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"The Anatomy of a High-Frequency Trader: Human and Machine Proportions"

A medieval architect named Marcus Vitruvius Pollio determined the ideal proportions of a man's body around the birth of Christianity: a man should be eight heads high. Vitruvius went to great lengths at describing how body parts should be related to each other, much like mechanistic parts in architecture or civil engineering. Later, around 1490, Leonardo da Vinci famously pictured the ideal proportions of a man in an illustration now known as the "Vitruvian Man." Da Vinci also coined an analogy between the workings of the human body and the universe. The symmetry of the man's posture in da Vinci's illustration is striking, representing the over-ruling systematicity everywhere.[2]

Whether ideal proportions of a high-frequency trader exist is the key question we ask in this article. What should an ideal high-frequency trader look like? To what extent should he be a human and to what extent a machine? If systematicity rules over trading, mechanistic parts may be expected to take control in the long run. Applying the ideology of Vitruvius and da Vinci, the ideal trader could be one hundred percent machine. And if he were a hybrid, as might be reasonably assumed in financial markets today, what are the proportions currently? Further, how fast should the hybrid trader converge to the proportions of the "ultimate trader"? It appears plausible that sometime in the future, a machine is able to think like a man with distinctive "Vitruvian symmetry and proportions."

To a casual observer, financial markets now appear to be moving and evolving at the speed of light. Reformations are truly noticeable, driven by a plethora of market regulations and politics – both of which are undoubtedly affected by human emotions. Machines have been charged for taking too much control over today's western financial markets. There is a fear that too much of total trading volume is, at least seemingly, has already fallen outside the control of humans. Has the man lost the battle against the machine it created? If the future holds a killer breed (of a trader) like in the movie "Alien," regulators need to known about the welfare implications of having a predator in a human pool, often pictured as innocent sheep. Such a nightmare scenario is hyped by media, and is directly linked to high technology applied by a certain type of traders known as "high-frequency traders."

How much do we know about this "alien breed"? Not enough, a casual observer might say. High-frequency traders are rather secretive of their trading practices, although this is also typical for hedge funds and many others. That is, until spring 2014 when Virtu Financial attempted an initial public offering.[3] (Their IPO got actually postponed because of the negative press associated with the book "Flash Boys.") Based on Virtu's description, plus anecdotal evidence from exchanges and other trading related institutions, certain characteristics of high-frequency traders can be named. The identifying features are technological savviness through co-location and other state-of-the-art technology solutions, and smart risk management that keeps the inventory in check at all times, often leading to high order-to-trade ratios and near to zero inventory positioning at the day's close. There it is: speed and smarts. In "Alien," these are the main characteristics of the ultimate predator.

One might wonder if there is any true reason to identify high-frequency traders with such predators. There is, and there is not. Most of the evidence is anecdotal. There exists little to none academic evidence to support predatory trading. However, there are no guarantees that such activity would not exist at all – and in fact, it is likely that it does to some extent. There is no reason to believe that high-frequency traders would be more honest or fair than the rest of the trading population. But this does not prove that high-frequency traders would be more predatory than the rest of the population. The key question is, apparently, do predatory practices somehow define high-frequency traders? In other words, are speed and smarts necessary and sufficient characteristics of a predatory trader? There is no evidence to show a causal link between the two characteristics and a wolf among sheep.

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1 E-mail: tommiavuorenmaa@triangleintelligence.com. First version of the manuscript. Comments welcome.

2 In this article, we speak of a "man" and "he," but naturally they could as well be replaced by a "woman" and "she."

3 Virtu's IPO document: https://www.sec.gov/Archives/edgar/data/1592386/000104746914002070/a2218589zs-1.htm

If being a high-frequency trader does not make you a predator, does it make you an ultimate trader? It is certainly arguable that one is better off having more advanced technology than other traders. Here, however, one must consider one key relation in capitalistic activity: the relationship between investments and profits. To own high technology is not cheap. It costs much more than normal traders are prepared to pay. To make a sound business decision, a basic finance rule states that the net present value of an investment must be above zero. That is, a wise business decision demands a certain amount of expected profit to make sense. In high-frequency trading, investing in high technology is not risk-free. While the risk might have been lower in the early stages, that is now gone. This is related to another basic capitalistic rule that says: when more competitors enter the field, (the probability of having) abnormally high profits go down. Furthermore, there does exist a considerable time delay from a technological investment to reaping reasonable profits, so one must take into account the (uncertain) amount of other competing high-frequency traders after that delay.

High-frequency traders typically operate in the microsecond range, depending on what kind of activity is required. Arbitrage between assets or exchanges is typically the most demanding one, taking advantage of modern microwave technology and apparatus specifically tuned to speed. On the other hand, market-making is not necessarily as speed sensitive, as speed can be at least partly offset by smarts. That is, smart risk management and modeling of order-book dynamics may offset losses on the speed side. This is sometimes necessary due to the fact that adding intelligence to the algorithms creates latency. Thus, there is often a trade-off between speed and smarts. You are able to be very fast with relatively simple and dumb algorithms, but more intelligent algorithms demand more thinking, which leads to increase in latency. The choice is a strategic one, and time varying.

Speed is typically considered to be mechanistic and part of the “machine.” The truth is, however, less clear than that. While it is true that certain technological solutions are mechanical, the solutions to create more speed may be ingenious, not mechanistic. Creativity often plays a key role in making machines faster. It is the man who is the mastermind and who ultimately decides how the machine operates. This is not only a philosophical question; It matters, for example, how exactly microwave towers are placed. If they are not optimally placed, considerable amount of speed advantage is lost. How to acquire such towers is a practical question, as well – again solved by humans, not machines. What is theoretically optimal and achievable by a machine alone, feasibility remains another matter. The machines also require maintenance and upgrades by a man. The tasks in speed are intertwined.[4]

Summarizing the above, trading speed and smarts are arguably almost completely created by a man. A line may be drawn on who executes trades, but not on the logic of the decision to trade (yet, that is). In large-scale trading of multiple assets across exchanges, machines have the upper hand. Thus, it is the execution, rather than smarts and creation of speed, that should be attributed to a machine. A man clearly cannot react and compute as fast as machines do, but the logic is still man-made; the logic and the concept of an algorithm can be traced back at least to Alan Turing in the 1930s. The smartest chess playing machines are man-made, although their execution time is beyond humans. However, creativity belongs to a man, and for this reason humans can still outperform a machine in chess. It is not only the brute-force that matters, it is the mind and heart that deliver the end-result.

Reflecting on da Vinci's illustration of the ideal proportions of a man, we can reasonably claim that the hands of the Vitruvian Man, that is, the execution side of high-frequency trading, are machine's. Those hands can execute thousands of orders in a blink of an eye, if necessary. The fact that those orders are sometimes sent in error, as in the case of Knight Capital in 2012 – losing $440 million in a matter of minutes – just proves the importance of a logical error and the effect of man's doings. Following this analogy, the mind and heart of a high-frequency trader are that of a man, while the legs, which only technically speaking support the speed (low-latency), again belong to a machine. This is how a typical high-frequency trader looks like. He is definitely partly a human, partly a machine, with carefully crafted proportions to match the increasing competition in global trading.

4 The art of placing microwave towers is discussed in this interesting series: http://sniperinmahwah.wordpress.com

But matters are not constant in life, nor in trading. There is no reason to suspect that development would stop in the near future. In which direction are high-frequency traders expected to develop? Are they destined to become more like a machine, with a decreasing proportional input from a man? This is hard to say in great detail as high-frequency traders form a surprisingly heterogenous group. One may simply wonder do the characteristics lead to a homogenous group of traders seeking high alpha with low risk, showing similar risk-to-reward ratios? At a first glance, such a proposition is contradictory as a higher competition should wipe out excessively large rewards with a fixed risk. There however does remain the dark possibility that high-frequency traders would be able to retain their presumably high profits by taking advantage of less technologically savvy traders, as certain authors have claimed them to do. While this is a possibility, like any, have they found the holy grail of trading: making money with minimal risk? If so, can we say something about the ultimate trader?

At this point, we need to cut open the body of a high-frequency trader and take a look inside. Da Vinci did this in his illustrations of a man, here we do it for the (potentially) new trader breed. To what extent is his success driven by technology and to what extent by his trading intelligence? To answer this, we now take it as given that smarts belong to man and technological power to machine. Because technology is presumably more time-varying than intelligence, the former often thought to be grow at an exponential pace while the latter at a slower, but still at a cumulative pace, we do not focus on technological aspects as much as smarts. Indeed, after a year or two, the speed that now would appear to be unreachable, may become the norm – much like computing power has done. It also follows that a definition of high-frequency trading becomes obsolete easily. Next, figuratively speaking, we open the brains of a head-frequency trader and investigate its decision making logic.

One of the key characteristics thought to be related to high-frequency traders is prudent risk management through tight inventory control, especially in market-making type of algorithms. These algorithms attempt to capture spread between the current bid and ask prices by buying and selling in a fashion that keeps the inventory close to zero, unless information regarding a future trend exists. As future typically remains hard to forecast, much uncertainty remains about the risk of inventory. Thus, market-making high-frequency traders may choose to optimize their bid and ask placement to minimize the size of inventory at each time point. This can be handled in many ways, using either passive or aggressive order placement strategies. What is often the key in such strategies is the use of speed and order-book dynamics. But as order-book dynamics can be extremely complex, they may also require complex models, thus slowing down the reaction time to changes in order-book.

The decisions of high-frequency traders demand fast reaction times. In the above market-making example, a high-frequency trader wants to minimize the probability of being adversely selected. Trading against informed traders would most likely lead to consistent losses. In order to keep the spread small, speed and highly actively order placements and cancellation becomes a necessity. Algorithms run by such market-maker must be able to identify times when the probability of trading against an informed trader becomes significant. Trading against uninformed traders, on the other hand, usually guarantees consistent profits. It also serves the purpose of decreasing the transaction costs to the uninformed through a smaller spread. High-frequency traders, acting as market-makers, should use all legal means to avoid being crushed by informed traders in order to stay profitable. The way this is accomplished is differentiation in business model, the way done in other fields, too.

According to basic market microstructure theory, the main type of traders that exist on a modern market place are noise traders (usually retail traders), market-makers (including, but not necessarily limited to high-frequency traders), and informed traders. Who are the informed traders, then? They are usually believed to be large institutional investors like hedge funds, controlling bulk of the money. In the above example, it is such institutional investors that high-frequency trading market-makers would like to avoid. If they did not, a trend might cost them quickly millions of dollars. Large-scale sells or buys from institutional investors, triggered by asymmetric information that is argued to exist between market-makers and companies spending large sums of money to research specific companies, are the steamrollers that uninformed market-makers must always keep eye on.

It is prudence that makes market-making profitable. This is made much more difficult by the fact that it must be executed for a large universe of assets. Penny-picking in front of a steamroller is a good analogy, except that penny-picking must be executed through a machine controlling the man-made algorithm. Here comes the trouble: once it is relatively easy to write code that works well for one asset at a time, it is much more difficult to take into account different dynamics of an universe of stocks. This means that the proportions of da Vinci's illustration must not only be set to be ideal, but the brains of a high-frequency trader must be able to produce universally working algorithms. This is a tall order, indeed. Especially because much of the dynamics are known to be time-varying. Ideally, then, a high-frequency trader must not only find the best execution, but also universal rules.

The stage is set for the following proposition. As high-frequency traders are sometimes accused of institutional investor front-running – of which academic proof is largely lacking – could one not claim, at least with the same level of confidence, that institutional investors front-run others with respect to information? That is, where does the line get crossed with respect to insider information? The Securities Exchange Commission in the U.S. has over the years accused, and found guilty, many large investors for using insider information.[5] Whether it is the information gathered legally that is the source of the profits of institutional traders, or the information in the "grey" insider area that is the source, should be compared to the profits of market-making high-frequency traders. One may then likely find that asymmetric information is much more valuable than provision of liquidity.

The above is but one example of what high-frequency traders can do. Clearly, with technology and smarts, many different trading strategies can be applied, from basic momentum to contrarian, and from event-based trading to liquidity provisioning. It is also certainly plausible that insider traders would use high-technology in some illegal manner. Thus, the question of homogeneity must be considered, especially because regulators are pushing for stricter rules for activities relevant to high-frequency trading. These include, but are not limited to, order-to-trade limits, minimum quote time limits, various other sorts of speed bumps, and transaction taxes. If high-frequency traders are not a homogenous group, the end-impact of regulation changes remain largely uncertain. It may be, in particular, that regulations hurt only a part of the population, and the hurt change their tactics to be in accordance by the law, thus increasing homogeneity. If homogeneity means a more aggressive behavior from the part of high-frequency traders, the end-result may be a suboptimal fragile market.

It is often claimed that an optimally behaving market is such that different type of breeds of traders exist. Using an analogy from biology, a healthy ecosystem consists of predators and prey, while suboptimal ones are such that the other is largely or completely missing. The existence of great white sharks do not generally pose any long-term threat to seals, for example. In trading parlance, heterogeneity is often characterized by the time-scale of asset holding times. While institutional investors typically hold their assets for weeks, months, or even years, high-frequency traders may lie in the other extreme, holding their assets for only seconds or even less than that. Similarly, within the population of high-frequency traders, one can define passive and aggressive ones. In today's markets, academic evidence tends to support high-frequency traders being mainly passive. Should regulations change to require minimum quote resting times, in particular, the technological stacks of high-frequency traders could very likely be used in directional betting and not passively.

Trading is about finding opportunities to make money. Traders are predators at their heart. They seek out opportunities to strike and take advantage of the weak. The ultimate trader – the potentially new alien breed – most likely seeks out basically the same opportunities but uses his edge in speed and smarts. High-frequency traders might be a somewhat early version of an ultimate trader. This does not necessarily has to have anything to do with so-called "predatory trading" often referred to as illegal activity. It is the nature of the game that investors always try out to out-smart each other. Otherwise, the price of an asset would perfectly reflect the asset's true value with little or no change. There are plenty of reasons for price movements, however, starting from pure liquidity needs that, if

5 Examples of enforcement actions taken by the SEC: http://www.sec.gov/spotlight/insidertrading/cases.shtml

executed in large quantities, may themselves alone move prices significantly from their true values.

What appears to matter is who is going to devise the strategies in the future. Until this day, it has been man's job to apply his creativity, senses, and logic to create new mathematical propositions, to prove them, and base sound statistical methods on those results. But it may not be impossible to let the machines to truly overrun a man. This would be accomplished by at first finding logical errors in man-made algorithms, then creating new useful algorithms – and not only optimizing them, but truly inventing new strategies at least from a set of known strategy types. This is not a typical machine learning problem. It is much more. It is like letting the machine to create an original type of painting in par with da Vinci's. It would converge to the ultimate trader, with logically flawless algorithms, with speed to match, and endless opportunities to change its behavior to be untraceable. Such an alien would indeed pose a threat to other predators – but not necessarily to the population.

Why would not the above described ultimate (high-frequency) traders pose a threat to the whole ecosystem? Because unlike in "Alien," traders in financial markets compete against each other. Should there be an ideal, special breed of a trader, these would trade against each other, as well. This would bring down their profits to the competitive limit as standard finance theory suggests. Unless, of course, regulations would allow them to amass a position that would allow almost a monopolistic situation with only few players involved and perhaps colluding. Tyrannosaurus Rex perhaps had dominating features in its own time, but it was not this beast that ended the regime of dinosaur. It was ended by an exogenous shock to the system. In financial markets, a regulatory shock could increase homogeneity among different kind of traders and threat the whole ecosystem.

The February 2014 issue of the National Geographic Magazine tells of the new science of the brain. Scientists of today are able to compile data of vision in the brain and create mathematical models based on that. The molecular machinery of the brain can be revealed, and most likely used to create stand-alone smarter machines, but the amount of data needed for this purpose is even more staggering than the data processed each day by high-frequency traders: While such traders may have to tolerate terabytes of data recorded on exchanges and transmitted to servers, the functions inside of human brains can easily create data worth of petabytes from just a microscopic area. Although the complexity of human brain is still overwhelming to analyze, scientists have found simple grid-like structures of pathways, with neurons connected to each other only through certain key places. In high-frequency trading, exchanges are linked through well-placed microwave towers.

Structure and formalism abound in nature, albeit it is clouded by complexity and randomness. For example, the fractal, or more generally self-similar, character of several natural phenomena has fascinated people since the times of Benoit Mandelbrot – from the length of the coastline of the Great-Britain to the distribution of word counts in a text. In financial markets, mathematical models applying the logic of fractals and chaos have been used since the 1990s. The basic proposition of such models is that a solid structure (an attractor) repeats at different scales, and even universally. Because a careful verification of fractal models often require the use of extensive computing power, such models have become more popular only during the last decade – a simple example of how the increased capacity of machines has helped high-frequency traders to use smarts and extend trading practices to new frontiers. Universality of mathematical models is what high-frequency traders seek.

It may well be that in the not-so-distant future we see the Earth interconnected with microwaves or another form of advanced technology, a general structure somewhat similar to the human brain. The proportions of this structure are the same while the scale is hugely magnified from the microscope. In such a future scenario, more precisely, trading centers are efficiently connected to each other and traders. The anatomy of a high-frequency trader, the topic of this article, and his mind especially, can thus serve as a descriptive model how everything is interconnected. This would be consistent what da Vinci apparently had in his mind with "Vitruvian Man": certain systematicity (symmetry) of a complex object revealed at different scales. That is to say, the development of modern trading runs on its natural course towards more efficiency, but the trading principles stay largely intact. □