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Cognition in High-Frequency Trading: The Costs of Consciousness and the Limits of Automation

Armin Beverungen
Universität Siegen

Ann-Christina Lange
Copenhagen Business School

Abstract
Certain strands of contemporary media theory are concerned with the ways in which computational environments exploit the 'missing half-second' of human perception and thereby influence, control or exploit humans at an affective level. The 'technological unconscious' of our times is often understood to work at this affective level, and high-frequency trading is regularly provided as a primary illustrative example of the contagious dynamics it produces. We challenge and complicate this account of the relation between consciousness, affect and media technologies by drawing on the recent work of N. Katherine Hayles and by focusing in detail on the ways in which the 'costs of consciousness' are accounted for and negotiated in high-frequency trading. We suggest that traders actively develop modes of awareness accounting for the costs of consciousness, and that the necessary 'stupidity' of high-frequency trading algorithms as well as competition pose limits to the full automation of financial markets.

Keywords
affect, automation, cognition, financial markets, high-frequency trading

Introduction

The practice of high-frequency trading (HFT), where traders execute orders almost at the speed of light, has in recent years received increasing attention in media and cultural studies (see e.g. Arnoldi, 2016;

Corresponding author: Armin Beverungen. Email: armin.beverungen@uni-siegen.de
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Golumbia, 2013; Lenglet, 2011), not to mention in economic sociology or the field of social studies of finance (e.g. Hardin and Rottinghaus, 2015; Lange et al., 2016). This is due in part to the financial crisis of 2007–8, which made quite clear that the complexity of financial markets (in particular derivatives) brought with it a 'failure of intelligence to master the world', and thereby a fundamental 'problem for the work of subjecting the world to the powers of cognition' (Martin, 2009: 345). This complexity of markets and failure of cognition sparked a widespread interest in many disciplines in understanding markets also in their social, cultural, and media technological set-up. While HFT was not associated with the financial crisis of 2007–8, the 'flash crash' of 6 May 2010 (Borch, 2016), where algorithms triggered other algorithms, has foregrounded how complex the human-machine and increasingly the machine-machine ecologies of financial markets have become.

HFT is a subfield of algorithmic trading in which the execution of trades takes place at time intervals below the threshold of human perception. High-frequency algorithms can execute several hundred trades before a human can notice or react. The more formal definition of HFT states that HF trading employs:

(a) algorithms for decision-making, order initiation, generation, routing, or execution, for each individual transaction without human direction;
(b) low-latency technology that is designed to minimize response times, including proximity and colocation services;
(c) high-speed connections to markets for order entry; and
(d) high rates of orders or quotes submitted. (CFTC, 2012)

Since HFT accounted for a little less than half of all equity trading in 2016 (Raykov, 2017), it seems fair to say that media technologically-armed financial markets constitute machine-machine ecologies in which human traders play an increasingly marginal role.

In their recent introduction to an essay collection on the cultures of HFT, Ann-Christina Lange, Marc Lenglet and Robert Seyfert (2016) note that HFT serves as 'an exemplary case for the study of algorithmic cultures', since its highly-developed media technological set-up raises more general questions regarding 'the proliferation of automated processes and their manifold entanglements with our daily lives' (2016: 154–5). As media and cultural studies more broadly engage with how the computational media that surround us constitute a 'technological unconscious' (Thrift, 2005; Hörl, 2015), and how algorithms condition our lives and cultures (Amoore and Piotukh, 2016; Seyfert and Roberge, 2016), HFT is often presented as emblematic both of fully automated computational systems and of affective contagious dynamics that mark these systems (e.g. Terranova, 2013; Lazzarato, 2014; Parisi, 2015). Key here is the assumption that algorithmic HFT, working at speeds below the threshold of human perception, escapes the cognitive capacities of

human traders, so that affective dynamics mark both the human-machine but also the machine-machine relations, as in the case of the flash crash.

In this paper, we want to contribute to this literature with a more nuanced account of affective contagion, cognition and automation in HFT. The literature in media and cultural studies cited above implicitly or explicitly conceives of financial markets as cognitive systems, and the literature in social studies of finance also foregrounds the problem of information, knowledge and cognition, noting how the opacity of financial markets produces 'epistemic uncertainty' (Lange et al., 2016: 161) and that 'the very core of HFT is the creation of information asymmetries' (Zook and Grote, 2017: 122) due to some traders accessing information faster than others. Drawing on our own empirical research and the recent work of N. Katherine Hayles (2014, 2016a, 2016b, 2017), we argue that focusing specifically on algorithmic devices operating at a micro-temporal regime inaccessible to humans (defined as 'costs of consciousness' by Hayles) highlights the role of human traders and their 'modes of awareness' both in reigning in affective contagion and in posing limits to automation. On the other hand, we do not want to indicate that algorithms are nothing more than an extension of the human trader. As MacKenzie has also made clear, 'it would plainly be a mistake to treat trading algorithms simply as the faithful delegates of human beings', since the functioning of the algorithm may not be the one intended by its human programmer (MacKenzie, 2014b: 3).[1] In this way we understand our empirical material as demonstrating the ways in which HFT traders remain if not central then certainly indispensable to the cognitive system of the markets in which they trade.

We thereby want to contribute to the social studies of finance through a close engagement with media and cultural theory concerned with the technological unconscious and cognition, and to media and cultural theory through a more thorough empirical encounter with the phenomenon of HFT. In doing so we also want to contribute to a broader literature on algorithmic lives and cultures (Amoore and Piotukh, 2016; Seyfert and Roberge, 2016). Where an important part of this literature has focused on how marketing and branding informed by cognitive neuroscience and propped up by ubiquitous media can exploit affect (Andrejevic, 2012; Sampson, 2016), here it is not a consumer encountering algorithmic media which are designed to control their affects and desires, but HFT traders actively partaking in the construction of the computational environments and cognitive systems in which they engage.

We will proceed by introducing key literature on the costs of consciousness, technological unconscious and nonconscious cognition, before briefly outlining the infrastructural and algorithmic set-up of HFT as well as the fieldwork we draw on. We then move on to discuss, first, how HFT traders account for and negotiate the costs of consciousness in relation to affective contagious dynamics in financial markets,

before, second, showing how both the necessary 'stupidity' of algorithms and competition currently pose real limits to automation. We finally conclude with some reflections on the wider implications of our case for an understanding of the technological unconscious and its complicity with financial capital.

The Technological Unconscious and Nonconscious Cognition

The term 'technological unconscious', although referring to work by Patricia Clough on autoaffection and unconscious thought (2000; Clough does not use the term herself), was popularized by Nigel Thrift, who suggested, with reference to logistics and technologies such as GPS, that knowledges of position and juxtaposition nowadays amount to a technological unconscious 'whose content is the bending of bodies with environments to a specific set of addresses without the benefit of any cognitive input, a prepersonal substrate of guaranteed correlations, assured encounters, and therefore unconsidered anticipations' (Thrift, 2005: 213).

The concept has also enjoyed an extensive career in media theory as a shorthand for referring to the ways in which media technologies more generally condition our existence. Erich Hörl, for example, notes that the infrastructural revolution associated with ubiquitous media will 'bring about a complete restructuring of everyday life and a readdressing of the world in general', and that it is in 'this new technical unconscious that we will eventually be forced to recognize a *technological unconscious* in the strongest sense' (2015: 8). Elsewhere, commenting on the ways in which media today distribute cognition and sensation in environments, Hörl suggests that we may now speak of an 'ecological unconscious' (2013: 127).

In a similar vein, Mark Hansen, in a discussion of ubiquitous computing, links the idea of the technological unconscious to debates around affect, cognition and perception. Since contemporary media operate independently at a fast speed,

> this microtemporal and imperceptible dimension of ubiquitous computational environments *can never be brought into the sphere of direct, conscious attention and awareness*; rather, it impacts sensory experience *unconsciously, imperceptibly – in short, at the level beneath the threshold of attention and awareness*. (Hansen, 2013: 70, emphasis in original)

Hansen has expanded on this work recently, in a consideration of how technical media 'now operate through microtemporal loops that are below the threshold of conscious attention' (2015: 43). Noting how a

key aspect of this is how social media draw on these operations for social feedback loops, Hansen suggests that, rather than a dystopian or defensive stance, this requires a rethinking of 'the scope of human agency itself in order to take stock of its tight correlation with technics' (2015: 78).

A key aspect of these debates around the technological unconscious are those strands of affect theory, including Hansen's work, which follow from the highly influential account of the autonomy of affect provided by Brian Massumi (1995; see Gregg and Seigworth, 2010). Much of this literature focuses on the ways in which the 'missing half-second' identified by cognitive sciences has been exploited in affective capitalism (Hayles, 2014: 211–12). That is not to say that affective capitalism relies solely on unconscious dynamics or affective contagion. Tero Karppi and his co-authors note how the modalities and apparatuses of affective capitalism 'operate on cognitive, non-cognitive, and even pre-cognitive regimes' (Karppi et al., 2016: 10). Yet the literature on marketing and branding has extensively discussed the ways in which cognitive neuroscience has been enrolled in the project to influence and control consumers at an affective, pre- or non-conscious level (e.g. Andrejevic, 2012; Sampson, 2016).

In such accounts, HFT is often used as an illustrative example of such tendencies of environments conditioned by media technologies to address and engage us at an affective, nonconscious level (e.g. Lazzarato, 2014; Parisi, 2015; Terranova, 2013). While overall this work shows how productive it is to think of a technological unconscious produced by contemporary environmental media, we hesitate regarding the case of HFT to fully endorse such an analysis. We suggest that the case of HFT allows us to unpick many of the specific observations and reflections offered here. The case of the relation between human sensation, perception and cognition and media technologies might be a little more complex and diverse than some of these accounts give credit to. To demonstrate this, we turn to the recent work of Hayles, focusing on the ways in which cognition is reconfigured through technology, drawing on recent developments in cognitive science and artificial intelligence.

Hayles distinguishes between *thinking* as 'what conscious entities such as humans (and some animals) do' and *cognition* as 'a broader term that does not necessarily require consciousness but has the effect of performing complex modelling and other informational tasks' (2014: 201; see also Hayles, 2016a). This allows her to identify the *cognitive nonconscious*, which 'operates at a lower level of neuronal organization not accessible to interpretation' within humans, but may also 'be instantiated in a technological device such as a computer' (2014: 201–2). The notion 'costs of consciousness', which Hayles considers central to the debate on automated trading devices, refers to 'the fact that consciousness is slow relative to perception', including the perception of the operations of

technical devices:

> consciousness is belated by several hundred milliseconds, the so-called 'missing half-second'. This cost, although negligible in many contexts, assumes new importance when cognitive nonconscious technical devices can operate at temporal regimes inaccessible to humans and exploit the missing half-second to their advantage. (Hayles, 2017: 44)

Hayles proposes to focus on 'modes of awareness', which is how humans deal with the cognitive nonconscious (see Hayles, 2016a). It is these modes of awareness, also taking account of the costs of nonconscious cognition, which we will focus on in relation to HFT traders. We can easily see financial markets as a good example of this kind of set-up wherein humans, algorithms, and trading platforms constitute a very complex system of cognition which is only partly accessible to human consciousness. This is no coincidence, since, as Philip Mirowski and Edward Nik-Khah (2017) show, economics as applied science has increasingly conceived and designed markets as information-processing machines in which human knowledge and cognition are assigned a progressively marginal role. Hayles notes in relation to automated trading that the exponential effects of such complex technical environments lead to a 'tectonic shift' which 'greatly magnifies the effect of the technical cognitive nonconscious on human systems with which it interacts' (2014: 211). More specifically, algorithmic trade in milliseconds is for Hayles 'opening up temporal regimes in which the costs of consciousness become more apparent and more systematically exploitable' (2014: 212). We will build on this analysis and through our empirical case show some of the intricacies associated with HFT in relation to consciousness and cognition.

The Infrastructural and Algorithmic Set-Up of High-Frequency Trading

Before we proceed, it is worth briefly exploring the set-up of HFT, specifically the role of algorithms and infrastructure in it. Very crudely, we can think of the key ingredients of HFT as a supply of finance capital, a trader's office equipped with HFT traders who also develop algorithms to be unleashed into the market, plus a complex communication and trading infrastructure mostly supplied by exchanges and auxiliary service providers. Enabled by the technological transformations of the financial industry and the possibilities afforded by media technologies – such as the building of fibre-optic cables and microwave towers (MacKenzie, 2014a) – traders now coordinate different productive moments and circulatory money flows across different trading venues and financial

products. The key to HFT is the speed of access to different trading exchanges, which allows for the quick execution of orders, of reading orders and prices, and so on.

What HFT traders do, for example, is to 'make the spread' (arbitrage) between highly correlated products – between, for instance, shares, which are traded on the NYSE and a corresponding futures contract traded on OneChicago LLC (OCX). It will take around 13 milliseconds for a price move on the NYSE to have an impact on the future's price. By optimizing the data transmission between the two exchanges, HFT traders can react faster (typically, in around 8 milliseconds) and earn a small profit on every such single trade. Another well-known strategy is 'scalping', where traders profit from the price differences that occur between two exchanges and again buy in front of this. By acting as the middlemen at the exact moment a product is bought and sold with accumulation of only very small inventory along the way, HFT firms provide the fluid or the glue that makes capital circulate (a function that was previously executed by the exchanges). The traders would never hold inventory overnight – the average holding time (i.e. the time they own a financial product) is about 20 seconds.[2] This means that the number of trades executed has skyrocketed since the introduction of HFT.

There are many other strategies that HFT traders deploy (see e.g. MacKenzie et al., 2012; Zook and Grote, 2017), and their specifics are changing constantly. The trading strategies employed by HFT traders depend upon automated implementation through servers, physical circuits to exchanges and in many cases placement of hardware and infrastructure as close to exchange sights as possible – what is called 'co-location'. What all strategies have in common, however, is that they rely on information asymmetries where the speed of information is closely reliant on space. As Zook and Grote note, 'the very core of HFT is the creation of information asymmetries', and 'the design of capital exchanges, particularly increasing information inequality among market participants, has been a key means through which HFT traders have extracted wealth' (2017: 122, 130). Financial markets have since the late 19th century been closely reliant on and driving technological developments (see e.g. Reichert, 2009: 83–157; Zook and Grote, 2017: 123). The advent of HFT, following the automation of financial markets (Zaloom, 2006), has exacerbated this tendency and has led to a veritable 'arms race' (Budish et al., 2015) in infrastructural connections between markets, in sophisticated trading platforms, and in specific computational capacities for the execution of HFT algorithms.

HFT, then, relies on a complex infrastructural set-up which provides a computational environment for its activities, and one where questions of cognition are central due to the incomprehensible speed of their operation. Furthermore, while algorithms in general are difficult to know because they are 'never fixed in nature, but are emergent and constantly

unfolding' (Kitchin, 2017), the dynamics of markets dominated by algorithmic trade surpass timely human comprehension. The HF trading systems that we observed compose several algorithms that would interact with other algorithms in advanced and pre-programmed feedback loops. This means that even though every single algorithm is fixed and its course of actions is predictable, in its interactions with other traders' algorithms, its behaviour becomes emergent. The algorithms are pre-programmed to rewrite themselves and the whole trading system develops into a complex evolving system of interactive feedback loops (see also Hayles, 2017: 163; Lange, 2017). The costs of consciousness are here apparent: humans are too slow in acting in markets, and their cognitive capacities by themselves are too limited for comprehending financial markets.

What we will demonstrate, nonetheless, in the following sections is how human traders assert themselves in the cognitive system of financial markets by developing modes of awareness which take account of and negotiate the limited capacities of human consciousness in relation to the nonconscious cognition taking place in financial markets. Besides existing literature on HFT, we draw on ethnographic insights from a six-week visit to a Wall Street HFT firm in April 2014, and follow-up visits in October 2014 and April 2016. The traders that were followed traded in what is called 'the high-speed game' – they had an internal response time (the time it takes to despatch an order) of around a 10th of a microsecond. The ethnographic data is complemented by 21 interviews conducted with HFT traders in New York and Chicago representing six other high-frequency trading firms. The results from this data have been compared with a database of 80 interviews with industry participants and central bank officials to allow for some more generalizable statements in relation to our overall arguments.[3]

Affective Contagion and Modes of Awareness

As mentioned above, here we would like to complicate the account of HFT and algorithmic trading in general which sees it as primarily to be understood as marked by affective contagion. Much of this came to the fore in public discussions of the flash crash of 6 May 2010, in which US stock markets crashed abruptly and recovered again, all within the space of 36 minutes and mostly due to automated trading (Borch, 2016). For Lazzarato, this perhaps was no surprise, as for him the financial trader represents the 'fully realized paradigm' of the 'caricatural yet widespread version of the "subject"' that is *homo economicus*, whose subjectivity, however, has 'nothing sovereign or rational' about it (2014: 96), as perhaps some accounts of finance would make us believe. Financial trade for Lazzarato is not characterized by cognition as much as it is marked by contagion, since communication and emulation in the market occur at the level of affect, and through the 'machinic subjectivity' of the trader

tied to algorithms and the infrastructural set-up of the market (Lazzarato, 2014: 99). Certain strands of media, cultural and affect theory today see this in similar ways, and argue more generally that the human subject has been decentred through computational networks.

Luciana Parisi (2015), for example, accepts the account of HFT provided by Johnson et al. (2013), wherein 'algorithmic agents make decisions faster than humans can comprehend', and thereby operate 'outside of human control and comprehension' (Parisi, 2015: 126). Parisi takes this account of HFT as a departure for her 'critique of automated cognition in the age of algorithmic capitalism' (2015: 126), in which she speculates on how the centrality of algorithmic randomness to contemporary computing might undermine the opposition between critical thought and automation. Without wanting to challenge or discredit Parisi's project, we would like to contest her starting point and assertion that HFT takes place 'outside of human control and comprehension' mentioned above. Certainly HFT takes place in milliseconds, and therefore in the cognitive gap. Yet this does not necessarily mean that HFT takes place outside of human control or comprehension. As we will outline below, our empirical research suggests that humans precisely devise algorithms as cognizers supporting their cognitive capacities for comprehending the market.

To take another example, Tiziana Terranova, writing on everyday psychopathologies of cognitive capitalism such as attention deficit disorder and anhedonia, discusses an experiment first applied to rats and then to humans. In the experiment, the rat endlessly triggers a certain sphere of its brain that activates pleasure, and does so in disregard of its biological functions (Terranova, 2013: 63). The experiment was then transposed to humans, where money was offered to make investment decisions, which triggered the same regions of the brain. Terranova compares the psychopathology of the rats in the experiment triggering its own pleasure with a financial trader 'involved in making neurochemically-fired choices triggered by anticipation of massive future gain' (2013: 64). The financial trader here appears as neurochemically programmed to act pathologically, and Terranova relates this behaviour to the irrationality of the ratio of the capitalist system: 'What in the rat was pathological, becomes rational for the economic actor' (Terranova, 2013: 66). She also relates this to her understanding of HFT as marked by 'affective contagion and the inhuman speed of digital technologies' (2013: 66), drawing again on Johnson et al. (2013, via Wilkins and Dragos, 2013). To her this discloses 'a collective capitalist brain exposed not simply to the occasional and random catastrophe or ''black swan event'', but, haunted by ''little cerebral deaths'', that is ''frequent black swan events with ultrafast duration''' (Terranova, 2013: 66; quoting Wilkins and Dragos, 2013).

We concur with Terranova that these 'black swan events' are actually quite frequent; Johnson et al. (2013: 1) counted more than 18,000

'ultrafast extreme events' in a five-year period between 2006 and 2011. Yet these would have little to do with the individual psychopathology of HFT traders, since these events are precisely features of the machine ecologies described by Johnson et al. which at the speed of their operation exclude human participation and intervention, since they normally lasted for less than 1500ms (Johnson et al., 2013: 1). Terranova, then, somewhat misrepresents how HFT is constituted by affective contagion associated with human psychopathology: the contagious dynamics here are associated with the cognitive system made up of HFT algorithms. Our empirical research suggests that the everyday realities of financial trade are somewhat different from the experimental situation, and produce different outcomes in terms of cognition and affective contagion. Thinking cognition beyond conscious thought as a feature of human-machine ecologies offers a productive way of thinking about something like collective cognition in financial markets.

The question of affect has of course not only become central to financial markets with the rise of algorithmic trading within the 'missing half-second'. Rather, as Zaloom (2006) and many others have demonstrated, the old trading pits were thoroughly affective places and already called for affective self-management. Borch and Lange (2017) extend earlier analyses of trader subjectivity (Knorr Cetina and Bruegger, 2002) with a focus on HFT. They note that, contrary to the self-representations of traders which suggest that 'while extreme commitment is central to HF traders, emotions are more or less absent from HFT', HFT in fact 'introduces a new set of emotional challenges', with the focus shifting from 'avoiding emotions that interfere in traders' *direct engagement with markets* to evading their *interference on the algorithms*', which traders manage primarily through complexity (Borch and Lange, 2017: 295–6). While Borch and Lange are concerned with emotions rather than affect and the 'missing half-second', we can also read their analysis as concerned by this issue.

It is important, then, not to conflate affect and contagion, i.e. not to assume that affect is always contagious, as much of the literature on the technological unconscious and affect in relation to mediated technological environments appears to do.[4] It is also important not to simply oppose (non-affective) cognition to (affective) contagion, since, as our examples will demonstrate, affective and cognitive elements of the HFT trading system are not easily separated. Consider, for example, the affective aspects of how algorithms and code are turned into a fetish and imbued with magical powers of execution, sustaining our habits (Chun, 2016: 79–85). The cases of HF traders we explore briefly show that although the human-machine set-up is very complex and full of (also affective) dynamics that exceed human cognition and control, a key moment of HFT traders' labour is precisely to try to reign in these dynamics, to establish control, awareness and consciousness of what is going on, through a kind of affective management.

The ideal of eliminating emotional responses – to be systematic instead – arises from a recognition by the traders themselves of being too attached to the algorithms. Some traders explained how they became somewhat subjected by the technology that they themselves invented. One trader explained his attachment to the algorithms he had developed as personal. He said:

> You know when you develop these algorithms you have certain ideas about how they should be working. And when they end up not working as they should be it can be very frustrating. It helps . . . I mean . . . You write this algorithm and maybe sometimes it does really well and sometimes it does poorly, and you really want it to do well, and you think: well, if we just gave this algorithm a chance maybe it would make us money. You really have to resist that impulse to think 'maybe I will get lucky and it will work'.

The trader explained this as a kind of addiction:

> You are compelled to let it run longer. You have this desire to make it back. With the algorithms it's the same way. If you are not honest with yourselves it can be very compelling to say I want to run this . . . even if you are not directly trading yourselves you do feel this personal attachment to what the algo is doing because if you write something from scratch you feel like you are acting indirectly through the algorithm. So when it is doing a trade you know what it was thinking when it made that trade. It is sort of an extension of yourselves in that way. . . . I see what it is doing and I think it is smart because I programmed it to be smart.

Another HFT described this as a gambler's fallacy. He said:

> you get attached to the algorithms that you have developed. Like, if you see that it's not working as you expected it to you want to make it work. You know, rationally, it won't. All the science tells you it won't. But still you think, if I can tweak it a little bit it might work.

It is in this way that the algorithms can be considered a suggestive or contagious object. But the trader already knows this and much of his practice is precisely concerned with managing emotions and affect. Our example here shows how traders seek to respond to the challenge of contagion and affect – they manage it. They are well aware of the costs of consciousness associated with the speed of HFT. The trader is not the master of the market – itself made up of algorithmic logics and

dynamics – but mostly in control of his own algorithms, as much as he is always entangled.

In larger trading rooms this becomes a question of risk management rather than complete awareness, one which also tries to limit affective and contagious dynamics, e.g. by separating traders so they don't affect each other and imitation is avoided. Lange (2016) showed that the organization of 'prop shops' in HFT actually relies on a kind of 'politics of non-knowing', wherein traders and programmers are largely isolated and their knowledge of the different workings of the organization, of code and strategies, is severely limited on purpose. The cognitive situation into which traders are thrown is therefore designed to restrict their knowledge of both the exact operation of their trading algorithms, but also the other trading strategies employed in the organization. While this may not limit their ability to trade, it points to the ways in which, at a systemic level, certain 'firewalls' are put into place, both between but also within organizations, which limit the efficacy of the financial market as a cognitive system – precisely because capital must be protected and relies on competition and potentially on a competitive advantage in knowledge.

We are not arguing that financial trade is not at all marked by affective contagious dynamics, but HFT is in many ways also not about affect or contagion (the algorithm as a contagious object) – it is quite boring and scientific, about seeking to establish cognition. This involves a lot of tedious and dull work, but it is work that deals with the costs of consciousness and the cognitive situation the trader finds himself in. The HFT trader has a capacity to design the cognitive system that surrounds her, and her algorithms are a key part of the nonconscious cognitive system that she can influence. Even though the HFT trader can never overcome the missing half-second, he can design his trading algorithms to account for this in terms of risk and in terms of the kinds of nonconscious cognition they enable. Even if these strategies and algorithmic designs might not suffice to put the human back in the centre of the complex ecology of the financial markets, they certainly demonstrate that beyond affective contagion traders are constructing modes of awareness which address the contemporary make-up of financial markets.

Stupid Algorithms and the Limits of Automation

The technological set-up and complex ecology of financial markets not only points to the ways in which affect, contagion and cognition work; it also allows us to address some of the ways in which HFT has been promoted as a prime example of the ways in which media technologies promote automation, as in the work discussed above. Now it is certainly the case that HFT favours automation, since the contemporary market set-up requires high volumes of transactions which can only be achieved by automated trade. And while the end point to be achieved is still

imagined to be a state of automated trading, often this is not achieved, and in fact a lot of manual trade becomes necessary.

HFT traders understand themselves as entrepreneurs, coders, and scientists rather than quants or financial experts. Their view of themselves is not at all close to the portrait of the Wall Street 'quants' or broker-dealers which has been widely analysed in social studies of finance (Knorr Cetina and Bruegger, 2002; Preda, 2009; Stark, 2011). HFT traders do not execute orders on behalf of a client; they don't invest other people's money. However, due to very high financial entry barriers into the field, the HFT firm we followed needed financial support and equity to be able to execute their strategy. The firm had investors investing in their algorithms; like any other kind of start-up entrepreneur they raise seed capital to be able to start their business. This is partly due to the consolidation of HFT. In the United States in 2009, high-frequency trading firms represented 2 per cent of the approximately 20,000 firms operating today, but accounted for 73 per cent of all equity orders volume.

Another incentive for increased automation is the operating of the exchanges' fee structures. One of the central aims or preconditions of HFT is the consumption of market data as efficiently as possible, directly from the source ('first look') and reduced exchange fees (the cost the exchange normally charge a trader to execute his or her order), which one has to negotiate. One of the traders, a partner in the HF-trading shop, explained that: 'if you don't have sponsored access [reduced exchange fees] – your exchange fees will kill you.' HF traders execute a huge number of orders every second and only earn a fraction of a penny. This means that they need the rebate to be able to make a profit from the strategies explained earlier. However, as one trader explained, the large number of orders that they execute might give access to certain advantages: 'at every exchange you have to hit a certain amount of volume in order to get the tiers back . . . the rebates back'. If you have a lot of 'flow' then you get given priority access to data, as one trader explained: 'you get first look basically at all incoming order flow . . . It significantly increases the amount of volume that you're able to transact.'

The consolidation of HF firms and the exchange fees mean, as one of the traders explained, that 'you need a certain size'. On average, it would take the traders six months to program the strategies to be fully automated and reach the size they need to earn the rebates. In the first six months the traders would be hand-trading (manually executing trades by clicking the mouse) on top of the automated system. However, visiting the firm six months later, they explained that they were still hand-trading. One trader explained:

> . . . it's impossible to fully test a strategy just in a sterile contained environment which I do. . . . I test them before I release them but

> even in production there are circumstances that you won't have encountered before in testing. There is no perfect simulation program so it's important when you launch a new strategy to test it with minimal possible risk … and I observe it full time if possible.

The building of the HFT trading systems is an ongoing developing process where new algorithms are produced to replace existing ones, and so on. This was a general point made by most of the HFT traders interviewed. High-speed algorithms are highly sensitive to major price moves and changes in the market. Most traders would pre-program their algorithms to automatically withdraw from trading if a major event or change in the market happened. Therefore, the trader would need to follow the market news closely to understand what parameters the algorithms would need to be pre-programmed to act upon.

So the first problem with automation is that the market cannot be simulated properly, and algorithms need to be tested in real market conditions and monitored closely before they can be left to their own devices. Another reason for the trader needing to closely monitor trading algorithms has to do not with the set-up but with long-term dynamics, as one trader explained:

> over time what ends up happening is that the machine will accumulate into a position a certain way, so it is losing one cent, it is losing two cents. So if you are seeing too much of that happening you say hey, there is some bleeding right now … and if we don't know where this is coming from we are supposed to stop. And we try to … the hand-trader comes in and tries to recover what he can recover.

This would happen every second week. In general, a strategy is profitable for around four months to a year. This job of recovering losing algorithms is considered to be quite boring by the traders themselves. The intention of the traders is to split their work between coding (mostly changing the codes), the test processes and the monitoring of their trades. As one of the traders explained: 'As a HFT trader I never run out of development and at the same time I have to watch the ''algos'''. When asked about how closely the algorithms need to be monitored one of our respondents explained that 'I don't go more than 45 minutes without checking my strategies that's absolutely sure', and when asked why he chose this interval of time he responded that it is 'probably to shake less. It's just at night. I guess that's just my comfort level'. The futures market is open 23 hours and the trader would never sleep more

than four hours and still wake up every 45 minutes to check the algorithms.

The systematic issue – at least in the current stage of development of HFT – is that risks cannot be foreseen, as one trader explained:

> These systems blow out all the time – the problem with an automated system is that it's making – possibly thousands of decisions in the space of a second and you know my biggest fear is that there is some case that I haven't thought of or something falls through on the cracks in the program and all of a sudden it decides to buy the offer and sell the bids – you know, precede my risk … It is certainly possible that my algorithm could lose in the space of 10 seconds enough to put my entire firm under. It's an incredible amount of responsibility I bear.

When asking the traders about the stage of using artificial intelligence (AI) or neural networks to execute their trades, everyone replied that it will take years before AI enters the field of finance. The AI practices in trading that we have encountered were at a very experimental stage and very unlikely to make a profit.

Overall, then, we can see that there are certain limits to automation in HFT. Certainly, exchanges themselves, once orders are submitted, function fully automatically, and here the computational architecture of trading platforms as well as their infrastructural set-up becomes central and a subject of HFT influences and strategies. And certainly, the individual HFT trader encounters the market as a very complex set of signs. Yet each individual trader, and in larger trading offices groups of traders, don't leave their algorithms to roam freely in the market – they are constantly being monitored, withdrawn, reworked, and relaunched.

Borch, Hansen and Lange (2015) have already emphasized that the bodies of the traders do not become irrelevant. Traders '*calibrate their bodily rhythms to their algorithms* (and thereby *indirectly* to markets)', even though 'market rhythms have become increasingly out of sync with natural body rhythms' (Borch et al., 2015: 12; emphasis in original). The challenge concerns 'being algorithmically present in markets in order to be able to sense their rhythms' (p. 14). Besides dealing with basic bodily needs such as nutrition and sleep, what is of primary concern for the traders here is the question of cognition and knowledge: adjusting their bodily rhythms to market rhythms via their algorithms, and to be algorithmically present in the market is an attempt to read and know the market. It is primarily a cognitive problem, one only insufficiently

addressed through adjusting sleeping patterns or the intake of substances that enhance attention. Here traders deal precisely with the costs of consciousness. These dynamics also demonstrate that humans remain essential to the functioning of financial markets and specifically HFT, limiting automation.

The idea that automation is progressing steadily with ubiquitous computing is still widespread in media theory. Tero Karppi and Kate Crawford, for example, explore a recent 'hack crash' where markets responded to a Twitter hoax, in order to show how social media are 'connecting human communicative spaces to automated computational spaces in ways that are affectively contagious and highly volatile' (2016: 76). Karppi and Crawford note that 'human agents are increasingly marginalized while computational processes operate autonomously or semi-autonomously' (2016: 83). They are quite careful in explicating the precise technical links between social media and financial trade which caused the hack crash – namely, a specific social media data mining algorithm called Dataminr connected to trading algorithms; yet they also somewhat overstate the ways in which computational financial systems are integrated and function autonomously, thereby exacerbating contagion and volatility.

We would not second the assessment that humans become 'marginalized' here. Instead, our analysis shows how central humans remain even to HFT, where the costs of consciousness are perhaps most apparent but where these are precisely managed through a number of strategies, where algorithms are nearly always monitored, and where a number of containment strategies have been developed. Furthermore, HFT is in principle marked by its insulation from social media and other media external to markets. The specificity of HFT precisely revolves around its focus on the market and nothing but the market and its transactions. The case that Karppi and Crawford present is certainly not singular, in that, as they already point out, several data mining companies offer their services to financial traders; yet we can only speculate at this stage to what extent this kind of integration of computational systems is progressing.

HFT certainly doesn't support such speculation, since it shows how much algorithmic trade is focused on internal market logics, on spreads within and between financial markets. This is not an accidental feature of HFT but quite central, at least to its current technological set-up. As Jakob Arnoldi puts it:

> Leaving trading to 'naïve' algos may hence be a choice of economic necessity for high frequency traders. ... The current technological developments strongly indicate that strategic priority is granted to speed rather than sophisticated data processing. Crudely put, algos get faster but not smarter. (2016: 46)

One of our interviewees – the head of a HF-trading shop – explained that HFT algorithms need to be stupid due to the speed. There is a limit to how much information the algorithms can process without losing the necessary milliseconds they need to be profitable. Computational financial systems are marked by a trade-off between speed and smartness, simplicity and complexity of data, and the dominance of HFT for now ensures that the technological make-up of markets favours quick execution, not complex data. The prospects given for the field of HFT by the head of the HF-trading shop was that within a span of five years the algorithms might be both smart and fast, depending on how the infrastructure of the market will look then. If the competition for speed is regulated the competitive advantage may shift from speed to smartness.

Conclusion

HFT provides a quite special case of distributed cognition. First, the system itself is not really designed, as would be the case in neuromarketing, to address humans directly at an affective level. Rather, humans are simply part of a complex ecology characterized by distributed cognition. Second, traders are not passive parts of a system which was wholly designed by others, but traders actively co-construct financial markets through their algorithms. HFT therefore provides a specific view of the technological unconscious, in that the tasks and the costs of consciousness are immediately apparent – and critical to the success of HFT traders – and are constantly accounted for and negotiated. While the technological unconscious remains, traders are aware of its workings – for example in terms of the affective contagions that mark frequent flash crashes in financial markets – and guard themselves against it. HFT, perhaps counterintuitively, might help our understanding of how humans relate to the technological unconscious, through the design of nonconscious cognition in technical systems.

At a more abstract level, arguably the set-up of HFT is still marked by the automatisms of capital. But there is no coincidence here between technological and capitalist automaticity, as for example Terranova insinuates. The critique of HFT would therefore have to move to a different level of analysis, to understand how capital reproduces itself also through automatisms. Our argument shows that what is key in terms of thinking about automation and automatisms is not only to account for the costs of consciousness – which are often presumed to be so high as to warrant full automation – but to also take into account the costs of nonconscious cognition. It is the costs of nonconscious cognition – as in the unpredictable dynamics of financial markets, as well as the tendency of technical systems to break down – which in our case meant that HFT is not fully automated. Yet HFT might still only be a short blip in the history of finance capital married to technologies of automation.

With developments in artificial intelligence and machine learning – for example neural networks applied to financial trade – more sophisticated forms of automation are on the horizon (see e.g. Wordsworth, 2016; Lewis-Kraus, 2016).

The costs of consciousness that HFT traders account for in our case are only to do with protecting their investments. Yet much of the wider debate associated with the instability of financial markets and their regulation (e.g. Lenglet, 2011; Zook and Grote, 2017) has focused on the social risks associated with HFT and its reliance on financial trade in milliseconds falling into the cognitive gap. A further critical consideration of cognition in the human-machine ecology of HFT might therefore want to ask what other costs are incurred when cognitive systems are designed for the speedy circulation of finance capital, in the process usurping a lot of cognitive resources that could easily have been put to different ends. With Lanchester (2014), we can lament not only the waste of human and intellectual capacities, but also the technological waste of a nonconscious cognition which could be used so productively for other things more important to life.

Notes

1. Even though HF traders have developed sophisticated systems to detect the behaviour of their trading algorithms, it is technically impossible to trace such behaviour in real time, which means that the traders can only retrospectively understand the behaviour of their trading algorithms. HF traders often cannot account for the interactional order to which their algorithms respond (MacKenzie, 2016).
2. We do not claim that these activities make up the majority of HFT activity; they were simply the kinds of strategies that one of the authors observed while conducting her field work inside an HFT prop shop.
3. For a more elaborated account of the kind of companies observed and the issue of how access was obtained, please see Lange (2016).
4. We want to express our gratitude to one of the anonymous reviewers for highlighting this point so clearly.

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Armin Beverungen is lecturer (*Akademischer Rat*) in media studies at the University of Siegen. He studied organization studies and sociology in Lancaster and Cambridge, and completed his PhD in critical management studies at Leicester. He now works at the interstices of media, cultural and organization studies, currently on the phenomenon of algorithmic management. He is one of the founding editors of *spheres: Journal for Digital Cultures*. Most recently he has published, with Florian Sprenger, a special issue of *The Fibreculture Journal* on 'computing the city'.

Ann-Christina Lange is a scholar of the sociology of finance. She currently works at Innovation Centre Denmark in Tel Aviv and is affiliated to the ERC-funded project on algorithmic finance (ALGOFinance) at Copenhagen Business School. Her research focuses on high-frequency trading and its relation to the *new* social. Lange has been Assistant Professor at Copenhagen Business School, where she was a part of the 'Crowd Dynamics in Financial Markets' research project. She obtained her PhD in economic sociology from Goldsmiths, University of London.