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Volume Visualization of Payoff Regions for Derivatives Risk Management

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***Abstract*:** Recently there has been research efforts to develop models and to use derivatives within a risk management program. However there has been not much effort to provide some insight into the type of conditions that tend to accompany the uses of derivatives. Once the type of risk has been identified, the next issue becomes the objective quantification of that risk. Regardless of the specific modeling approach employed, there are at least three key elements that need to be included in the quantification effort to enable subsequent risk management decisions: the volatility changes in risk profiling (direction of risk exposure), the Option's value determinant based on the underlying spot price (underlying assets and liabilities creating the risk exposure) and the days to maturity (term of risk exposure). As a result of addressing the above mentioned risk identification and quantification issues, we propose a new approach whereby it is fairly easy to construct a visual representation of the performance profile of the underlying portfolio. This research attempts to use volume visualization as the visual representation mechanism to quantify the risk and to visually estimate the payoff for derivatives risk management.

***Keywords*:** Option, Black-Scholes-Merton pricing model, risk management, volume graphics.

1. Introduction

Volume graphics has been widely used in various sectors due to its capability of enabling extra information in visual form for human analysis and decision making. Recent advances in computing has made volume visualization for imaging feasible. We use the Black-Scholes-Merton (Kolb, 1995) Option pricing model for our project. These are sophisticated and complex products that help in accurate valuation of portfolio's risk.

1.1 Definitions

We provide some simple definitions for the terms used in this paper.

(1) Derivatives - Financial instruments whose value or price can be derived from the value(s) of other underlying instruments that can be observed in the marketplace.
(2) Option - A contract which grants the buyer rights, but not the obligation, to buy or to sell a stock or future contract at a predetermined price until a predefined expiration date.
(3) Payoff - Payment in full of all monies due under the contract delivered to the purchaser from seller, to convey to the purchaser the remainder of the seller's title in the property, whether legal or equitable, as prescribed by the terms of the contract.
(4) Portfolio - From financial point of view, is a collection of financial securities that constitutes a compelling argument that a trading strategy is proficient or has made progress toward a goal.

(5) Volatility - Measurement of the amount by which an underlying stock or future is expected to fluctuate in a given period of time.

1.2 Risk Management

One of the biggest costs in business is variability and uncertainty. To minimize the risk that is involved in the financial sector, derivatives are widely used to manage and to control the possibilities of substantial losses. Nevertheless, without a clear set of risk-management goals, using these products can be dangerous and generate an undesired outcome that can bring a company to bankruptcy, such as the 'Short Straddle' strategy in a very volatile market. Furthermore, the insights of the financial engineers do not give managers any guidance on how to deploy the derivatives most effectively (McLaughlin, 1999).

Due to these undesired issues, we definitely believe that our volume visualization project will bring one step closer to a proper and effective risk management using derivatives that deal with volatility aspect.

1.3 Risk Visualization

In Option trading strategies, risk is inspected all the time in any portfolio. A lot of work has been done by financial and academic researchers in visualizing the hazard of different strategies.

Most of the currently available software in the market uses surface rendering with iso-contouring techniques to visualize the risk of derivatives portfolio (Clewlow and Strickland, 1997; Nelken, 1996; Hiong et al., 1997). The weakness for this method of visualization is the volatility parameter has to be fixed to a certain value for projection. The 'What-If' scenario is hard to visualize when user wishes to inspect the changes of risk involved corresponding to change in asset volatility.

1.4 A Game of Volatility

Option is a game of volatility (Gallacher, 1999). The market uncertainty cannot be predicted accurately at all while the Option's price fluctuation is highly correlated with the volatility of the market. Hence, it is hard to trade the derivatives effectively unless we have a clear understanding of its behavior. Generally, the value for Call and Put Option becomes more expensive when the volatility is greater. Therefore, implied volatility (http://www.optionetics.com/investor.asp) and volatility moving average are being discussed and estimated daily for Option business among the financial communities.

2. Visualization

2.1 Surface Rendering

Majority of the research and software development in three-dimensional visualization for Options is based on surface rendering (Hiong et al., 1999). The common X, Y and Z axis normally are mapped to the payoff value for a portfolio, spot price and time to maturity, or spot price and the asset volatility. In either case, one of the major determinants has to be sacrificed in the visualization due to the constraint of 'shortage' of axis. Figures 2(a), 3(a) and 4(a) are the typical samples of surface rendering technique that being discussed previously.

2.2 Volume Rendering

In our volume visualization project, the individual X, Y and Z axis represents the determinants value of Black-Scholes-Merton model (Kolb, 1995). By choosing a proper color map for different payoff levels, and setting the voxel opacity for visibility, the inner risk pattern which is normally hidden in a portfolio can be discovered and analyzed. Segmentation on a data set can be done on any axis for visualization and for further investigation of the portfolio behavior. The selected area of interest eventually can be inspected by a financial analyst and hence, strategize a solution to overcome the unfavorable situation that might occur some time in the near future.

In our volume visualization model, we mapped the spot price value on X axis, days to maturity on Y axis, and the volatility, which is in percentage, is mapped to Z axis. The idea of the representation is illustrated in Fig. 1(a). For the value to RGBA mapping, we used Blue ('deep-in-the-sea') and Cyan color to define the negative value region. For the break-even point and positive regions, we used White, Yellow and Red ('sun-in-the-sky') colors. The current scaling value of Option portfolio for RGBA color table mapping in our project is described in Fig. 1(b).

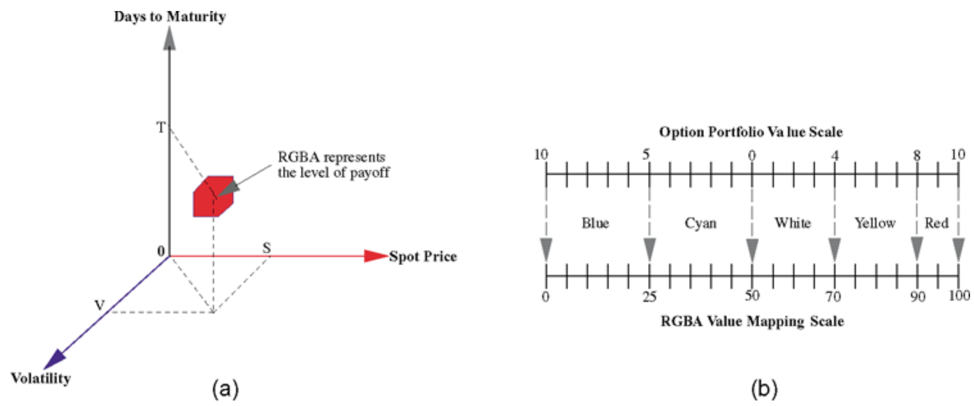


Fig. 1. (a) Voxel-based representation and (b) Option value map to RGBA table.

2.3 The Advantages

By using volume visualization, the dimension and the magnitude of the risky regions can be visualized more effectively. All the possible risk involved is bounded in the volume visualization box, which eventually can be segmented specifically by controlling the opacity for the region of interest. The boundary between the risky regions and the safe regions hence can be seen clearly, and this enhances the strategy's payoff structure analysis for different environment circumstances. Figure 2 until Figure 4 are the samples of risk profiling for three different kind of Options portfolio. In each individual set of figures, picture (a) depicts the theoretical and payoff value of portfolio in surface rendering mode, using a fixed volatility that we set at 50%. Picture (b) is corresponding to picture (a) respectively for the same portfolio, but visualized in volume rendering technique.

3. Mathematical Pricing Model

3.1 Black-Scholes-Merton Model

The underlying mathematical model is the Black-Scholes-Merton (Kolb, 1995) Option pricing formula and the volume visualization project is built on top of VisAD.

$$c_t^M = e^{-d(T-t)} S N(d_1^M) - X e^{-r(T-t)} N(d_2^M)$$

$$p_t^M = X e^{-r(T-t)} N(-d_2^M) - S e^{-d(T-t)} N(-d_1^M)$$

$$d_1^M = \frac{\ln\left(\frac{S_t}{X}\right) + (r - d + 0.5 s^2)(T-t)}{s\sqrt{T-t}}$$

$$d_2^M = d_1^M - s\sqrt{T-t}$$

c_t^M = European Call Option price
p_t^M = European Put Option price
S = Spot price of the underlying asset
X = Exercise price or strike price of the Option
r = Risk-free interest rate
$(T - t)$ = Time to expiration in years
$N(x)$ = Cumulative probability function for a standardized normal variable
ln = The natural logarithm
s = Volatility of the stock price or the variability of the annual stock return

There are five determinants for the Option's price based on Black-Scholes (Kolb, 1995) model:
(1) The underlying asset price (observe from the market).
(2) The exercise price of the Option (specified in the contract).
(3) The time remain to the expiration (current date versus the expiration date).
(4) The risk-free interest rate (observe from the market or predict through the Treasury Bills).

(5) The volatility of the underlying asset (using Historical Volatility or Implied Volatility).

Generally, stock does pay dividend for the shares holders. Therefore, Merton (Kolb, 1995) has revised the Black-Scholes model (Kolb, 1995) where the dividend paid is being taken care of. The spot price for the underlying asset needs to be adjusted prior to the price calculation if dividend is known to be paid within a certain period of time. This continuous dividend is considered as a rate of leakage of value from stock (***d***).

3.2 Historical Volatility

Volatility is one of the parameters used in Black-Scholes-Merton pricing model (Kolb, 1995). Historical volatility is a measure on the sensitivity of price change based on historical closing prices. The relative price, the mean and the standard deviation of the logarithmic relative price are calculated to obtain the volatility. Below is the formula to compute the historical volatility.

$$PR_t = \frac{P_t}{P_{t-1}}$$

$$\overline{PR} = \frac{1}{T}\sum_{t=1}^{T} \ln PR_t$$

$$VAR(PR) = \frac{1}{T-1}\sum_{t=1}^{T} (\ln PR_t - \overline{PR})^2$$

$$\text{Annualized } s = \sqrt{VAR(PR)} \times \sqrt{250}$$

In the equations, P_t denotes the price at time t and T represents the number of historical data, ln is the natural logarithm and 250 is the estimated number of trading days in a year. However, since the volatility always changes in different time frames, the accuracy of the volatility used in the equation to reflect a better Option's value is crucial to achieve a good trade. Therefore, in most of the occasions, implied volatility is being used instead of the historical volatility.

3.3 Implied Volatility

Implied volatility is being used to observe the market's opinion about the volatility of a particular asset. This method uses the market data, together with the Black-Scholes model (Kolb, 1995) to estimate the asset volatility. The actual Call or Put Option's price from the market is applied in the pricing model. By exercising a series of trial-and-error process for different standard deviation, the objective is to get the correct Call or Put Option's price (as observed from the market) from the formula until it is success. The standard deviation value that we obtained from the evaluation will be the current expected volatility of the asset.

4. Experimental Visualization

4.1 Data Transformation

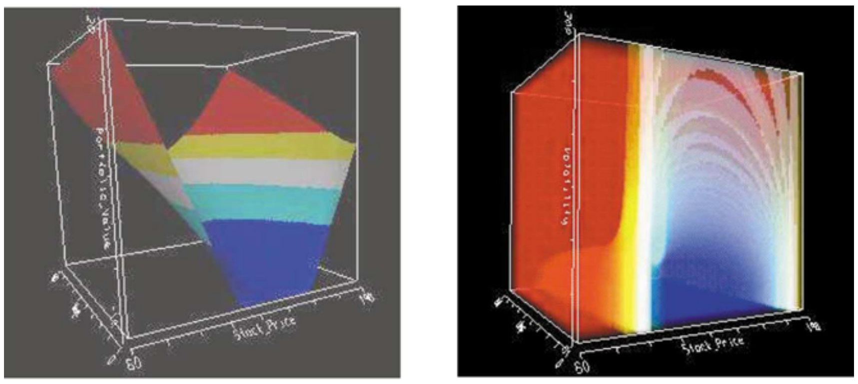
Data objects have been created for the asset spot price, the time remain to maturity and the volatility, together with the value of the portfolio. The value is a function of these three determinants, value = $f(P, t, v)$, where P denotes the asset spot price, t denotes the time remains to maturity and v denotes the volatility, with the assumption that the interest rate and the underlying asset dividend rate are constant for the certain period of time.

4.2 Parameters

We have deployed different kinds of Option trading strategies (Fontanills, 1998) in our volume visualization project. The interesting and informative risk patterns are discovered at different levels of volatility. For a broader view of visualization purposes, we have the volatility scale ranging from 0% up to 300%. For the days to maturity, we use the scale within 0 to 180 days, since the Options we chose from the derivatives market will expire in January 2001, on the day of initiating our synthetic portfolios in July 2000. The end of day closing premiums for the Options in each respective portfolio are used and incorporated into the visualization in order to reflect the actual break-even and payoff situation. The risk free interest rate we used for the model is 6.5% and the dividend rate is assumed as 0%.

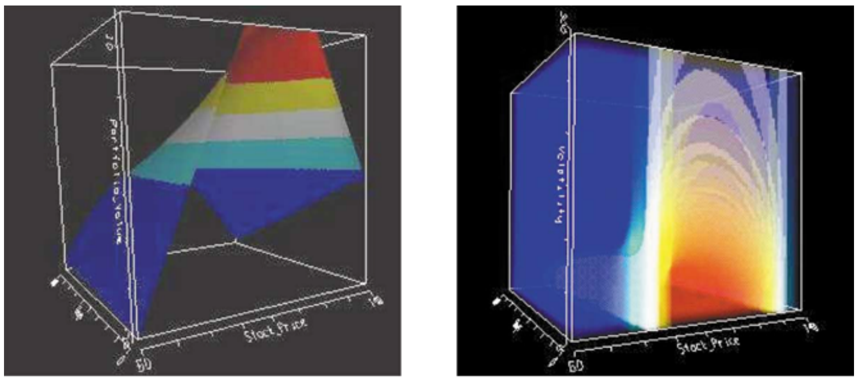
4.3 Results

The details of the individual synthetic Options portfolio is as shown below:



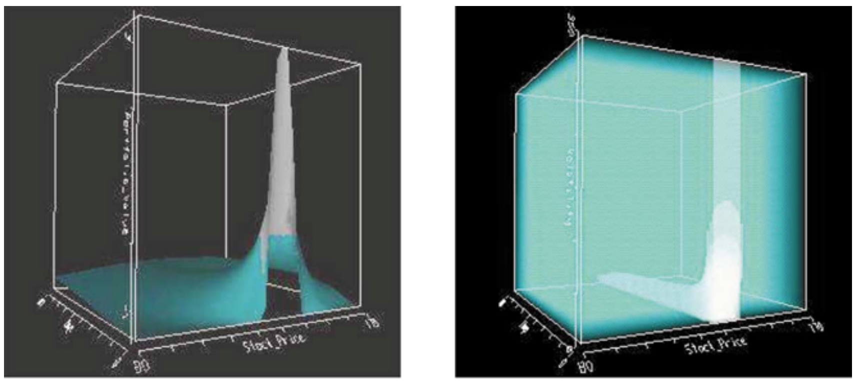
(a) (b)

Fig. 2. Long strangle with IBM Options.



(a) (b)

Fig. 3. Short strangle with IBM Options.



(a) (b)

Fig. 4. Short butterfly spread with INTEL Call Options.

(1) Figure 2 : Long strangle with IBM Options: Long 1 Call Strike at 120, Long 1 Put Strike at 95, days to expiry is 180, total premium paid is $13.75.

(2) Figure 3 : Short strangle with IBM Options: Short 1 Call Strike at 120, Short 1 Put Strike at 95, days to expiry is 180, total premium received is $13.75.

(3) Figure 4 : Short butterfly spread with INTEL Call Options: Long 1 Put Strike at 125, Short 1 Put Strike at 130, Short 1 Call Strike at 135, Long 1 Call Strike at 140, days to expiry is 180, total premium received is $3.50.

5. Discussions

5.1 Color Interpretation

The mapping for the RGBA value corresponding to portfolio payoff level is subjected to the analyst expectation. Different sets of color coding can be defined and deployed for individual user's preferences. The opacity level for the voxels which ties to its respective color map is adjustable, to enhance the pattern exploration. Typically, we used the following color coding to visualize the different levels of payoff value in our experimental work.

(1) Red color, alpha = 0.15 : Value above \$8 (High Profit Region).
(2) Yellow color, alpha = 0.20 : Value range from \$4 to \$8 (Profit Region).
(3) White color, alpha = 0.50 : Value range from break-even point (\$0) up to \$4 (Near to Break Even).
(4) Cyan color, alpha = 0.20 : Value range from −\$5 up to break-even point (\$0) (Loss Region).
(5) Blue color, alpha = 0.15 : Value below −\$5 (Deep Loss Region).

5.2 RGBA Control

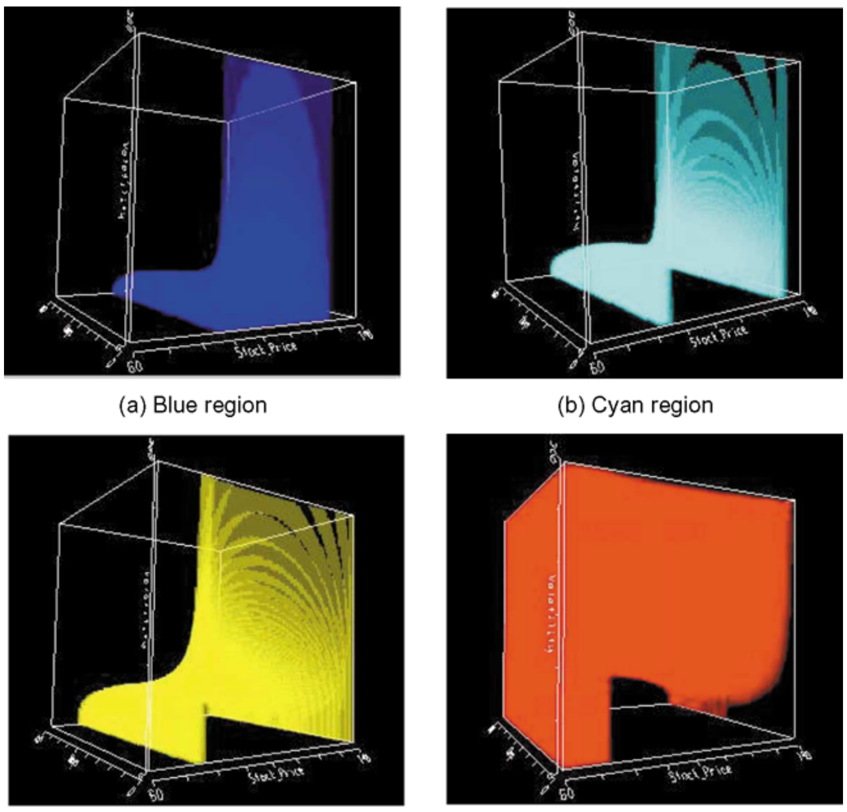
The alpha value in our figures is mapped in such a way that the break-even area is visible from any viewing angle. For certain occasions, where those low alpha colors are significant and important to be visualized, we can increase the region's opacity level for further investigation. The different boundary values for various levels of payoff are definable to match with individual expectation.

Referring to Fig. 1(b), we use the portfolio value ranged from −10 to 10 and mapped it to the color table with a size of 100. We chose this number due to the simplicity for calculation. There might be some arguments or disagreements for the domain we used for the mapping. However, this is only a proposed sample of mapping which can be revised and fine tuned according to user requirements.

Figures 5(a) - 5(d) are the extraction of different region based on Fig. 2(b). The region of interest is selected through setting its alpha value to 0.40 for visualization while zeroing the alpha value for other regions. With this individual introspection of region visualization, a much better foreshadow of risk related to the change of determinants is obtained.

5.3 Data Set Segmentation

Different controls can be used to segment the data set and select the specific region for visualization and investigation. Four major controls should be available to adjust the range of spot price domain, range of days to maturity, the volatility domain and the opacity of the voxels. With volume visualization, we believe that financial



(a) Blue region (b) Cyan region

(c) Yellow region (d) Red region

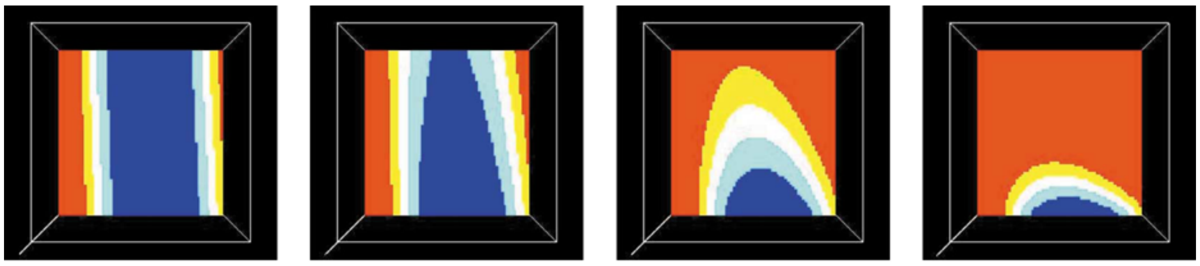
Fig. 5. Long strangle with IBM Options - region breakdown.

engineers can possess a better understanding of the risk which is not normally discovered most of the time using traditional surface plots.

5.4 Visualization Analysis

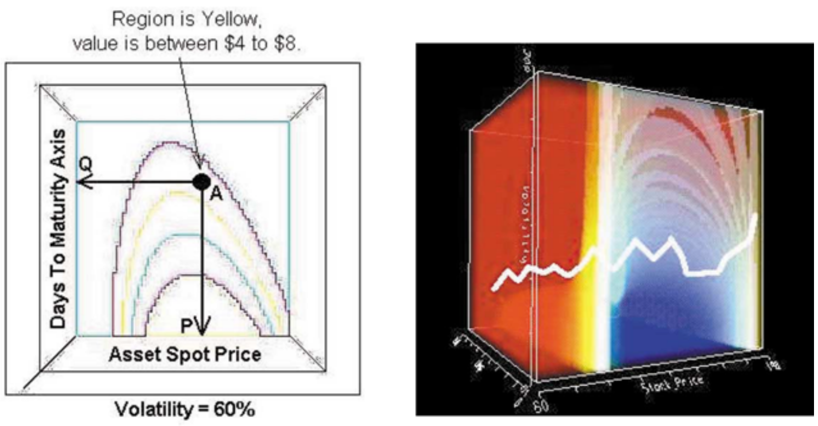
5.4.1 Quantitative information

We have extracted some slices from Fig. 2(b) to elaborate the quantitative measures represented in our volume rendering. This is illustrated in Fig. 6 where slices are extracted at different levels of volatilities, from low volatility up to high volatility, to show the valueness of the selected portfolio. As we can observe from the diagrams, the portfolio becomes more valuable when the volatility is getting higher, which is depicted in big proportion of red color region, since this color represented the high value area.



(a) 0% (b) 30% (c) 60% (d) 100%

Fig. 6. Slices extracted from Fig. 4 for different levels of volatilities



(a) (b)

Fig. 7. (a) Quantitative analysis for slice extracted with 60% volatility and (b) traversal of real data in projected model domain.

Figure 7(a) is the sample of quantitative measurement based on Fig. 6(c). If the current spot price is at point P and the days remain to maturity is at point Q, with 60% volatility, we can see that based on Black-Scholes-Merton model, the fair value of the portfolio is located in the yellow color region. Hence, the value should fall between $4 and $8. Even though the range is not precise enough to measure the correct value of the portfolio, modification to the color mapping scale can be done in order to reflect from a better view position or to reduce the gap. Since the volatility is fixed for the analysis, surface rendered visualization obviously is recommended to be used to capture the exact value. The main strength of this volume visualization is to enable a better view of individual regions proportion for different level of volatility. This enhances the user perspective in understanding the risk that is involved relative to volatility changes.

5.4.2 Envisioning of information

Volume visualization in financial risk profiling allows us to inspect the structure of the theoretical risk. The break-even area is highlighted in such a way that the separation of risk and profit areas can be seen easily. Furthermore, it encourages the concentration of the area to investigate rather than the unnecessary one, such as volatility fall in between 50% to 100%. Normally, different formation of risk structure is unknown when a new Options portfolio is constructed. This is particularly true when the number of instruments being used is increased. Hence, volume visualization enables user to perceive the risk in a clearer form.

5.4.3 Visual explanations

The visual effect of the model can be enhanced if real market data for asset spot price, the days remaining to maturity and volatility are incorporated into the volume visualization. With these, the associated real data will form the actual traverse path of the value inside the graphical model in three-dimensional space. Great effort and tremendous work for this aspect is required to achieve this kind of visualization, which merit the real movement of the market information with the projective data set from the famous pricing model. Intensive research in technical aspect for implementation issue yet needs to be carried out to accomplish the idea. Once the objective is achieved, further research can be done to fine-tune the visualization effectiveness in understanding and predicting the portfolio behavior. The idea of this concept is illustrated in Fig. 7(b).

6. Conclusion

Volume visualization of Options in risk management is very interesting. It helps in risk identification and quantification besides estimating the payoff level of the performance portfolio. Upon initiating a new Options strategy, the underlying hidden risk patterns can be observed and explored. Even though volume rendering mechanism takes longer time to execute compared to surface rendering, we are convinced that volume graphics in such applications for financial sector is essential to fulfill the proper risk management goals.

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Optionetics, http://www.optionetics.com/investor.asp

VisAD, http://www.ssec.wisc.edu/~billh/visad.html

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