# orderbook

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## Introduction

The **orderbook** package provides facilities for exploring and visualizing the data associated with an order book. An order book keeps track of the outstanding limit orders for a financial instrument, e.g. a stock. A *limit order* is an order to buy or sell a given quantity of stock at a specified limit price or better. The number of shares to be bought or sold is known as the *size*. An order remains in the order book until fully executed, i.e. until its size is zero as a result of trades. Partial executions occur as a result of trades for less than the entire size of the order. In this case the order remains in the order book at the same price, but with an appropriately reduced size.

Consider a simple order book containing five limit orders: sell 150 shares of IBM at $11.11, sell 150 shares of IBM at $11.08, buy 100 shares of IBM at $11.05, buy 200 shares of IBM at $11.05, and buy 200 shares of IBM at $11.01.

```
                Price          Ask Size

                $11.11         150
                $11.08         100
     300        $11.05
     200        $11.01

Bid Size        Price
```

Orders on the *bid* (*ask*) side represent orders to buy (sell). The price levels are $11.11, $11.08, $11.05, and $11.01. The *best bid* at $11.05 (highest bid price) and the *best ask* at $11.08 (lowest ask price) make up the *inside market*. The *spread* ($0.03) is the difference between the best bid and best ask. The *midpoint* ($11.065) is the average of the best bid and best ask.

There are four types of messages that traders can submit to an order book: *add*, *cancel*, *cancel/replace*, and *market order*. A trader can *add* a limit order into the order book. She can also *cancel* an order and remove it from the order book. If a trader wants to reduce the size of her order, she can issue a *cancel/replace*, which cancels the order, then immediately replaces it with another order at the same price, but with a lower size. Every limit order is assigned a unique ID so that cancel and cancel/replace orders can identify the corresponding limit order. A trade occurs when an order is executed through a *market order*, which is an order to immediately buy or sell a given quantity of stock at the best available prices.

All orders also have timestamps indicating the time at which they accepted into an order book. The timestamp determines the *time priority* or an order. Earlier orders are executed before later orders. For example, suppose that the order to buy 100 shares at $11.05 was submitted before the order to buy 200 shares at $11.05. Suppose a market order selling 200 shares is submitted to the order book above. The first order will be fully executed, while the second order will only be partially executed. A limit order to buy 100 shares at $11.05 will remain in the order book. Market orders can also execute through price levels. Suppose a market order to buy 200 shares is also submitted. The order at $11.08 will be fully executed, while the order at $11.11 will be partially executed. An order to sell 50 shares at $11.11 in the order book.

```
                Price          Ask Size

                $11.11         50
     100        $11.05
     200        $11.01

Bid Size        Price
```

Note that cancel/replace orders can lower the size of an order, but not increase it. Cancel/replace orders maintain the time priority of the original order, so if size increases were allowed, traders with orders at the highest time priority for a price level could perpetually increase the size of their order, preventing others from being able to buy or sell stock using limit orders at that price level.

See Johnson (2010) for more details on the order book.

## Examples

NVIDIA is a graphics processing unit and chipset developer with ticker symbol NVDA. Consider the order book for NVDA at a leading electronic exchange on June 8, 2010. We create the `orderbook` object by specifying the location of our data file.

```
> library(orderbook)
> filename <- system.file("data", "sample.txt",
+ package = "orderbook")
> ob <- orderbook(file = filename)
> ob <- read.orders(ob, 10000)

> ob

An object of class orderbook
--------------------------
Current orderbook time:    09:35:02
Message Index:             10,000
Bid Orders:                631
Ask Orders:                1,856
Total Orders:              2,487
```

We read in the first 10,000 messages then `show` the object. The order book time is displayed in 24-hour time, so it is currently 9:35:02 AM. The message index indicates which row in the data file the object

has read through. The display also shows that there are 631 bids and 1,856 asks outstanding, for a total of 2,487 orders. This indicates that many earlier orders have been removed through either cancels or trades.

```
> summary(ob)

Current time is 09:35:02

Ask price levels:   540
Bid price levels:   179
Total price levels: 719
----------------------------
Ask orders:         1,856
Bid orders:         631
Total orders:       2,487
----------------------------
Spread:             0.02

Mid point:          11.37
----------------------------
Inside market

Best Bid:           11.36
Size:               2,700

Best Ask:           11.38
Size:               400
```

Using `summary` the total order information from `show` is repeated. We see that there are 540 ask and 179 bid price levels, for a total of 719. This indicates that many orders are have been submitted at the same price level. The spread is $0.02, and the midpoint is $11.37. The inside market is composed of 2,700 shares offered at the best bid of $11.36 and 400 shares offered at the best ask of $11.38.

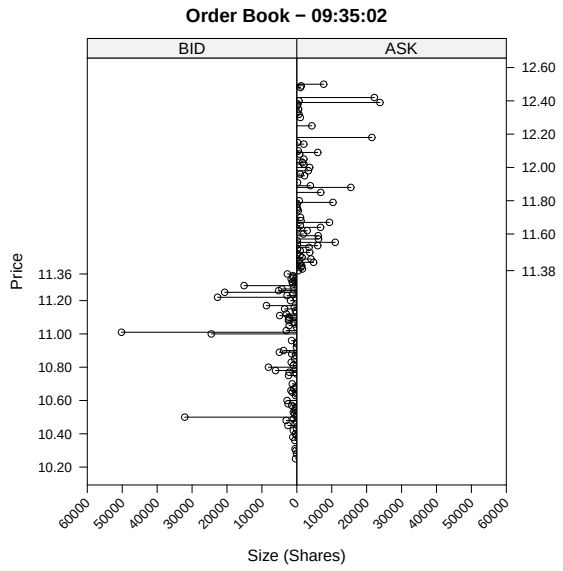
```
> display(ob)

Current time is 09:35:02

                 Price          Ask Size
--------------------------------------------
                 11.42          900
                 11.41          1,400
                 11.40          1,205
                 11.39          1,600
                 11.38          400
--------------------------------------------
  2,700          11.36
  1,100          11.35
  1,100          11.34
  1,600          11.33
    700          11.32
--------------------------------------------
Bid Size          Price
```

`display` shows the inside market, along with the four next best bid and ask price levels and the size at each price level. This gives the user a snapshot of the supply and demand in the market.

```
> plot(ob)
```




`plot` is essentially a graphical representation of `display`. Price levels are on the y-axis, and size is on the x-axis. The maximum and minimum price levels are 10% above and below the midpoint. Note the large number of shares at $11.01. It is helpful to know whether the depth at that price level is comprised of a single order, or several. Using the ■[■ method we can view the order information at particular price levels.

```
> ob["11.01"]

  price  size type     time      id
1 11.01   109  BID 34220988 4403084
2 11.01 50000  BID 34220988 4403085
3 11.01   100  BID 34220988 4403086
```

There is an order for 50,000 shares at the $11.01 price level that accounts for almost all of the size. We can view a plot of the number of orders rather than the number of shares at each price level by specifying `type = 'o'` when using `plot`. In the previous plot the maximum and minimum price levels were 10% off from the midpoint, but for this plot we specify a bound of only 3.3% above and below the midpoint.

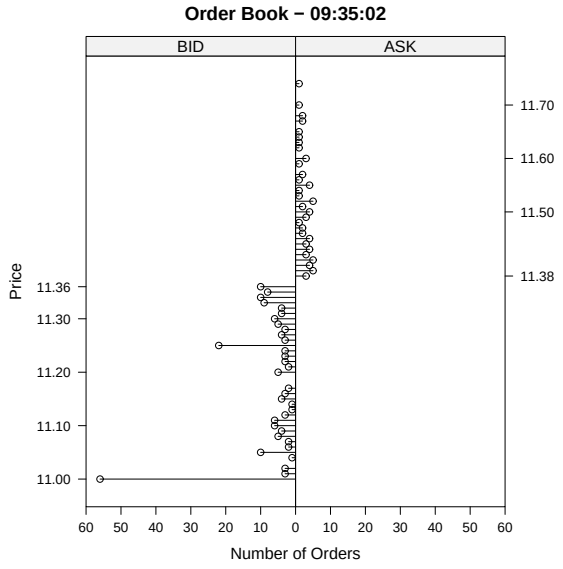
Note the large number of orders at $11.00. The `[` method returns a `data.frame`, so we can use `nrow` to return the number of orders at $11.00.

```
> nrow(ob["11.00"])

[1] 56
```

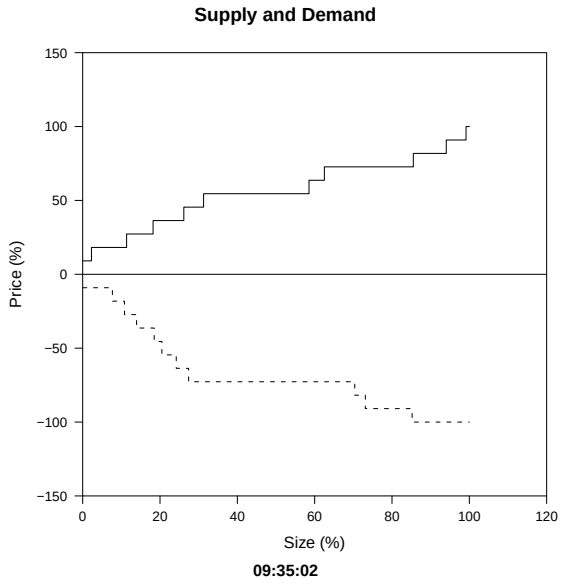
There are 56 orders at that price level, which confirms what we see in the plot.

```
> plot(ob, bounds = 0.033, type = "o")
```




The following plot shows the supply and demand curves for the order book. The demand (supply) curve is downsloping (upsloping). This is because more people want to buy (sell) a stock when the price decreases (increases). The ask (bid) prices are normalized by the absolute value of the difference between the highest (lowest) plotted ask (bid) price level and the the midpoint. The sizes are normalized by the sum of the sizes across all plotted price levels for each side. See Cao et al. (2009) for more details.

```
> plot(ob, bounds = 0.01, type = "sd")
```




The following plot shows the supply and demand curves for the order book. The demand (supply) curve is downsloping (upsloping). This is because more people want to buy (sell) a stock when the price decreases (increases). The ask (bid) prices are normalized by the absolute value of the difference between the highest (lowest) plotted ask (bid) price level and the the midpoint. The sizes are normalized by the sum of the sizes across all plotted price levels for each side. See Cao et al. (2009) for more detail.

**orderbook** has methods for creating new `orderbook` objects at different times of interest.

```
> ob <- read.time(ob, "9:30:00")
```

`read.time` returns an `orderbook` object at the first message after the specified time. For example, this returns the `orderbook` object at 9:30:00.

```
> ob <- read.orders(ob, n = -50)
> ob

An object of class orderbook
--------------------------
Current orderbook time:    09:34:59
Message Index:             9,950
Bid Orders:                621
Ask Orders:                1,857
Total Orders:              2,478
```

`read.orders` is used to move forwards or backwards in the order book by a specified number of messages. In this case, an `orderbook` object at 50 messages before the current message is returned.

# Data

Most brokers and exchanges have their own format for transmitting raw order data to customers, so it would be unfeasible for us to write scripts to automatically process all data formats. Consequently, raw data for an `orderbook` object must be in the following form:

```
type,time,id,price,size,type
A,31285893,1231884,11.49,200,ASK
R,31295779,1231884,150
C,31295781,1231884
```

where A, R, and C mean Add, Replace, and Cancel, respectively. The second column is the timestamp of the message in milliseconds after midnight of the users timezone, and the third column is the ID of the order. For a cancel/replace the next column is the new size, while for Add and Trade a column for price comes before the size column. Add messages also have the type of order (BID/ASK) in the sixth column.

In this example an order to sell 200 shares at $11.49 is added to the order book, followed by a cancel/replace that changes the size of the order to 150 shares, and finally a cancel order that removes the order from the book.

Note that the cancel/replace and the trade have the same timestamp and ID. This is because the `orderbook` object needs to be told the new share size after the trade occurs, in addition to information on the trade. It will not adjust the size of a previous order after a trade occurs without an accompanying

cancel/replace present. A trade that leads to a full execution should be accompanied by a cancel message. Since trade messages do not alter the order book, they are not necessary for the functions mentioned above, but can be included if the user wants to take advantage of added functionality.

## Trade Data

Users can choose to include trade data, as well as data on which orders and executions are theirs. This allows a user to create plots that show the time priority of her own orders, as well as the ability to calculate the returns of her trades. If users wish to take advantage of this functionality, the raw data should be in the following form:

```
A,34226539,5920814,25.95,100,ASK,TRUE
A,34226788,5933949,25.91,100,BID,FALSE
C,34226904,5920814
T,34226904,755377,25.95,100,TRUE
```

The main difference between the two data formats is that this one has an additional column for add and trade orders indicating TRUE if the order or trade belongs to her. If the user wants to be able to calculate the returns of trades, but has no orders or trades of her own, this new column can be omitted.

Note that the cancel and the trade have the same timestamp. This is because the `orderbook` object needs to be told that the trade has fully executed an order by submitting a cancel order removing the trade that was executed. In the same vein, if a trade partially executes an order, it should be accompanied by a cancel/replace message. Since trade messages do not alter the order book, they do not need to be included if the user wants to build the order book.

```
> filename <- system.file("data",
+ "tradersample.txt",
+ package = "orderbook")
> ob <- orderbook(file = filename, trader = TRUE)
```

Creating the `orderbook` object this way lets it know to expect an additional column in trade and add messages that indicate whether or not the trade belongs to the user.

```
> ob <- read.time(ob, "9:30:05")
> ob <- next.trade(ob)
```

This function sets the state of the order book to when the trade after the current time occurs. There is also a `previous.trade` function that sets the order book to when the trade before the current time occurs.

```
> view.trade(ob, tradenum = 584)
```

```
       Trade 584
row         6062
time    09:30:05
id        636783
price      25.94
size        1000
status     FALSE
```

```
> mid.point(ob)
```

```
 price
25.935
```

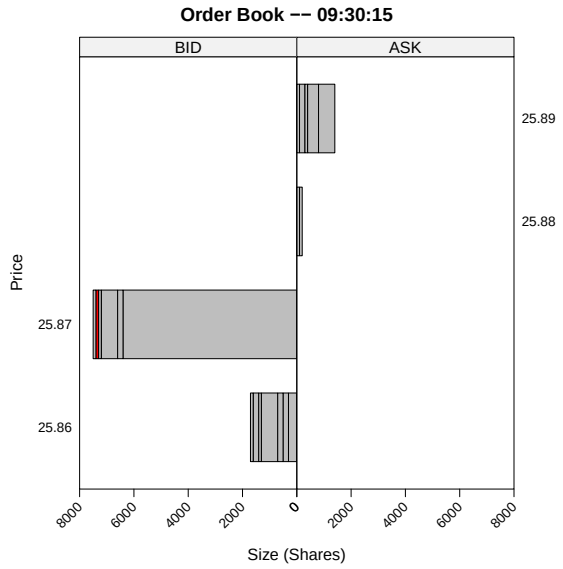
Since the trade price is higher than the midpoint price, we know that the trade occurred as a result of an ask order getting hit. Note that trade data is stored into the order book only after it has read through the corresponding trade message.

```
> midpoint.return(ob, tradenum = 584, time = 10)
```

```
                midpoint
10 second return    0.065
```

The *midpoint return* is the difference in cents between the execution price and the midpoint price after a specified period of time. For example, the above calculates the ten second midpoint return for the first trade. Since it was a sell order, the midpoint return will be positive if the stock price decreases, and negative if the stock price increases.

```
> ob <- read.time(ob, "9:30:15")
> plot(ob, type = "t", bounds = 0.02)
```




This plot shows two pennies above and below the best bid and best ask. We see that the midpoint has dropped to 25.875, confirming the midpoint return above. This graph shows two pennies above and below the best bid and ask. Orders at these price levels are shown in time priority, with the earliest submitted order being closest to the middle y-axis. Note the red order–this is an order marked `TRUE` by the user, indicating that it belonged to her.

## Simulation

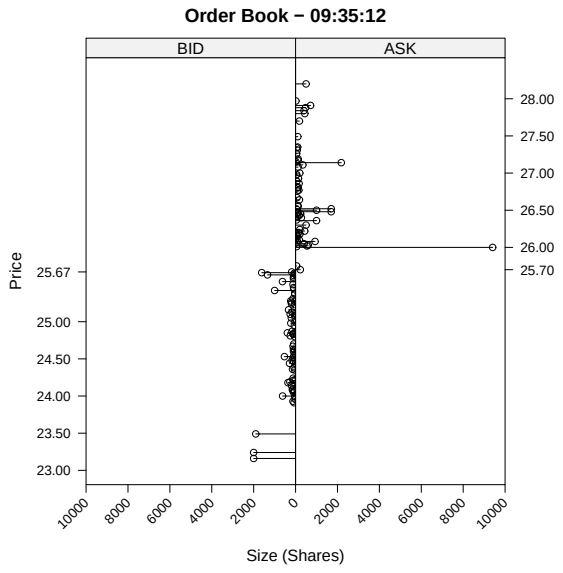
**orderbook** supports adding, replacing, and cancelling orders. Add orders require the price, size, and type (ASK/BID) of the limit order. Time and ID are optional, and will default to the maximum time + 1 and the maximum ID + 1. Replace messages require the new size and ID. Cancel orders only require ID. In addition, market orders can be issued to the order book. Market orders require size and side (BUY/SELL).

```
> ob <- add.order(ob, 11.2, 300, "ASK")
> ob <- remove.order(ob, 1231883)
> ob <- replace.order(ob, 1231883, 150)
> ob <- market.order(ob, 200, "BUY")
```

Using these tools, the user can write functions to simulate the an order book. In the following example, we consulted Gilles (2006). We simulate 1,000 messages. The messages are chosen based on the following probabilities: 50% for a cancel message, 20% for a market order, and 30% for a limit order. In the event of a cancel message the order cancelled is randomly chosen. Market order have a 50-50 chance for a buy or sell order. The size of the market order always corresponds to the size of the individual order at the best ask or bid with the highest time priority. Limit orders have a 50-50 chance to be an ask or bid. There is a 35% chance for the price of a limit order to be within the spread. If the price is outside of the spread, a price is chosen using a power law distribution. Finally, the size follows a log-normal distribution. A plot of this example simulation is shown below.

```
> ob <- simulate(ob)

> plot(ob)
```




## Conclusion

The current release of the **orderbook** package is meant to serve as a proof-of-concept. Relatively sophisticated order book analytics are possible using an open source package. The **orderbook** package is part of a collection of packages for performing tests of financial conjectures. See Campbell et al. (2007) and Kane and Enos (2006) for more information on the **backtest** and **portfolio** packages, respectively.

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