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Introduction To Quant Workshop

SIGN UP

Workshop Outline

- Introduction to trading
  - Trades, orders, order matching
  - Overview of the industry
- Roles in trading, research and engineering
  - Job description
  - Interview process
  - Interview problems

What is Quantitative Finance?

Quantitative finance is the use of mathematical models, statistics, data, and algorithms to make trading decisions.

- Quantitative finance is a broad term, encompassing a wide range of activities and roles.
- Different types of firms in the trading industry incorporate quantitative finance.

Why the Trading Industry?

- Intellectually challenging
  - Fast paced environment, complex and ambiguous problems, interdisciplinary work
- High agency and ownership
  - Smaller teams, flatter hierarchies, less bureaucracy
- Benefit to society
  - Liquidity provision, making markets more efficient, price discovery
- High compensation

Trading Introduction

We will introduce the concepts of

- Trading
- Exchanges
- Orders and the orderbook

I thought that firms don't care about prior knowledge of finance?

Motivation:

- this is only true during the interview stage for large HFT firms
- beginner understanding of orderbook dynamics is useful for
  - mock trading games
  - general understanding of the industry

Spot Trades

Alice says to Bob:

"I want to to sell you 5 AAPL shares. Each share will be sold at $30. This transfer will occur by the end of the next business day (tomorrow)."

This defines a **spot trade** (as opposed to a **future trade**).

A **spot trade** is an agreement to exchange assets for money, with the actual transfer occuring almost immediately (within 1 or 2 business days).

- sides (Alice is selling, Bob is buying)
- quantity of the asset being traded (5)
- price per asset ($\$30$)

Trade Execution and Settlement

Once Bob **agrees** to this trade, the trade can be **executed**.

Upon trade **execution**, both parties are given **settlement obligations**.

For example, in Alice & Bob's equity spot trade, the obligations are:

- Alice must give Bob 5 shares of AAPL by the settlement deadline
- Bob must give Alice $5 \times \$30 = \$150$ by the settlement deadline

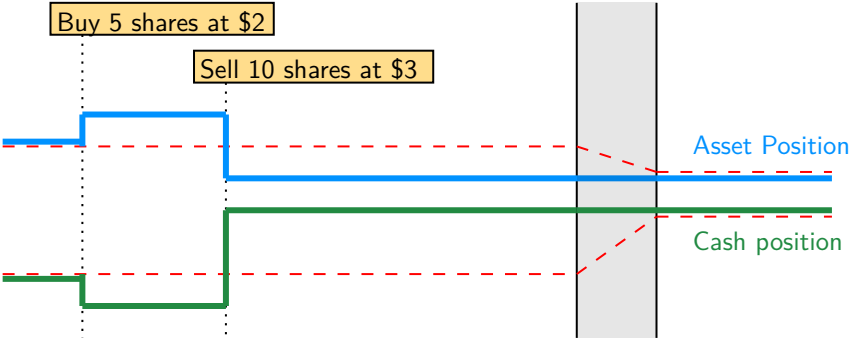
Once the obligations are fulfilled, the trade is considered **settled**.

Obligations on other asset classes and types of trades (e.g. futures and options) are considerably more complex than this. Concepts related to **clearing** and **settlement** are considered part of the **post-trade life-cycle**.

Holdings and Position

At each point in time, each participant has a **holdings** and a **position** in each asset.

Position includes the effects of executed **trades** that have not been **settled** yet.



Holdings and Position

Your **exposure** and **PnL** is determined by your **position**.

This is because the terms of the trade (price, quantity) are locked in immediately upon trade execution, so the transfer of assets and money can be thought of as occuring immediately.

For example, you agree to buy a share of AAPL at $30. Immediately, you are "exposed" to the movement of AAPL stock price. If the market price goes down to $10, you are still paying $30 for it upon settlement, but might end up having to sell it away for $10.

As a result, for trading games and simulations, we can abstract away the entire post-trade life-cycle and just consider our asset and cash **position**, disregarding **holdings** entirely.

What is an Exchange

An **exchange** is a centralised venue for participants to find willing counterparties to make **trades** with.

If a trade does not occur on an exchange, then the trade is **over-the-counter** (OTC).

US exchanges

- (XNYS) NYSE
- (XNAS) Nasdaq
- (XCBO) CBOE
- (XCME) CME

APAC exchanges

- (XHKG) HKEX
- (XSHG) SSE
- (XSGE) SHFE

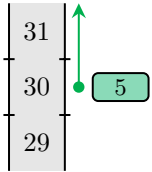
Limit Orders

Each participant maintains a set of **limit orders**, which the exchange uses to automatically infer whether they would agree to any hypothetical trade or not.
Here is what a limit order may look like:

Alice tells the exchange

"I am willing to sell a maximum of 5 AAPL shares.
I am willing to sell each share at a price of $30 or better."

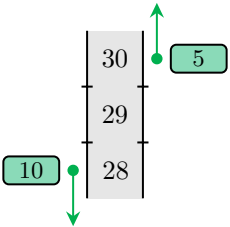
This is called **inserting** an order.



Bids and Offers

By submitting the **sell order**, Alice authorizes the exchange to accept trades on her behalf, until 5 AAPL shares have been **sold**. Once this happens, the order is considered **filled**.

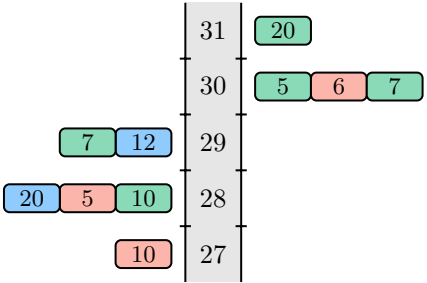
- A **bid** (buy order) expresses a willingness to buy
- An **offer/ask** (sell order) expresses a willingness to sell



Orderbook

The exchange keeps track of each participant's **open orders** (unfilled), and collects them into an **orderbook**.

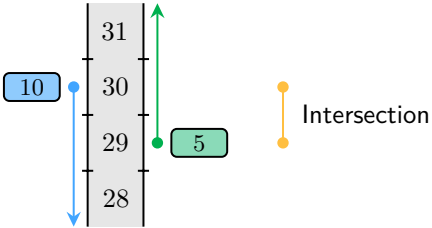
- Alice
- Bob
- Charlie



Limit Orders In Cross

Two limit orders are **in cross** if

- One order is a **bid** and the other is an **ask**.
- There exists an **intersection** between the price ranges they are willing to trade at

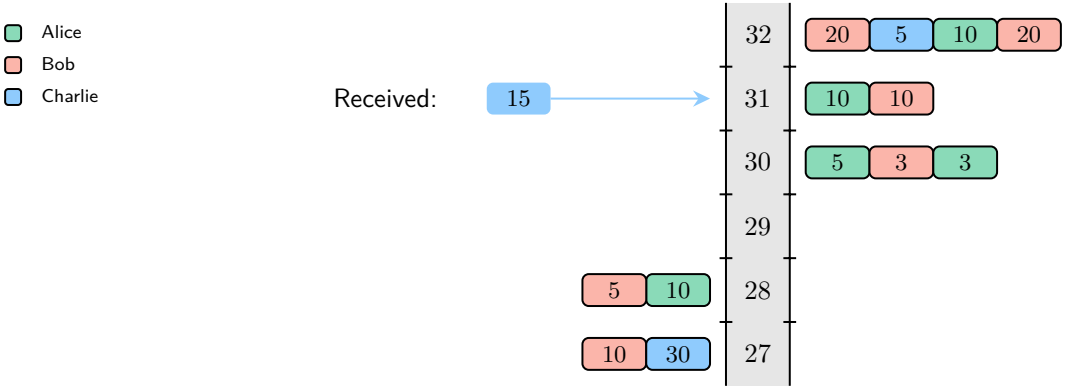


Order Matching Algorithm

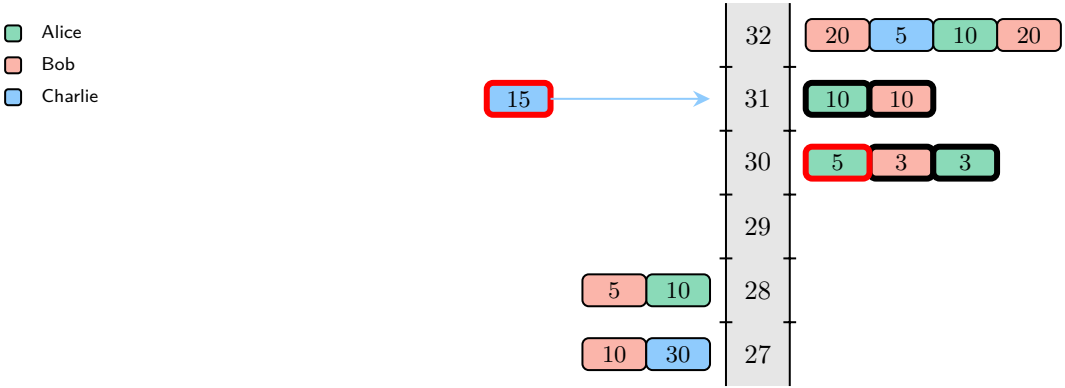
We will demonstrate **continuous matching** with **price-time priority**.
This is a **matching algorithm** that determines the trades made when orders are inserted.

- Orders are **received** and then **handled** by the exchange one at a time.
- The order currently being **handled** is the **aggressing order**.
- The **aggressing order** is matched against **open orders** it is **in cross** with.
  - Choose the **open order** according to **price-time priority**.
  - Execute the trade at the price level of the **open order**, for the maximum quantity possible.
- This matching occurs until either:
  - The aggressing order runs out of quantity:
    - The order is considered **filled** and is discarded.
  - No more orders **in cross** remain:
    - The order is **unfilled** or only **partially filled**.
    - If the order was a **fill-and-kill** (FAK), then the order is discarded.
    - If the order was a **good-till-cancel** (GTC), then it is inserted at its price level at the back of the queue.

Small GTC Buy Order: Initial



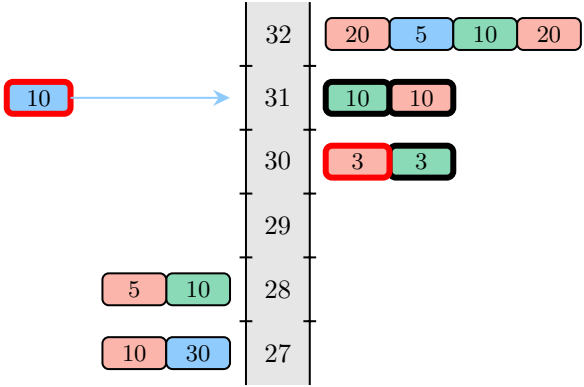
Small GTC Buy Order: Animation



Small GTC Buy Order: Animation

- Alice
- Bob
- Charlie

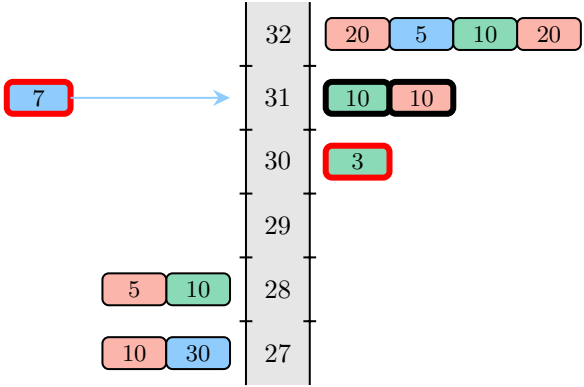
C buys 5 shares from A at $30



Small GTC Buy Order: Animation

- Alice
- Bob
- Charlie

C buys 5 shares from A at $30
C buys 3 shares from B at $30



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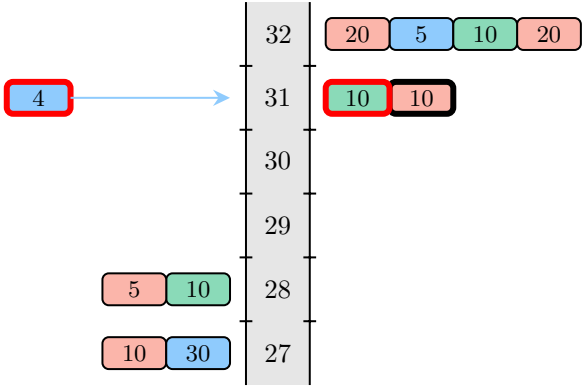
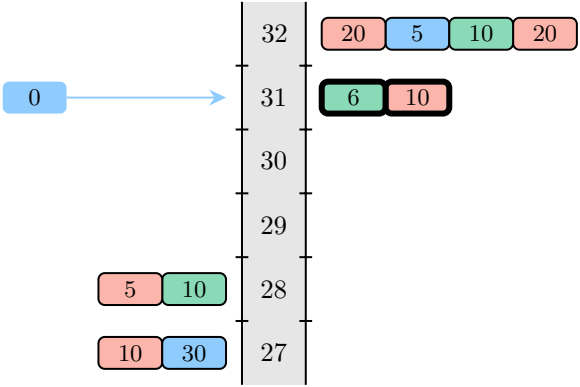


Small GTC Buy Order: Animation

- Alice
- Bob
- Charlie

C buys 5 shares from A at $30
C buys 3 shares from B at $30
C buys 3 shares from A at $30
C buys 4 shares from A at $31



Small GTC Buy Order: Result

- Alice
- Bob
- Charlie

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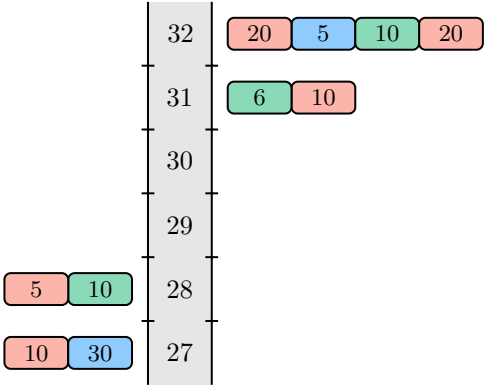
C buys 3 shares from A at $30
C buys 4 shares from A at $31



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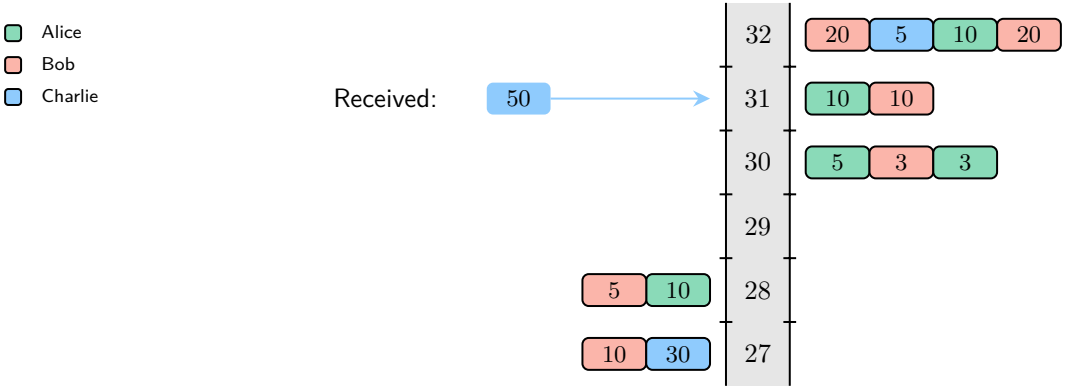

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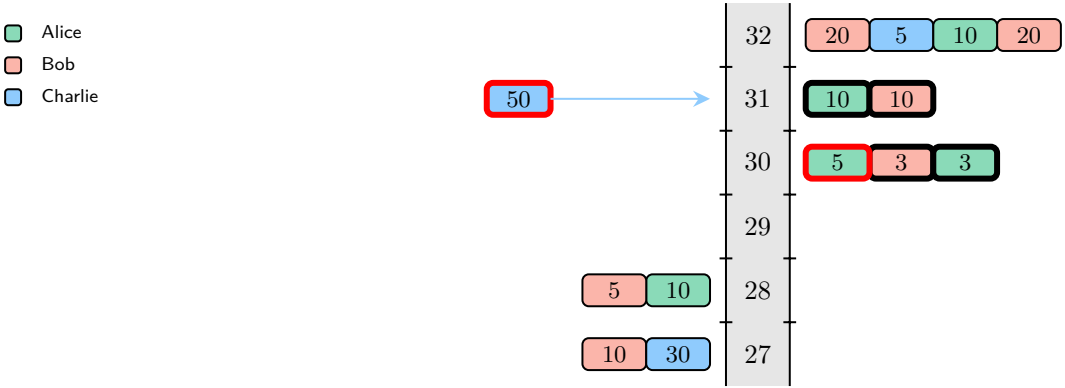

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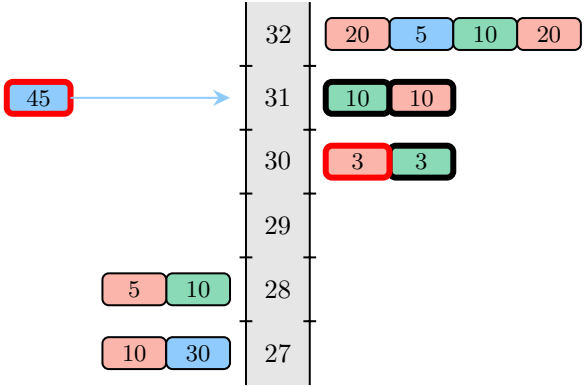

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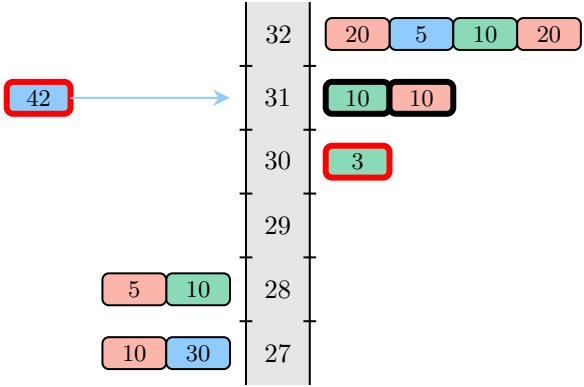

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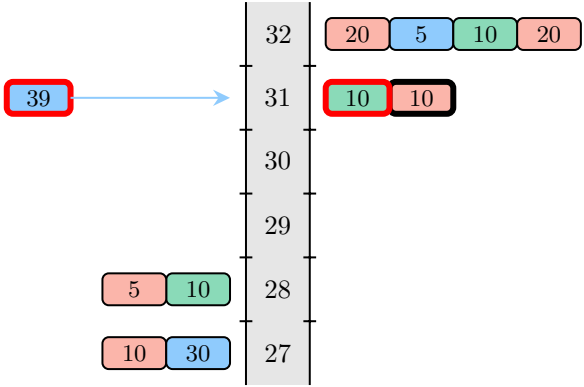

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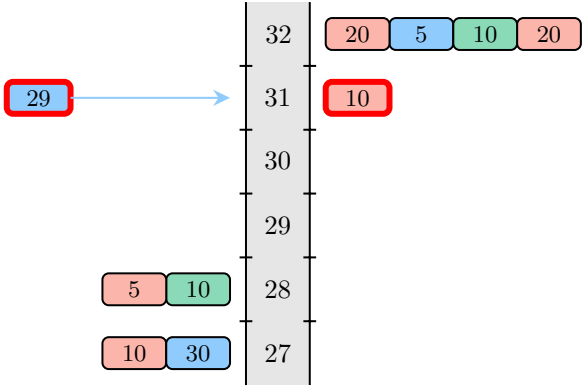

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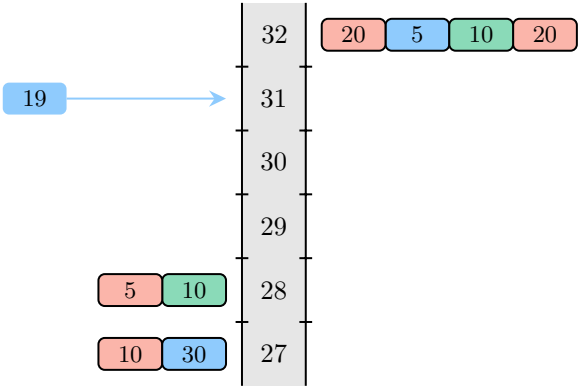

Large GTC Buy Order: Result

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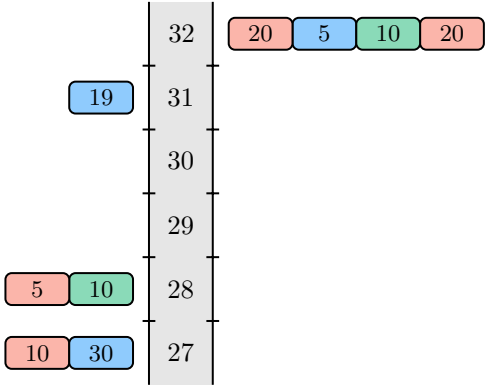
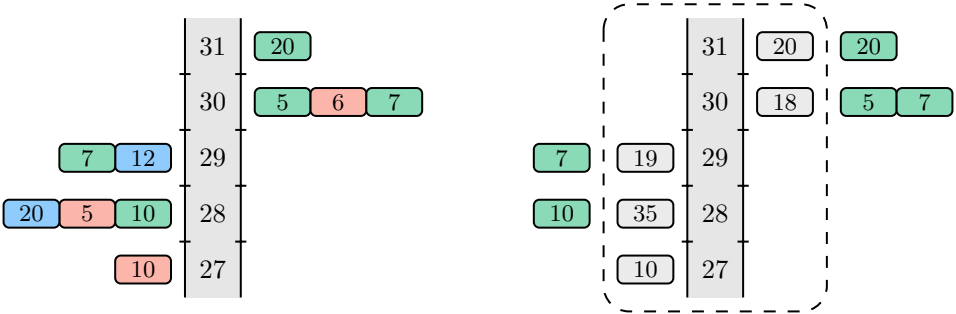


Aggregated Orderbook

Usually, exchanges only reveal to the participants:

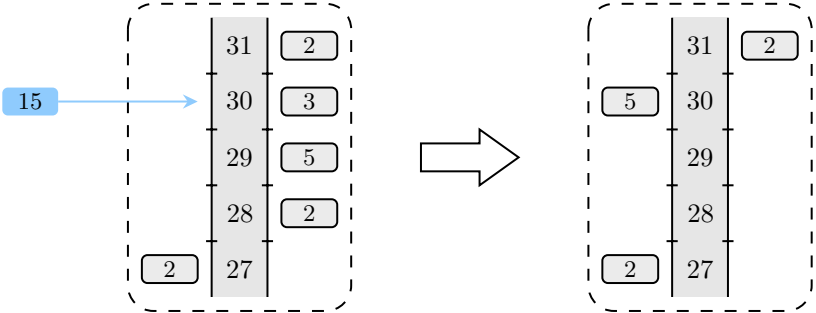
- the set of **their own** open orders
- the **aggregated** orderbook (all quantities on each level are aggregated)



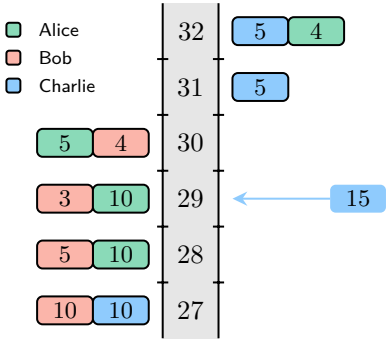
Liquidity and Market Impact

An orderbook with tight spreads and large volume is considered **liquid**.

In an **illiquid** market, orders can **eat through** the orderbook.
Market impact is when an action (order insertion) has an effect on the market price.



Limit Orderbook Examples



Discussion Questions

- What trades are made when Charlie inserts the offer?
- How does each person's position change?
- What does the orderbook look like afterwards?
- How does Charlie's opinion differ from Alice's and Bob's?

What Are Trading Games?

Setup

- Players trade a stock whose true value is unknown
- Everyone starts with equal cash and position
- Players send bids and asks, which get matched by the engine

Information

- Partial information about the true value is revealed over rounds
- Players update their estimates and trade accordingly

Scoring

- At the end, true value is revealed, and all positions are liquidated at this price.
- Final Cash Position $=$ cash $+$ (position $\times$ true value)

Trading Game Example

"The stock value is the volume of the tallest building in the world."

Round 1: "The height of this building is 828 meters."

- Players estimate volume and trade

Round 2: "The base area is 8,000 m^2."

- Players refine estimates and trade

End: True volume revealed, positions liquidated.

Trading Game Formats

How We Play

- **Open outcry**: verbal, shouting quotes, manually tracking position on paper
- **Electronic**: enter orders into a simulated exchange

Why They Matter

- Build intuition for markets, orderbooks, and spreads
- Improve estimation & mental math skills
- Appears in interviews at some trading firms (Jane Street, Optiver)

Open Outcry Rules

There are many variations of how you can play trading games without an electronic system. Any player can shout a quote at any time:

- **Bid [bid]** (i.e. insert bid at [bid])
- **Offer [offer]** (i.e. insert offer at [offer])
- **"[bid] at [offer]"** (i.e. insert both bid and offer)

Trading against passive orders:

- **"Yours"**: trade against the highest bid (the asset is now "yours")
- **"Mine"**: trade against the lowest offer (the asset is now "mine")

Example Markets

Make a market on...

- Number of sheep in New Zealand
- Distance from Sydney to Perth in inches
- Number of 7-Elevens in Tokyo

Extra information can be released as the market develops.

Keep track of your own PnL!

What can be Traded?

An **instrument** is any tradable financial asset or contract.

Examples of instruments/securities:

- **Equity Securities** (common stocks)
- **Fixed Income** (debt, bonds, MBSs, CDOs)
- **Derivative Contracts** (futures, options, swaps, BTIC)
- **Pooled Investment Vehicle** (ETFs, mutual funds)

Types of Firms

Proprietary Trading Firms

- Trade using the firm's own money (no outside investors)
- Examples: Optiver, Jane Street, IMC, SIG

Hedge Funds

- Manage money from outside investors
- Examples: Citadel, Two Sigma, DE Shaw, Qube Research & Technologies

Banks

- Quants (often called "Strats") price products, run trading desks, build risk systems
- Examples: Goldman Sachs, JP Morgan

Types of Firms

Asset Managers

- Manage retirement funds, ETFs, etc.
- Focus on long-term growth rather than short-term trading
- Examples: BlackRock, Vanguard

The Exchange Business Model

- Exchanges make money by charging a fee per trade.
- Benefit from high trading volume, thus have an incentive to attract participants.

To attract customers, exchanges:

- provide a fair and transparent trading environment.
- maintain high liquidity (by attracting market makers).

Market Makers

A **market maker** is a participant in an exchange who provides liquidity by continuously quoting buy and sell prices for a security.

Market makers must fulfill obligations, and maintain a good relationship with exchanges:

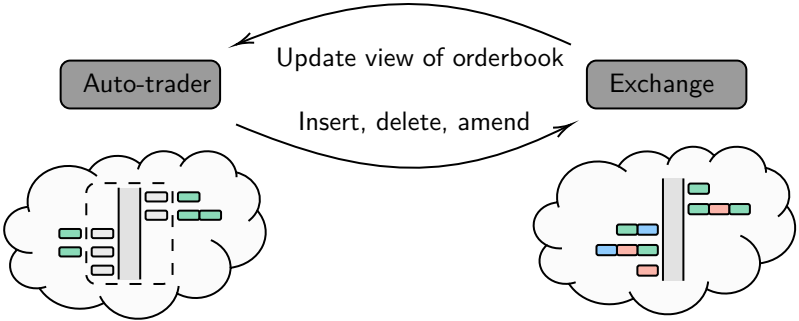
- Quote a minimum size at all times
- Quote within a certain spread
- Don't do disorderly or manipulative trading

In return, the exchange rewards market makers with:

- Fee rebates
- Not getting blacklisted

Automated Trading

- Programs run on machines that receive information from the exchange.
- The information allows them to build a view of the orderbook.
- They send messages to the exchange (insert, cancel, amend).



High Frequency Trading

High frequency trading (HFT) uses low latency infrastructure, to react quickly to changing market conditions within micros.

Colocation is when you rent a rack at the exchange to place your autotraders.

- Low latency allows you to react faster and mitigate **adverse selection**
- Improved queue positions allows for more fills and better prices

Hedge Funds

A **hedge fund** holds investor money and assets. An **investment management firm** trades the assets in the fund and makes returns, taking fees.

- Examples: Citadel, Two Sigma, DE Shaw, Qube Research & Technologies, Antipodes Partners, Hyperion Asset Management, Plato Investment Management

Buy Side and Sell Side

- The **buy side** wants to trade (buy or sell assets).
- The **sell side** provides services that enable trading.

A pension fund (buy side) wants to buy $10M of shares. They go to a broker (sell side) who executes the trade for them.

The Buy Side

Entities that want to invest, speculate, or manage risk.

- **Asset managers**: invest client money (pension funds, mutual funds)
- **Hedge funds**: invest client money, seeking returns uncorrelated with the market
- **Corporations**: hedge business risks (e.g., airlines hedging fuel prices with futures)
- **Retail investors**: individuals trading their own money

The Sell Side

Entities that provide trading services to the buy side.

- **Brokers**: execute trades on behalf of clients
  - Examples: Interactive Brokers, Charles Schwab
- **Dealers / Market makers**: provide liquidity by quoting prices
  - Examples: Citadel Securities, Jane Street, Optiver
- **Research**: produce equity research reports to buy-side clients
  - Examples: Macquarie
- **Investment Banking**: underwrite securities, advise on deals
  - Examples: Goldman Sachs, Morgan Stanley

Trader Roles

Traders make the trading decisions.

- Somewhere on a scale between fully systematic and fully manual
  - Systematic: adjusting strategies, closer to research role
  - Manual: reacting to news, morning macro meeting
- In HFT, traders adjust the parameters of autotraders
- They also write a lot of random scripts.

Trader Interviews

- Mental math (OA)
- Probability & combinatorics (technical interview)
- Estimation / trading games ("make me a market on X")
- Python (numpy, pandas)

Researcher

Researchers analyse data of all kinds.

There is much more to research than just alpha and pricing theory. There are a wide variety of research roles across different types of firms (HFT, market makers, hedge funds).

- Analyse past trades to see how the strategy can be improved.
- Research trading patterns of counterparties and competitors.
- Making interaction (placing and pulling orders) with exchange faster.
- Pricing exotics.
- Alpha research.
- Execution research, transaction cost analysis.
- Portfolio optimization, researching correlation matrices.

Researcher Interviews: Core Skills

- Probability and statistics
  - Statistical models, linear regression, generalized linear models
  - Machine learning, time series
- Take home project

Engineering Roles

- **Software Engineer**
- **Quantitative Developer**
- **Hardware Engineer**

Software Engineering Roles

Software engineers build the trading/risk/data/research infrastructure that the trading firm relies upon.

- **Application Development**
- **UI Development**
- **Data Engineering**

Sometimes there is a greater focus on

- latency (optimising hotpath)
- data throughput

while in big tech there is a bigger focus on graceful error handling and uptime.

Software Engineering Interviews

Skills assessed:

- **Data Structures & Algorithms**: implementation, complexity/speed analysis
- **Design Skills**: System design, API design, OOP
- **General Knowledge**: Databases, Networks, OS, Concurrency, Compilers
- **Testing**: Unit tests, mocks, designing for testability

Software Engineering Specialized Tracks

Many firms separate candidates into specialized tracks early in the process.

Low-Latency Track

- C++
- Operating Systems
- Networks
- Computer Architecture

Example firms: Citadel Securities, QRT

Python Track

- Probability and statistics
- Data manipulation (Pandas, SQL)
- Other stats (machine learning)

Example firms: Citadel Securities

Quantitative Development

A **quant dev** is half developer, half researcher.
They are developers who also contribute to the trading strategies.

Math/Stats Skills

- Undergrad math (linear algebra, probability, statistics)
- ML techniques (linear regression, clustering, decision trees, gradient boosting)
- Python for research (NumPy, Pandas, sklearn, statsmodels, plotting libraries)

Dev Skills

- Expected to be as proficient as any other dev

Example firms: Citadel Securities, Optiver

Interview Process Overview

1. **Online Assessment**
   - Mental maths, probability, sequences, aim trainer
2. **Behavioural Interview**
   - Motivations (why trading), typical culture fit questions
3. **Technical Interviews** (1–3 rounds)
   - Typically 1-on-1 with a trader
   - Probability, brainteasers, market making
4. **Final Round (Superday)**
   - Full day of interviews
   - Interactive trading games, creative problems
   - Behaviourals with head of trading / team leads

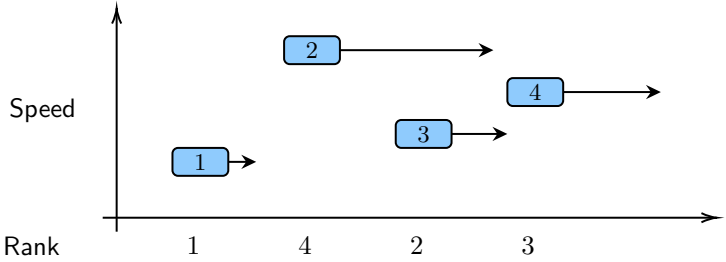
Car Crash

From: https://www.quantguide.io/questions/car-crash

- N cars placed on a line, and given an initial rightward velocity i.i.d.
- When a faster car catches up to a slower car, it assumes the speed of the slower car.
- Eventually, the cars have settled into K clusters.
- What is the expectation of K when $N = 10$?

Car Crash: Solution with Order Statistics

- Let S_n be the set of all $n!$ possible rankings σ_i of n cars.
- Since the speeds of the cars are i.i.d., each ranking is an equally likely outcome.
- The ranking completely determines K.



Car Crash: Solution with Order Statistics

- Let f map a ranking σ to the resultant K.
- Let A_n be the sum of $f(\sigma)$ over all $\sigma \in S_n$, given by

$$A_n = \sum_{\sigma \in S_n} f(\sigma).$$

- The expectation of K (answer) is given by

$$\mathbb{E}(K) = \frac{A_N}{N!}.$$

Can we find a formula/pattern for A_n?

Car Crash: Solution with Order Statistics

$$
\begin{aligned}
f(1) = 1 \quad & f(2,\ 1) = 1 \quad & f(3,\ 2,\ 1) &= 1 \\
& & f(2,\ 3,\ 1) &= 1 \\
& & f(2,\ 1,\ 3) &= 2 \\
& f(1,\ 2) = 2 \quad & f(3,\ 1,\ 2) &= 2 \\
& & f(1,\ 3,\ 2) &= 2 \\
& & f(1,\ 2,\ 3) &= 3
\end{aligned}
$$

$$A_n = nA_{n-1} + (n-1)!.$$

$$\left[\frac{A_n}{n!}\right] = \left[\frac{A_{n-1}}{(n-1)!}\right] + \frac{1}{n}.$$

Car Crash: Solution with Arbitrary Distribution

- The answer should be the same regardless of the distribution of the velocities, as long as the car velocities are i.i.d. and continuous.
- We will assume that all the velocities are $X_i \sim \mathrm{Unif}[0,1]$.

Notice that the event $B_k := \{X_k > \min(X_{k+1}, \ldots, X_n)\}$
is the event that the k-th car will crash into a slower car ahead of it.
Let $I_k := \mathbf{1}_{B_k}$ be the indicator variable for this event.

- $I_k = 0$ if the k-th car does not crash into any slower car ahead of it.
- $I_k = 1$ if the k-th car crashes into a slower car ahead of it.

$$\mathbb{E}(I_k) = \mathbb{P}(I_k = 1) = 1 - \frac{1}{n-k+1}.$$

Car Crash: Solution with Arbitrary Distribution

Each time a car crashes into a slower car ahead of it, the number of clusters K decreases by 1.

$$K = N - \sum_{i=k}^{N} I_k$$

$$\begin{aligned}
\mathbb{E}(K) &= N - \sum_{k=1}^{N} \mathbb{E}(I_k) \\
&= N - \sum_{k=1}^{N} \left(1 - \frac{1}{n-k+1}\right) \\
&= \sum_{j=1}^{N} \frac{1}{j} = H_N.
\end{aligned}$$

Die Game

You have a 10-sided die with faces 0–9. You can roll as many times as you want. Each roll, the value is added to your score. However, if you roll a 0, you go **bankrupt**: your score resets to 0 and the game is over. You can choose to stop at any time and keep your current score.

What is the optimal strategy? What is your expected payout?

Typically no calculators, pen and paper allowed.

Die Game: Solution Strategy

Let current bankroll be x.

Expected value of rolling:

$$\text{EV(roll)} = \frac{1}{10}(-x) + \frac{9}{10}(5) = -\frac{x}{10} + 4.5$$

Expected value of stopping: 0

Take action with higher EV. Equate to find optimal stopping point:

$$-\frac{x}{10} + 4.5 = 0 \implies x = 45$$

Optimal strategy: Keep rolling while $x < 45$. Stop when $x \geq 45$.

Die Game: Estimating Expected Value

Calculating exact EV requires Markov chain analysis. In interviews, estimation is valuable.

Quick estimation:

- Expected number of rolls before stopping $\approx 45/5 = 9$
- Probability of surviving 9 rolls $= (9/10)^9$
- $(1 - 1/n)^n \approx e^{-1}$ for large n
- So $(9/10)^{10} \approx e^{-1} \approx 0.37$
- Therefore $(9/10)^9 \approx 0.4$

EV $\approx 0.4 \times 45 = 18$

Actual answer (Markov simulation): 17.68

Resources

Trading Fundamentals Talks

- Oden Petersen & QuantSoc - Systematic Trading Workshop
- George Mukun Wang & SQT - Intro to Quant Trading

Trading Interview Prep

- *A Practical Guide to Quantitative Finance Interviews - Xinfeng Zhou* (Green book)
- *A Collection of Dice Problems - Matthew M. Conroy*
- Jane Street Puzzles
- Quantguide
- Quantprof

Resources

Probability and Statistics

- *A First Course in Probability - Sheldon M. Ross*
- *An Advanced Course in Probability and Stochastic Processes - Zravko Botev*
- *Data Science and Machine Learning - Zdravko Botev*

Math

- *Linear Algebra Done Right - Sheldon Axler* (LADR)

Resources

Software Engineering Classics

- *Designing Data-Intensive Applications* (DDIA)
- *Operating Systems: Three Easy Pieces* (OSTEP)

C++ Classics

- *Exceptional C++* by Herb Sutter
- *Effective Modern C++* by Scott Meyers

Blogs, Websites, Videos

- agner.org (Agner Fog Website)
- beej.us (Beej's Guides)