payout3[i]=(strikeprice-Stockprice[yLength-1]);
                   }
                }
              else{
                  payout3[i]=0;
                  }
                }
     //---Calculating UOB Options price for a VG-process-
```

```
    if (uobBox.isSelected()) {
     if(Max<b1){
         if(strikeprice>Stockprice[yLength-1]){
           payout4[i]=(strikeprice-Stockprice[yLength-1]);
             }
          }
        else{
            payout4[i]=0;
            }
       }
 //---Calculating LookBack Options price for a VG-process-
    if (LbBox.isSelected()) {
        if(Max>Stockprice[yLength-1]){
            payout5[i]=(Max-Stockprice[yLength-1]);
               }
        else{
            payout5[i]=0;
            }
         }
       } // end of else callPutTypeButtons[1].isSelected()

// adding up all the payouts for i simulations
        PayoutSum1 +=payout1[i];
        PayoutSum2 +=payout2[i];
        PayoutSum3 +=payout3[i];
        PayoutSum4 +=payout4[i];
        PayoutSum5 +=payout5[i];


         variance1+=Math.pow((Avpayout1-payout1[i]),2);
        variance2+=Math.pow((Avpayout2-payout2[i]),2);
        variance3+=Math.pow((Avpayout3-payout3[i]),2);
        variance4+=Math.pow((Avpayout4-payout4[i]),2);
        variance5+=Math.pow((Avpayout5-payout5[i]),2);
    }  //end of i loop

    // average payout for s*intervals independent simulations
         Avpayout1 =PayoutSum1/(s*interval);
         Avpayout2 =PayoutSum2/(s*interval);
       Avpayout3 =PayoutSum3/(s*interval);
       Avpayout4 =PayoutSum4/(s*interval);
       Avpayout5 =PayoutSum5/(s*interval);


// Creating array of  Standard Error of DIB,DOB,UIB AND UOB
```

```
                StandardError1[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                                        *variance1);
                   StandardError2[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                                       *variance2);
                    StandardError3[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                                        *variance3);
                       StandardError4[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                                        *variance4);
                      StandardError5[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                                        *variance5);


                        // Creating array of Option prices
        OptionPrice1[s]=(Avpayout1)*Math.exp(-(interestRate*timetoMaturity));
        OptionPrice2[s]=(Avpayout2)*Math.exp(-(interestRate*timetoMaturity));
        OptionPrice3[s]=(Avpayout3)*Math.exp(-(interestRate*timetoMaturity));
        OptionPrice4[s]=(Avpayout4)*Math.exp(-(interestRate*timetoMaturity));
        OptionPrice5[s]=(Avpayout5)*Math.exp(-(interestRate*timetoMaturity));


                         // creating series for graphs
                         if(optionPriceBox.isSelected()){   //optionPrice series
                          series1.add((s*interval),OptionPrice1[s]);
                          series2.add((s*interval),OptionPrice2[s]);
                          series3.add((s*interval),OptionPrice3[s]);
                          series4.add((s*interval),OptionPrice4[s]);
                          series4L.add((s*interval),OptionPrice5[s]);

                            }
                        if(standardErrorBox.isSelected()){  //standardError series
                           series5.add((s*interval),StandardError1[s]);
                          series6.add((s*interval),StandardError2[s]);
                          series7.add((s*interval),StandardError3[s]);
                          series8.add((s*interval),StandardError4[s]);
                          series8L.add((s*interval),StandardError5[s]);

                           }
                        }// end of s loop

   // creating data for plot of Option prices against number of simulations graphs
if(optionPriceBox.isSelected()){
        dataset.addSeries(series1); // data series for dib option pricess
        dataset.addSeries(series2);// data series for dob option prices
        dataset.addSeries(series3);// data series for uib option prices
        dataset.addSeries(series4);// data series for uob option prices
```

```
        dataset.addSeries(series4L);// data series for Lb option prices
        JFreeChart chart = ChartFactory.createXYLineChart(
          "Barrier option prices with variance gamma Lévy process",  // chart title
                                    "number of Simulations",     // x axis label
                                    "Barrier price",             // y axis label
                                     dataset,                    // data
                                     PlotOrientation.VERTICAL,
                                     true,                     // include legend
                                     true,                     // tooltips
                                     false                     // urls
                                      );
                         graphics1_Panel.setChart(chart);
                         graphics1_Panel.setVisible(true);
                                //return;
                         }

     //Creating data for plot of standard error with number of simulations graphs
       if(standardErrorBox.isSelected()){
    dataset1.addSeries(series5);// data series for standard error dib option prices
    dataset1.addSeries(series6);// data series for standard error dob option prices
    dataset1.addSeries(series7);// data series for standard error uib option prices
    dataset1.addSeries(series8);// data series for standard error uob option prices
    dataset1.addSeries(series8L);// data series for standard error Lb option prices

JFreeChart chart = ChartFactory.createXYLineChart("Standard error  of Barrier
option prices (variance gamma process)",  // chart title
                                  "number of Simulations",     // x axis label
                                  "Standard error",             // y axis label
                                   dataset1,                    // data
                                   PlotOrientation.VERTICAL,
                                   true,                     // include legend
                                   true,                     // tooltips
                                   false                     // urls
                                    );
                       graphics2_Panel.setChart(chart);
                       graphics2_Panel.setVisible(true);
                              return;
                        }
                      }// end of processType[0] loop
           else{

            //for (s=(simulations/interval);s>0;s--){
              for (s=1;s<(simulations/interval)+1;s++){

                    variance1=0;
```

```
                variance2=0;
                variance3=0;
                variance4=0;
                variance5=0;

                PayoutSum1 =0;
                PayoutSum2=0;
               PayoutSum3=0;
               PayoutSum4=0;
               PayoutSum5=0;

               StandardError1[s]=0;
               StandardError2[s]=0;
               StandardError3[s]=0;
               StandardError4[s]=0;
               StandardError5[s]=0;
          for(int i=0;i<(s*interval);i++){
                  // Simulate y and Y, i.e. time grid
                        for(int j=1;j<yLength;j++){
                        y[j]=y[j-1]+vgkappa*(vgeta-y[j-1])*deltaTime
                                  +vglambda*Math.sqrt(y[j-1])
                                  *((random.nextGaussian())*stddev);

                     //-(2)--calculate from (1)the rate of time change Y
                           Y[j]=Y[j-1]+y[j]*deltaTime;
                                       }
        //-simulate the Lévy process X(.ie.the Normal inverse Gaussian Process)-
                        for(int j=1;j<yLength;j++){
                     // Generate a standard normal random variable
                                  w=random.nextGaussian();
                                 double u = (Y[j]-Y[j-1]);
                                 double nigY=Math.pow(w,2);
                                 double niglamb=Math.pow((Y[j]-Y[j-1]),2)/kap;
   // simulation of ylength number of independent standard normal random variable
    double nigX=u+(u*u*nigY)/(2*niglamb)-((u/(2*niglamb))*
Math.sqrt((4*u*niglamb*nigY)+(u*u)*nigY*nigY)) ;
                     //Generate a uniform random variable
                                   double nigU=random.nextDouble();

                               if(nigU<=(u/(nigX+u))){

                                   nigX1=nigX;
                                 }
                              else{
```

```
                                nigX1=(u*u)/nigX;
                                }
                        //   Simulate normal inverse Gaussian random variable..
                                double w1=random.nextGaussian();
                         double Xn=sig*nigX1*Math.sqrt(nigX1)+thet*nigX1;
                                                X[j]=X[j-1]+Xn;
                         //    Generating of stock prices
Stockprice[j]=initialstockprice*Math.exp((interestRate-dividend)*j*deltaTime+X[j]
                -(Y[j]/kap)+(Y[j]/kap)*Math.sqrt(1-sig*sig*kap-2*thet*kap));
                                }

                  // Calculating Barrier prices--
                        Min=Stockprice[1];
                        Max=Stockprice[1];
                   for(int j=1;j<yLength;j++){
                         if(Stockprice[j]>Max){
                             Max=Stockprice[j];
                                   }
                               else{
                                   Max=Stockprice[1];
                                   }
                               }
                     for(int j=1;j<yLength;j++){
                         if(Stockprice[j]<Min){
                              Min=Stockprice[j];
                                   }
                              else{
                                   Min=Stockprice[1];
                                   }
                              }

                if(callPutTypeButtons[0].isSelected()){
                //---Calculating DIB Options price for a NIG-process-
                    if (dibBox.isSelected()) {
                           if(Min<=b1){
                               if(Stockprice[yLength-1]>strikeprice){
                                payout1[i]=(Stockprice[yLength-1]-strikeprice);
                                    }
                                  }
                              else{
                                   payout1[i]=0;
                                   }
                                }
                   //---Calculating DOB Options price for a NIG-process-
                    if (dobBox.isSelected()) {
```

```
            if(Min>b1){
              if(Stockprice[yLength-1]>strikeprice){
              payout2[i]=(Stockprice[yLength-1]-strikeprice);
                   }
                 }
              else{
                   payout2[i]=0;
                   }
                }

        //---Calculating UIB Options price for a NIG-process-
         if (uibBox.isSelected()) {
               if(Max>=b1){
                  if(Stockprice[yLength-1]>strikeprice){
                     payout3[i]=(Stockprice[yLength-1]-strikeprice);
                      }
                   }
                else{
                     payout3[i]=0;
                     }
               }
          //---Calculating UOB Options price for a NIG-process-
              if (uobBox.isSelected()) {
               if(Max<b1){
                   if(Stockprice[yLength-1]>strikeprice){
                     payout4[i]=(Stockprice[yLength-1]-strikeprice);
                       }
                    }
                else{
                     payout4[i]=0;
                     }
               }
           //---Calculating LookBack Options price for a NIG-process-
              if (LbBox.isSelected()) {
                  if(Stockprice[yLength-1]>Min){
                      payout5[i]=(Stockprice[yLength-1]-Min);
                         }
                else{
                     payout5[i]=0;
                     }
                 }
               }// end of if  callPutTypeButtons[0].isSelected()
      else{ // ie. if callPutTypeButtons[1].isSelected()

     //---Calculating DIB Options price for a NIG-process-
```

```
   if (dibBox.isSelected()) {
          if(Min<=b1){
              if(strikeprice>Stockprice[yLength-1]){
               payout1[i]=(strikeprice-Stockprice[yLength-1]);
                   }
                }
             else{
                 payout1[i]=0;
                 }
              }
    //---Calculating DOB Options price for a NIG-process-
  if (dobBox.isSelected()) {
          if(Min>b1){
             if(strikeprice>Stockprice[yLength-1]){
             payout2[i]=(strikeprice-Stockprice[yLength-1]);
                  }
               }
             else{
                 payout2[i]=0;
                 }
              }
    //---Calculating UIB Options price for a NIG-process-
     if (uibBox.isSelected()) {
          if(Max>=b1){
             if(strikeprice>Stockprice[yLength-1]){
                payout3[i]=(strikeprice-Stockprice[yLength-1]);
                  }
               }
             else{
                 payout3[i]=0;
                 }
              }
      //---Calculating UOB Options price for a NIG-process-
         if (uobBox.isSelected()) {
          if(Max<b1){
              if(strikeprice>Stockprice[yLength-1]){
                payout4[i]=(strikeprice-Stockprice[yLength-1]);
                  }
               }
             else{
                 payout4[i]=0;
                 }
            }
       //---Calculating LookBack Options price for a NIG-process-
         if (LbBox.isSelected()) {
```

```
            if(Max>Stockprice[yLength-1]){
                payout5[i]=(Max-Stockprice[yLength-1]);
                   }
            else{
                payout5[i]=0;
                }
             }
           } // end of else callPutTypeButtons[1].isSelected()

// adding up all the payouts for i simulations
             PayoutSum1 +=payout1[i];
            PayoutSum2 +=payout2[i];
            PayoutSum3 +=payout3[i];
            PayoutSum4 +=payout4[i];
            PayoutSum5 +=payout5[i];


            variance1+=Math.pow((Avpayout1-payout1[i]),2);
            variance2+=Math.pow((Avpayout2-payout2[i]),2);
            variance3+=Math.pow((Avpayout3-payout3[i]),2);
            variance4+=Math.pow((Avpayout4-payout4[i]),2);
            variance5+=Math.pow((Avpayout5-payout5[i]),2);

        }  //end of i loop

         // average payout for s+1 independent simulations
            Avpayout1 =PayoutSum1/(s*interval);
            Avpayout2 =PayoutSum2/(s*interval);
           Avpayout3 =PayoutSum3/(s*interval);
           Avpayout4 =PayoutSum4/(s*interval);
           Avpayout5 =PayoutSum5/(s*interval);


       // calculating of standard error
    StandardError1[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                            *variance1);
    StandardError2[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                          *variance2);
    StandardError3[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                            *variance3);
    StandardError4[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                            *variance4);
    StandardError5[s]=Math.sqrt((1/Math.pow(((s*interval)-1),2))
                            *variance5);
```

```
            // discounting of expected value of prices to present
          OptionPrice1[s]=Avpayout1*Math.exp(-(interestRate*timetoMaturity));
          OptionPrice2[s]=Avpayout2*Math.exp(-(interestRate*timetoMaturity));
          OptionPrice3[s]=Avpayout3*Math.exp(-(interestRate*timetoMaturity));
          OptionPrice4[s]=Avpayout4*Math.exp(-(interestRate*timetoMaturity));
          OptionPrice5[s]=Avpayout5*Math.exp(-(interestRate*timetoMaturity));


                        // choice for which series to create for data plotting
                         if(optionPriceBox.isSelected()){
                          series1.add((s*interval),OptionPrice1[s]);
                          series2.add((s*interval),OptionPrice2[s]);
                          series3.add((s*interval),OptionPrice3[s]);
                          series4.add((s*interval),OptionPrice4[s]);
                          series4L.add((s*interval),OptionPrice5[s]);

                           }

                          if(standardErrorBox.isSelected()){
                          series5.add((s*interval),StandardError1[s]);
                          series6.add((s*interval),StandardError2[s]);
                          series7.add((s*interval),StandardError3[s]);
                          series8.add((s*interval),StandardError4[s]);
                          series8L.add((s*interval),StandardError5[s]);
                           }
                        }// end of s loop

// creating data for plot of Option prices against number of simulations graphs
                     if(optionPriceBox.isSelected()){
                         dataset.addSeries(series1);
                         dataset.addSeries(series2);
                        dataset.addSeries(series3);
                        dataset.addSeries(series4);
                        dataset.addSeries(series5);
     JFreeChart chart = ChartFactory.createXYLineChart(
  "Barrier option prices with Normal inverse Gaussian process",  // chart title
                                  "number of Simulations",     // x axis label
                                  "Barrier price",             // y axis label
                                   dataset,                    // data
                                   PlotOrientation.VERTICAL,
                                   true,                    // include legend
                                   true,                    // tooltips
                                   false                    // urls
                                    );
```

```
                        graphics1_Panel.setChart(chart);
                        graphics1_Panel.setVisible(true);
                                //return;
                         }
      //Creating data for plot of standard error with number of simulations graphs
                       if(standardErrorBox.isSelected()){
                            dataset1.addSeries(series5);
                            dataset1.addSeries(series6);
                           dataset1.addSeries(series7);
                           dataset1.addSeries(series8);
                           dataset1.addSeries(series8L);
JFreeChart chart = ChartFactory.createXYLineChart("Standard error  of Barrier
option prices (Normal inverse Gaussian process)",// chart title
                                  "number of Simulations", // x axis label
                                  "Standard error", // y axis label
                                   dataset1, // data
                                   PlotOrientation.VERTICAL,
                                   true,   // include legend
                                   true, // tooltips
                                   false// urls
                                    );
                        graphics2_Panel.setChart(chart);
                        graphics2_Panel.setVisible(true);
                                return;
                         }
                          }// end of else
                    }

          // Add choice for single or several price calculations
            if (source ==  numberofpricesButtons[0]) {
              if ( numberofpricesButtons[0].isSelected()) {
                  numberofpricesbuttons = true;
                  graphButton.setEnabled(false);
                  variates2Field .setEnabled(false);
                 calculateButton.setEnabled(true);
                 standardErrorBox.setEnabled(false);
                  standardErrorLabel.setEnabled(false);
                  optionPriceBox.setEnabled(false);
                  optionPriceLabel.setEnabled(false);
                  standardErrorBox.setSelected(false);
                  optionPriceBox.setSelected(false);
                 dibLabel.setEnabled(false);
                  dobLabel.setEnabled(false);
                 uibLabel.setEnabled(false);
                 uobLabel.setEnabled(false);
```

```
        LbLabel.setEnabled(false);

        dibBox.setEnabled(false);
         dobBox.setEnabled(false);
        uibBox.setEnabled(false);
        uobBox.setEnabled(false);
        LbBox.setEnabled(false);

        dibBox.setSelected(false);
         dobBox.setSelected(false);
        uibBox.setSelected(false);
        uobBox.setSelected(false);
        LbBox.setSelected(false);
        barrierTypesButtons[0].setEnabled(true);
        barrierTypesButtons[1].setEnabled(true);
        barrierTypesButtons[2].setEnabled(true);
        barrierTypesButtons[3].setEnabled(true);
        barrierTypesButtons[4].setEnabled(true);

      }
    }
    if (source ==  numberofpricesButtons[1]) {
    if ( numberofpricesButtons[1].isSelected()) {
         numberofpricesbuttons = false;
         graphButton.setEnabled(true);
         variates2Field .setEnabled(true);
        numberofsimulationsLabel.setEnabled(true);
        calculateButton.setEnabled(false);
        standardErrorBox.setEnabled(true);
         standardErrorLabel.setEnabled(true);
         optionPriceBox.setEnabled(true);
         optionPriceLabel.setEnabled(true);
         dibLabel.setEnabled(true);
         dobLabel.setEnabled(true);
        uibLabel.setEnabled(true);
        uobLabel.setEnabled(true);
        LbLabel.setEnabled(true);

        dibBox.setEnabled(true);
         dobBox.setEnabled(true);
        uibBox.setEnabled(true);
        uobBox.setEnabled(true);
        LbBox.setEnabled(true);

        barrierTypesButtons[0].setEnabled(false);
```

```
            barrierTypesButtons[1].setEnabled(false);
            barrierTypesButtons[2].setEnabled(false);
            barrierTypesButtons[3].setEnabled(false);
            barrierTypesButtons[4].setEnabled(false);
            standardErrorBox.setSelected(true);
             dibBox.setSelected(true);
             barrier6Field.setText("1.00");

         }
        }
    //--Making process parameter fields editable depending on choice---
       if (source == processTypeButtons[0]) {
         if (processTypeButtons[0].isSelected()) {
             processtypebuttons = true;
             nig_1Field.setEnabled(false);
             nig_2Field.setEnabled(false);
            nig_3Field.setEnabled(false);
            nig_4Field.setEnabled(false);
            nig_5Field.setEnabled(false);
            nig_6Field.setEnabled(false);
            vg_1Field.setEnabled(true);
             vg_2Field.setEnabled(true);
            vg_3Field.setEnabled(true);
            vg_4Field.setEnabled(true);
            vg_5Field.setEnabled(true);
            vg_6Field.setEnabled(true);
           }
          }
        if (source == processTypeButtons[1]) {
         if (processTypeButtons[1].isSelected()) {
            processtypebuttons = false;
            nig_1Field.setEnabled(true);
            nig_2Field.setEnabled(true);
           nig_3Field.setEnabled(true);
           nig_4Field.setEnabled(true);
           nig_5Field.setEnabled(true);
           nig_6Field.setEnabled(true);
           vg_1Field.setEnabled(false);
            vg_2Field.setEnabled(false);
           vg_3Field.setEnabled(false);
           vg_4Field.setEnabled(false);
           vg_5Field.setEnabled(false);
           vg_6Field.setEnabled(false);

           }
```

```
        }


    }
}
```