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Hybrid materialities, power, and expertise in the era of general purpose technologies

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ABSTRACT
This article proposes three distinct perspectives on and approaches to the study of *hybridisation* across society, industries, and academia enabled by General Purpose Technologies like AI and blockchain. The term hybridisation is frequently invoked to describe and prescribe human-machine interaction and technological interoperability. Critically assessing processes of hybridisation through the perspectives of (1) materiality, (2) power and (3) expertise, we argue that the language of hybridity smoothens out frictions between human judgment, on the one hand, and automated decision-making, on the other, and that processes of hybridisation veil technology-induced epistemic and economic inequalities. In each of these perspectives, we draw on fieldwork conducted at different sites where general-purpose technologies are in play.

KEYWORDS
Domain expertise; hybridity; general purpose technologies; materialities; power

Introduction

In 2022, McKinsey estimated that, by 2024, 70 percent of all companies would be employing hybrid or multi-cloud management technologies, tools, and processes, and that more than 50 percent of user interactions would be augmented by AI-driven speech, written word, or computer-vision algorithms. Blockchain technologies that were initially associated with cryptocurrencies are now marketed as technologies with broader applications including supply chain tracking, digital identity management, and smart contracts and are being experimented with by actors as diverse as banks, land registries, and international organisations. In short, both in the aspirations of technology enthusiasts and

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in the array of applications that are being deployed, AI and blockchain are emerging as general purpose technologies.

The concept of general purpose technologies originates in innovation economics as an attempt to 'internalise' technology in economic theory and models; that is, to prevent technology from being an exogenous source of shocks and changes, and instead act as an endogenous resource able to respond to and incorporate economic trends. General purpose technologies denote technological innovations that are *pervasive* (they spread to most sectors), *constantly improving* (getting better and becoming cheaper over time), and *innovation-spawning* (producing positive externalities that facilitate the emergence of other innovations) (Bresnahan and Trajtenberg 1995, 1; Bresnahan 2010, 1185; Eloundou et al. 2023; Goldfarb, Taska, and Teodoridis 2023; Trajtenberg 2018). Taking seriously the claims offered by tech industries about the strides they have taken towards developing general purpose technologies, this article asks: what are the analytical, political and ethical implications inherent in these claims and how can theories on hybridity help us understand better these stakes?

Concerning AI, its consecration as a general purpose technology came from the paper co-authored by Stanford academics at the Institute for Human-Centered Artificial Intelligence (HAI) (Bommasani et al. 2022, 149), where the term 'foundation models' was also coined to denote Transformers, Diffusion Models and other large generative AI models. One of the key determinants of AI achieving full general-purpose status is the 'generative turn' that has traversed the fields of computer and data science in the past five to ten years. Up until the emergence of Generative Adversarial Networks, Diffusion Models, and Transformers, the main task that machine learning algorithms were entrusted with was *classification* (i.e. assigning hitherto unseen data to classes, labels or clusters learned from training data). Contrarily, general purpose technologies are multi-functional and 'task-agnostic', yet still apt at classification (Burkhardt and Rieder 2024, 2).

In artificial intelligence, the ambition of generality is not only embodied in the present combination of techno-optimism and 'doomerism' associated with the risks and opportunities of achieving Artificial General Intelligence (AGI): creating a general-purpose technology has always been the intended goal of the field of Machine Learning, insofar as it offers a set of tools to analyse patterns in any kind of data. In particular, Natural Language Processing has been striving to combine the capacity to produce human-like text across fields with the capacity to retain the depth of detail and expertise in specific fields and tasks such as translation, biomedical and juridical text summarisation (Chowdhary 2022). This is for instance the case in the recent development from Recurrent Neural Networks (Li et al. 2014) and Transfer Learning (Bengio 2011) to approaches focused on the pre-training of generalist transformer models (Vaswani et al. 2017) that are then fine-tuned through exposure to specific textual corpora (Devlin et al. 2019). Finally, the present 'pre-train, prompt and predict' paradigm (Liu et al. 2021) aims for a model to be trained 'once and for all' and subsequently adapted to 'downstream tasks' with the help of human-generated language in the form of prompts (T. Brown et al. 2020; Kojima et al. 2023; Radford et al. 2019).

To appreciate both the opportunities and risks associated with understanding general purpose technologies as hybrids, we need conceptual and methodological tools to gain more specificity and granularity in our analysis of the conditions under which hybridity takes place and its political economic consequences. Therefore, this article combines three distinct yet complementary perspectives on and approaches to the study of hybridisation that diverge from the narratives of abstract hybridity and instead shed light on the material politics (Law and Mol 2008) and translatory practices that enable software to engage with the world and enact new worlds. Viewing hybridisation through the lenses of (1) materiality, (2) power, and (3) expertise, we offer a conceptual framework that can help unpack the societal, ethical, and political implications of the increased use of general purpose technologies in business and society.

First, as infrastructure studies have shown (Furlong 2020, 2021; Howe et al. 2016), the materialities of software are stratified, retrofitted, and contingent. In keeping with this view, we shed light on the material tensions inherent in and through efforts to hybridise general purpose technologies. Second, hybridity is an increasingly important concept in political science analyses of digital power dynamics across market, state, and networked governance. We discuss how political hybridisation between algorithms and regulation engenders new forms of social ordering through general purpose technologies, for instance in blockchain-based land registries which promise to formalise land tenure but may exacerbate inequalities and alter existing property rights dynamics. Third, the notions of hybridisation and hybridity are often used to denote the emergence of areas of expertise that straddle pre-existing domains or to denote technologies that can operate in a domain-independent fashion. Through a critical reflection on attempts to hybridise machine learning and human judgment, we propose that tech-centric discourses on hybridisation may conceal the frictions emerging out of meetings between automated decision making and human expertise, and thus sideline the tensions, uncertainties, and qualms inherent in any introduction of new machinic procedures in professional domains of expertise.

Through these three distinct though invariably connected perspectives on hybridisation, we critically scrutinise the (infra)structural dependencies, power dynamics, and socio-material relations underpinning the pretence of hybridisation's 'seamlessness' which is often found in the more tech-centric visions of a machine – and data-driven society. Before we get to the three perspectives on hybridisation in the era of general purpose technologies, we first need to unpack and situate this article vis-à-vis scholarship on hybrids and hybridisation.

The return of hybridity

Originating in Latin to specifically denote the progeny of a tame sow and a wild boar, the term rapidly took hold in plant and animal taxonomy to refer to 'the offspring of a mating by any two unlike animals or plants' (Stross 1999, 254). From there, however, the concept was expanded further into the humanities and social sciences as 'a usefully slippery category, purposefully contested and deployed to claim change' (Hutnyk 2005, 80), be it in the form of post-modernity, post-colonial orders, globalisation, technological change, post-Cold War geopolitics, etc. One of the early adopters of the term in the social sciences, Homi Bhabha, used it in a way that was a precursor to the present-day critique of grand narratives based around dichotomies like human/non-human, nature/culture, and subject/object.

Postcolonial scholarship (Bhabha 2004; Kraidy 2002) has long emphasised that the idea of cultural hybridity can be mobilised both to challenge essentialist notions of culture and identity by highlighting their fluid and dynamic nature, but also to express hegemonic co-optation and co-modification of marginalised elements, raising questions of authenticity, representation, and ownership. Crucially, as Hall (2015, 202) argued, such processes of cultural 'transculturation' produce 'third vernacular spaces', 'marked by the fusion of cultural elements drawn from all originating cultures, but resulting in a configuration in which these elements, though never equal, could no longer be disaggregated or restored to their original forms, since they no longer exist in a "pure" state but have been permanently "translated"'. Pratt refers to these spaces of entanglement as 'contact zones', which are 'social spaces where disparate cultures meet, clash and grapple with each other often in highly asymmetrical relations of domination and subordination' (Pratt [1992] 2008, 7). From Hall's as well as Pratt's perspectives, hybridisation is thus a two-way struggle which is at the same time reciprocal and mutually constituting (Hall 2015).

Science and Technology Studies (STS) scholars have shown how intensely embodied hybridity is, constituting the very crux of the coexistence of bodies and technology (Oudshoorn 2016). Early STS and neo-materialist research brought to the fore the cyborg (Haraway 2016a) as the embodied hybrid which replicates within itself a microcosm of global networks, while also bearing the marks of the conflicts, frictions and broken promises of ideas of seamless and instantaneous connectivity (Strathern 1996). The cyborg takes the place of a person seen as a hybrid, where hybridity emerges from the way differences are sustained between the social relations that maintain it. At a collective level, the cyborg as a hybrid resonates with kinship studies (Haraway 2016b) echoing the ways that protocols of social interaction such as marriage and funeral payments serve to truncate the chains of claims that persons extend to each other and make the constitutive relationships of a person visible through these ceremonial performances (Rodima-Taylor 2013). Exchange thus builds a person as a composite of past transactions with diverse others.

The concept of hybridity has been extensively used in the analysis of power structures in political science and cognate disciplines to nuance dichotomised debates over power, legitimacy, and authority in complex mixes of market, state, and networked forms of formal and informal governance across public-private, local-global divides. Political hybrids are understood as 'social constructs that contain both scientific and political elements, often sufficiently intertwined to render separation a practical impossibility. They can include conceptual or material artifacts […], techniques or practices […], or organizations' (Miller 2001, 480; see also Kohli-Laven et al. 2011). Global Public Policy and International Relations concepts such as Abbott and Faude's (2022) 'hybrid institutional complexes', or Belmonte and Cerny's (2021) 'heterarchy' are attempts to embrace the growing complexity of activities associated with instabilities and crisis, such as the 2008 global financial crisis when '[f]aced with extraordinary complexity, including the need to manage the negative effects of fast-paced global markets, public authorities have increasingly shifted from centralised "command and control" to rely more on hybrid mixes of decentralized public and private regulation' (Porter 2009, 3). Hybrid powers and authorities are seen to be emerging out of a 'de-territorialization of publics and privates' (Sheller and Urry 2003, 108; Aoyama and Parthasarathy 2016). However, hybridity is also seen as a form of deterritorialization and reterritorialization of global, national, and local scales (Sassen 2008), producing 'hybrid spaces' of connectivity, mobility, and sociality (de Souza e Silva 2006, 2023). Hybridisation produces materially substantiated artefacts and technologies such as 'cars, information, communications, screens, [which] are all material worlds, hybrids of private and public life' (Sheller and Urry 2003, 113).

The STS and political science understanding of hybridity as the fundamental source of knowledge and power offers analytical traction to investigate present-day institutions and technologies. However, when hybridity is deployed 'with only a theoretical nod that belies its complexity and nuance', this concept encounters two opposite risks: That of reifying the 'pure breeds' from which the hybrid derives, on the one hand, and reifying a homogeneous 'hybrid condition', on the other (Hameiri and Jones 2018; Witschge et al. 2019). In the first instance, hybridity betrays the paradox that 'classification provides the basis for, as well as the justification of, the notion of hybridity and all things considered to be hybrids' (Stross 1999, 255). In the latter sense, the 'banal invocations of hybridity in which everything becomes equally and continuously intermixed' (Gilroy [2000] 2016, 275) deprives us of the very tools that hybridity promised in the first instance, namely an analytical sensitivity toward 'struggles, entanglements, patterns of occlusion and exclusion, [and] processes of reworking' (Brown 2018, 22). It allows us to counter 'boundary fetishism' in the social sciences and move away from either/or modes of thinking and towards 'not only, but also' alternatives, in a way that challenges essentialisms (Chadwick 2017). In other words, hybridity should enable us to complicate the ostensibly homogeneous, rather than simplify the evidently complex. Or, as Hutnyk (2005, 83) puts it, 'hybridity appears in several guises, it is important to look at what it achieves, what contexts its use might obscure, and what it leaves aside'.

Furthermore, underspecified accounts of hybridity risk obscuring the extent to which hybridity lacks uniform and unambiguously emancipatory politics, and is instead prone to co-option:

> To a bell hooks, Stuart Hall, Homi Bhabha or Edward Soja hybridity may be a significant means to create new kinds of radical political alliances by opening up and articulating to one another categories of race, class, and gender. To a John Huang, or to the Hong Kong investors in Vancouver of whom Mitchell writes, hybridity is a means to creating alliances ("bridges") between different states or national and diasporic capital, the consequence if not the intention of which is to erase those radical alliances. (Dirlik 1999, 113)

At stake, Mitchell (1997, 534) notes, is that 'without context, this "in-between" space risks becoming a mobile reactionary space, rather than a traveling site of resistance'. As scholars of hybridity in media studies, cultural studies, and STS have argued, the ambiguous politics of hybridity can be summarised in a set of tensions surrounding the act of *translation* and the hidden forms of power it entails. Hybridisation represents a hidden politics of seamless translation 'where no objects, spaces, or bodies are sacred in themselves; any component can be interfaced with any other if the proper standard, the proper code, can be constructed for processing signals in a common language' (Haraway 2016a, 163). For Hutnyk, hybridity *qua* the translation of one language, one logic, one culture, one institutional framework into another evokes the old and problematic subject positions of translators and ethnographers as 'interpreters' of cultures. These brokers 'between cultural forms' reside in a powerful in-between position where the translation is determined and conducted (Hutnyk 2005, 86). Conversely, in Hutnyk's opinion, Derrida encapsulated the tension inherent in translation as an act of hybridisation, when he wrote that '[i]n a sense, nothing is untranslatable; but in another sense, everything is untranslatable; translation is another name for the impossible' (Derrida 1998, 56–7). Hence 'language and cultural experience is idiomatic, and the idea of a perfect translation is misguided, and yet, attempts to translate are made, however quixotically' (Hutnyk 2005, 86). Translation and hybridity are thus both simultaneously impossible and omnipresent. The task of the social scientist then becomes to unpack the politics, political economy, and epistemology underpinning both.

In this article, we adopt the stance and arguments of critical approaches to hybridity such as those proposed by Bhabha, Hall, and Haraway, approaching hybridity as a metastable, contingent process of ontogenesis (De Boever et al. 2013; Simondon 2016, 2020) steeped in much deeper structures of language, materiality and power. Hybridisation as a process is a problematic project that is never fully actualised, because its full actualisation rests on the impossible presuppositions (a) that stable separate domains exist to begin with and (b) that material and technical bridges can be constructed between any domains to produce seamless translatability of problems, meanings, and solutions. At the same time, however, we approach hybridity as something that is open to multiple and contradictory political, epistemological, and material outcomes, especially when considering the emergence of general purpose technologies. The discourse around these technologies often actively promotes hybridity and hybridisation not as a deconstructive move towards an essentialist understanding of identities, knowledge domains, political institutions, but rather to apply specific rationalities to multiple tasks, problems, and questions in a way that is ostensibly 'agnostic' vis-à-vis expertise and context.

The following three sections of this paper unpack (1) the materialities underpinning and enabling hybridisation, (2) the power-relations that are shaping and being shaped by hybridisation, and (3) the effects hybridisation has on the exercise of judgment and the value ascribe to expertise in data-driven economies.

Materiality

The first perspective in hybridisation stems from the direct and indirect material instantiation of all forms of code (linguistic, professional, computational). In his study of crypto currency platforms, Çalişkan (2021, 129), for example, uses the dichotomy of tangible and intangible materialities to argue that representations of information (e.g. encryption algorithms and accounting standards in blockchain technologies) have embodied properties that make information amenable to be manipulated in different ways. In other areas of financial activity, the fortunes of cryptoasset miners are being decided on nanometre-scale efficiencies obtained when designing Application-Specific Integrated Circuits tailored around specific cryptographic algorithms (Rella 2024; Taylor 2013). However, this is by no means the only source of profits, as we shall discuss below.

Materiality is often seen as an obduracy of infrastructures in contrast to the 'immateriality' of software and information. We, however, propose to challenge this binary view. Amoore (2020, 54) describes how algorithmic systems 'modify themselves in and through their recursive relations to input data' in such a way that '[l]ittle pieces of past patterns enter a training dataset and teach the algorithm new things … on and on iteratively, recursively making future worlds'. Materiality actively contributes to this iterative making of future worlds that Amoore references. For example, in the case of Artificial Intelligence, Turing laureates Yann LeCun and Geoffrey Hinton (among others) have acknowledged the role that highly parallel hardware, such as Graphic Processing Units (GPUs, or graphic cards), have played in ushering in the hegemony of connectionism and neural network(s) in the AI community (Rella 2024). No one has stated the epistemological relevance of hardware more bluntly than LeCun (2019), who argues that.

> [h]ardware limitations influence research through action: computer scientists like to think that they think in abstract and hope that the hardware will one day support their idea, but their thinking is always limited by the hardware we have at our disposal.

The emergence of GPUs, and the massive computing parallelism they imply, prompted an epistemological turn in the Artificial Intelligence research community away from 'Good Old-Fashioned AI' (Pettersen 2019) based on sequential and deductive if–then-else steps and towards connectionism, a paradigm based on feature extraction and error reduction from matrix multiplication. Without a material infrastructure enabling simultaneous multiplication across several matrices, the connectionist turn would have remained limited, just like in the 1980s and the early 2000s.

Even the recent turn towards generative large language models (LLMs) is contingent on computational materiality: In the paper that introduced the Transformer, the neural network architecture on which LLMs like ChatGPT are based, one of the main concerns was that language machine learning had hitherto been constrained by analysis of texts as sequences, an exercise that is hard to parallelise. A Transformer, conversely, de-prioritises sequence in favour of attention, moving the focus to the co-occurrence of words and markers of logical and semantic connections between disparate terms:

> This inherently sequential nature precludes parallelization within training examples, which becomes critical at longer sequence lengths, as memory constraints limit batching across examples. […] The Transformer allows for significantly more parallelization and can reach a new state of the art in translation quality after being trained for as little as twelve hours on eight P100 GPUs. (Vaswani et al. 2017, 2)

Hence, materiality plays a crucial role in sustaining particular knowledge and truth claims over others. Hybridity is at the heart of the stacked combination of materiality and textuality that gives agency to digital media. As Straube explains it, 'each layer depends on the one below to function, and adds a dimension of abstraction that is in turn the base for the layer above'; it is 'a gradual translation, a transparent chain of deciphering calls through a series of descending levels of abstraction all the way 'down' to the material handling of bits' (Straube 2016, 6). In short, 'the hierarchy of layers is real', and the task of social inquiry is to stay as 'close to the metal' as possible (Rella 2024). The material properties of computational stacks are a specific instance of the material agencies of scientific instrumentations and (measurement) apparatuses. As Barad argues

> [t]he measurement apparatus is the condition of possibility for determinate meaning for the concept in question, as well as the condition of possibility for the existence of determinately bounded and propertied (sub)systems, one of which marks the other in the measurement of the property in question. (Barad 2007, 127)

This materiality also has emergent forms of agency beyond deliberate design. For example, the image recognition algorithm AlexNet, which ushered in the wave of Convolutional Neural Networks that have constituted the state of the art in all image recognition technologies for the past decade, was originally trained on two separate GPUs. To the authors' surprise, those GPUs seemed to have autonomously 'learnt' different features about the images they were exposed to: one learnt shapes, while the other learned colour patterns (Krizhevsky, Sutskever, and Hinton 2012, 6).

The role materiality plays in computation will only become more salient as the increasing energy costs of data centres might lead to offloading of computing power from the Cloud onto sensors, smartphones, and the Internet of Things (Munn 2020, 2022). However, the materiality of hardware is far from the only constraint or affordance that takes on more salience. In the case of cryptoasset miners, profitability and viability are not only determined by the materiality and energy consumption of hardware but are also heavily impacted by environmental and climate concerns like temperature, humidity, and energy availability. Another categorically different form of influence comes from regulatory codes of conduct and other forms of power being exerted over, and sometimes by, cryptoasset mining firms. It is to this form of hybrid power that we now turn.

Power

As previously discussed, power sits central in accounts of hybridity, especially in the context of its uptake in political science, human geography, humanities, international relations, development studies, postcolonial studies, and cognate disciplines. The hybridisation between algorithms and regulation configures a plurality of 'human-machine hybrids' which constitute '"cyborg" systems of social ordering' (Wu 2019, 2004), or the emergence of a *lex cryptographica* where law resembles code in the same way that code has turned into law (Wright and De Filippi 2015). In addition to the influence of the state, importantly, one must consider markets and marketisation as forces of hybridisation.

Hybridity is frequently articulated at the intersection between politics and technologies, and often in experimental configurations. We highlight two sites of encounter here, namely border control algorithms and land registry blockchains.

Aradau (2022) has for instance shown how experimentalism is paramount to the reorganisation of border zones through data technologies (Armeni 2015; Rodima-Taylor, Campbell-Verduyn, and Bernards 2024). Hybridity, here, is deeply implicated in questions of power and domination, producing and reproducing forms of imperial domination and colonisation (Abraham 2023; Rajão and Duque 2014). Research on the geopolitics of multiple information technologies has shown how the state brings sectors such as the Internet of Things, and semiconductors in general, under its purview while also forbidding knowledge transfer in sectors that have national security import. Amoore's work on the deep border also contributes to re-framing the question of political hybridity more accurately: '[I]t is not a question limited to what machine learning algorithms are making of society, but primarily one of how society comes to understand itself and its problems differently through the aperture of the algorithm' (Amoore 2021, 2). In place of wondering how the world looks when seen by the algorithm as opposed to the State, we might instead question how the State sees itself and others through the prism of the algorithm, and vice versa (Scott 1998).

The combination of multiple forms of code and materialities, as well as the specific ways in which they are combined in producing a distributed accounting and record keeping system, gave rise to an understanding that blockchain technologies are institutions in and of themselves: 'As socio-technological assemblages that coordinate and enforce property rights [which] seem to fulfil [the] definition of an institution, […] a body that sets forth rules that shape behavior and expectations' (Hayes 2019, 65). It is necessary to problematise the idea that technologies can become institutions directly and without friction, and, at the same time, that all technologies are the result of a plethora of agencies coming together to enable and disable specific patterns. For example, a blockchain is often understood as a distributed, time-stamped, append-only accounting ledger, simultaneously held by all users across a decentralised network which is updated and validated following a set of rules, instructions, and procedures – a 'consensus algorithm' or 'consensus mechanism'. From this definition, it is possible to conceive of a blockchain as not a mere software application, but as a network of machines plus code or, more accurately, as several global networks of machines that are prepared to talk to each other via different layers of protocols (Antonopoulos 2017).

Turning to the example of blockchain-based land registries, we can identify a difference between the multiple materialities that a blockchain utilises to produce new forms of power while changing and reproducing existing ones. For example, in Ghana a substantial percentage of rural land is unrecorded, and many city dwellers live in informal settlements (Rodima-Taylor 2021). Title registration is slow and costly, impeded by the lack of written title documents to solve overlapping ownership claims. But using digital registry platforms based on blockchain technologies could deepen inequalities by introducing new layers of intermediation and creating parallel institutions. New digital registries in Ghana would need to incorporate elements from other infrastructural modalities and temporalities defined by the histories and regional variety of the country's land tenure institutions as well as both colonial and neoliberal policy initiatives. The main goals of the blockchain land registry are to eliminate the pervasive informality of land rights and improve the functioning of land markets in the context of growing land scarcity and rural commercialisation. This also entails the conversion of customary rights – often unrecorded and with important group-based entitlements – into formal, private land rights. It is not certain, however, that this promise of land tenure formalisation through blockchain technology would resonate with most of the population as it would entail transformations in existing patterns of property access (Rodima-Taylor 2021).

This example highlights the importance of viewing blockchain registries specifically as part of a broader configuration that necessarily combines the electronic and digital spheres with paper deed registries, oral use claims and narratives about land ownership, and customary authorities overseeing land allocation. Blockchain databases often develop as a layer metaphorically above and in addition to existing knowledge and material networks, situated at much more than arm's length from traditional record-keeping devices. This results in the obscuring of the deeply complex layering of formal and informal, institutionalised and grassroots systems of property rights. As the Ghanaian case indicates, rather than serving as a panacea for fuzzy title registries, blockchain links into existing dilemmas surrounding property rights and the tensions between their individual and collective dimensions (Rodima-Taylor 2021; see also Rodima-Taylor and Campbell-Verduyn

2023). As they hybridise power, general purpose technologies do so by changing the ways of knowing that are deemed necessary of being governed, the tools of governing, and the rationality of the acts of government.

Expertise

The conceptual and empirical difficulties associated with a notion of hybridised expert practices and expert knowledge reverts to a notion developed in the fields of history and sociology of scientific knowledge in the late 1990s, namely that of trading zones. The concept of the trading zone pioneered by Galison (1996) and later adopted in STS and organisation studies assumes that when two bodies of expertise with a fundamental communication problem encounter each other, a two-dimensional relationship is established between them constituted from one dimension of knowledge and one of power. Trading zones tend to emerge when communication across expert groups and practices is problematic. Traditional approaches to trading zones emphasise the emergence of interlanguages or of interactional expertise to facilitate or enable communication. In practice, however, issues related to trading zones cannot easily be reduced to simply understanding the vocabulary and concepts of the other practice. In many instances we have observed, such understandings are asymmetric. Practitioners from one expert domain understand more of their collaborators' vocabulary and concepts than said collaborators do of theirs. To give a concrete example, software engineers seem to understand more of the financial vocabulary and concepts than finance professionals do of the engineering vocabulary. This unequal grounding has consequences for how the power relationship is configured and, consequently, for the outcome of such collaborations.

Epistemologically, the notions of hybridisation and hybridity are often used to denote the emergence of areas of expertise that crosscut pre-existing domains or, as often argued by the practitioners who participate in our fieldwork, to refer to technologies that can operate in a domain-independent fashion. Recent scholarship suggests that the concept of 'domain independence' (Ribes et al. 2019) is a data science ideal (McQuillan 2018) and an identity project (Avnoon 2021) more than it is an actual feature of the data science techniques applied in practice. Ethnographic studies of the use of machine learning techniques in different organisations thus show that domain expertise remains an important part of automated decision-making practices (Hansen and Souleles 2023). What is changing, however, are the ways in which machine learning projects activate domain expertise in organisational processes on a more fundamental level (Shestakofsky 2017; Van Den Broek, Sergeeva, and Huysman Vrije 2022). Rather than effacing domain expertise, AI algorithms should instead be included in 'new hybrid practices' which could be described as 'human – AI/ML hybrids' (Van Den Broek, Sergeeva, and Huysman Vrije 2022; see also, Jarrahi, Lutz, and Newlands 2022). As Aoyama and Parthasarathy (2016, 29) argue.

> [t]he hybrid domain is constituted by the constellation of actors and technologies that produce formulations of novel designs and solutions […] is not confined to a particular scale; rather, it coordinates knowledge and technologies globally, and leverages multiple national regulations.

For example, machine learning invokes the hybridisations between knowledge and expertise domains, as well as professional cultures. Ribes et al. (2019) show that the proliferation of data science methods – including machine learning in science, business, and society – articulates the problematic relationship between scientific domains and informational representation systems in a novel way. Computer science has, in fact, always tried to grapple with the tension between providing general purpose solutions to data handling and analysis, and the fact that knowledge is organised in distinct domains, albeit with permeable and shifting boundaries. Machine Learning, with a radical inductivist approach that seeks to identify patterns in data (irrespective of the domains to which said data might belong), promises full domain agnosticism and the capability to produce fully generalisable insight (cf. McQuillan 2018). These framings not only suggest the existence of multiple domains, but also provide a method of traversing domains through the construction of new hybrid intelligence. The ideal competence-profile in the data – and machine-driven economy is, in popular parlance, π-shaped with one leg representing in-depth domain knowledge and the other data science expertise (Ribes 2019, 526). While this ideal competence-composition is – to the extent that it exists – in high demand in a thoroughly datafied industry like finance, the practical reality of excelling or just merely staying on top of things in social systems as complex as the financial market makes commanding both sets of competencies difficult if not impossible (Hansen and Souleles 2023). The interplay between human domain knowledge and machinic processes and their influence on one another across the financial industry, shape organisational practices and spark new market opportunities, yet also produce uncertainties and dependencies that can become real risks and vulnerabilities.

Although these knowledge-hybridisation activities occur constantly within the financial industry – especially in areas like automated algorithmic trading and quantitative investment management – the idea that the introduction of machine-learning techniques creates frictionless and complete hybridity is undermined by actual observations in the field. On the contrary, the use of machine – and especially deep-learning in quantitative investment management, risk management, and algorithmic trading is often a highly constrained process influenced by norms such as simplicity-preference in modelling and the associated fear of losing the intuitive 'feel' for the model (Hansen 2020). The hybridity ideal is predicated on a smooth integration between professional practices and cultures, however studies of trading and investment management firms wielding machine – and deep-learning techniques suggest a more complex and conflictual organisational dynamic wherein multiple forms of expertise collide and then need to be communicated, negotiated, and sometimes forced into co-existence. These frictions are not easily ironed out during the harmonising process of hybridising forms of expertise, but are instead mitigated to a tolerable level through (a) micro-level creative bricolage modelling activities that enable the migration and translation of techniques from one domain to another (Hansen and Thylstrup 2023; MacKenzie and Pardo-Guerra 2014; MacKenzie and Spears 2014a, 2014b) as well as the more (b) meso-level organizational politics surrounding the composition of forms of expertise in individual firms and the alignment of technology-adoption and existing calculative cultures (Hansen 2021; Svetlova 2018). In the end, it boils down to a material politics (MacKenzie 2017) of emerging technology adoption and expertise in the financial industry that is intricate, less reconcilable, and indeed more political than the hybridity ideal suggests.

However, instituting an efficient, dynamic, and low-risk relationship between machinic classification and prediction capacities and a balanced composition of forms of expertise is still very much the aspiration in the financial industry which represents the data-driven economy writ large. The processual lens of hybridisation is thus not at odds with the organisational gaze in finance, yet the caveat here is that the 'invisible work' (Star and Strauss 1999) of facilitating productive co-existence between various forms of expertise and different machine-learning techniques should neither be overlooked nor underestimated. In this sense, studies of hybridity in the technology – and data-driven economy need a 'material politics inversion' on a par with Bowker and Star's call, voiced 30 years ago, for an 'infrastructural inversion' in studies of classificational technologies (Bowker 1994; Bowker and Star 1999). Bowker and Star saw the need for an infrastructural inversion that would orient the analytical focus towards the infrastructural underpinnings of technology that would otherwise 'fade into the woodwork (sometimes literally!)', thereby recognising 'the depths of interdependence of technical networks and standards, on the one hand, and the real work of politics and knowledge production on the other' (Bowker and Star 1999, 34). Similarly, underneath the somewhat abstract ideas of human-AI/ML hybrids lies the material politics that drive and determine the extent to which such hybridisation efforts materialise in practice.

Circling back to expertise in the financial domain, the debate about the value or possible depreciation of domain knowledge in machine-driven investment management and trading shows that financial domain expertise is not a stable or historically invariant category (Hansen and Souleles 2023). The friction between ML models and already existing codes of expertise further complicates the picture of clearly demarcated and neat human – ML hybrids. Hence, what constitutes expertise in an industry where financial economists are being crowded out by software developers, computer scientists, and data scientists is not as clear-cut as one might think. One example of a human – ML hybrid was observed by one of the authors in a quantitative risk management team of a large European bank. The team were tinkering with the well-known yet highly contested classic in financial risk management, the Value-at-Risk (VaR) model (Millo and MacKenzie 2009). Leveraging their High-Frequency Trading (HFT) clients' accumulated trade data, they experimented with an unsupervised deep learning model that should have the capacity to detect anomalous trading behaviour (Hansen 2021). Spotting risk indicators as quickly as possible would be crucial for firms that undertake a very high number of trades per day. The model, which had not been put into production at the time the fieldwork was conducted, created a dynamic interplay with its users and the data being handled to include domain expertise in a feedback loop to optimise the model's anomaly-detection accuracy. The local risk managers' role would be to assess model output (anomaly scores) and feed their assessment back into the next iteration of the model. The risk manager would receive the anomaly scores from the model and then contact the client if seemingly anomalous trading behaviour had been detected (considering that what might be scored as an anomaly by the model may not ultimately be one). The dual domain expertise of risk managers and clients would thus help improve the model's anomaly-detection accuracy. The anomaly-detection model used by the banks presents an illustrative example of a deliberate effort to ally the sheer data-processing power of machine learning with a human dimension consisting in the risk manager's domain expertise and the client's discretionary knowledge of specific trading strategies.

In this sense, the inclusion of forms of domain expertise in loops feeding back into the training of the actual machinic part of the model points to a version of human-AI/ML hybridisation that is more than merely an aspiration or abstract ideal. However, this attempt to unite automated anomaly-detection with the analogue exercise of expertise was far from frictionless, and the material politics of machine learning adoption in finance became evident in the internal struggles between different actors within the bank. Higher-ups initially would not sign off on the purchase of the expensive hardware needed for the quant risk team to develop and run the model at scale; and the quant risk team, for their part, kept the use of open-source software in the development process under wraps out of near-certainty that their superiors, the model validators, and their compliance department would never allow it. Whereas forms of expertise (those of the software developer, risk manager, and client) ought ostensibly to have complemented each other in this case, their co-existence and hybridisation potential are largely determined by the material politics unfolding in the increasingly overlapping domains of finance and data science.

In a similar vein, when it comes to blockchain, the expert practices of assessing machines' properties are often very different to the expert financial talk used in front of investors, and this relationship is never a purely cognitive one as a power component is always present. It is not possible to understand how finance professionals and software engineers collaborate within blockchain projects, for instance, without opening the black boxes of expert practice. For example, finance professionals can either develop *tokenomics* models (i.e. models of asset or rights issuance that will attract and incentivise participants) or business models for a startup. These models, however, are themselves bundles of different expert practices such as writing down sets of equations that express demand and supply equilibrium, and rationalisations thereof, and making coherent oral presentations to investors. Software engineers' expert practices are quite fundamentally different: They include, but are not limited to, writing code and transposing sets of equations from symbols on paper into machine code, as well as evaluating the properties of machines or monitoring block and node activity on the blockchain. It is hard to see how expert talk about the deflationary properties of a coin can be hybridised with monitoring node activity, which explains why collaborations between finance professionals and software engineers tend to maintain the separation between these practices. Epistemic hybridisation, therefore, is not seamless: In many if not most instances it is more akin to a relationship of 'working alone together' (Bruns 2013) in which two expert practices are deployed separately, but their respective outcomes are exchanged and gradually modified or adapted in parallel. The final product of such collaborations is not necessarily a single 'hybrid' output; it may be several outputs which are specific to each practice and produced in such a way that other practices can be oriented to them.

Conclusion

With the proliferation of general-purpose technologies such as blockchain and artificial intelligence, the somewhat hackneyed trope of the hybrid has resurfaced as a concept that lends itself well to explanations of the ways in which such technologies hybridise software and hardware, materiality and textuality. Moreover, these general-purpose technologies are changing perceptions of what human-machine interaction is and ought to be as well as challenging conventions about domain expertise and judgment. The notions of the hybrid, hybridity, and hybridisation seem to aptly capture practices of advanced technology use, yet also prescribe an ideal for how human strengths such as creative thinking and informed judgment calls are not supplanted by, but instead supplemented with capacity – and scale-superior technologies in seamless hybridisation. With this combination of descriptive and prescriptive aptitude, hybridity seems to appeal broadly as a conceptual means to explain modes of working, deciding, organising, and perhaps even being in tech-intensive societies.

However, in this article we have argued that despite its neat rhetorical sway, the language of hybridisation, in mainstream discourses of general-purpose technology applications, in fact conceals and smoothens the social, political and material frictions that subtend these bundled, layered, and stacked technologies. Specifically, we have discussed three areas where we see frictions ironed out in the language of hybridisation.

First, materiality matters. Software code's intangible materialities are stratified, retrofitted, and concrete-laden, far from the idealised vision of interconnected, interoperable networks. The material politics undergirding hybridisation shapes the rollout and configures the use of technologies – reinforcing some processes and practices and repressing others.

Second, hybridity emerges as a crucial concept in analyses of digital power structures and struggles. Political hybridisation occurs when algorithms intersect with regulation, shaping new forms of social order. Blockchain technologies exemplify this dynamic, acting as institutions that coordinate and enforce property rights. Yet, as we show, they also raise concerns about inequality and property dynamics. As political and, to some extent, politicised technologies, they are always also technologies of power that order, rank, and stratify.

Third, we explored how claims of domain agnosticism give way to the reality of more complex translations of expertise, often involving an enactment of imitative strategies and on-the-floor frictions across the algorithmic assemblages.

While attempts to reap the benefits of human-AI hybridisation (mainly cost-reduction- and operational efficiency-related) are made in many areas of business and society – from more mundane incorporations of AI that aim to enable and optimise a hybrid workforce to more complex human-AI hybrid trading and risk management systems used in algorithmic trading – these are not characterised by symbiotic hybridisation. Instead, they are underpinned by struggles over how to value domain expertise and human judgment, as well as distinct modes of relation that seemingly incongruent elements of hybrid arrangements can enter with each other while remaining suspended in multiplicity. Negotiations around the value of domain expertise are integral to these hybridisation efforts, which means that these frictions are inescapable as elements of the material politics of AI/ML adoption. We show that claims of domain agnostic tech – expressed in some computer and data science AI narratives – face the organizational and societal reality of much more complex translations of expertise, often involving an enactment of on-the-floor frictions across algorithmic assemblages.

We hope that the three-pronged frame of analysis as well as the observations shared in this article may be fruitful to future inquiries into hybridity in technological settings. While ideas about neat and frictionless human-machine hybridisation might reinforce techno-progressive imperatives and imaginaries, we believe that they can also incite reflexive discussions about the ways in which complex, multi-layered technologies are increasingly folded into existing bureaucratic, cultural, and institutionalised practices with more or less friction. Our call to caution is, then, that the notion of hybridisation should not be hijacked as a trojan horse for techno-progressivism. Instead, we encourage more empirical research that digs into frictions in human-AI hybridisation efforts and in hybrid general-purpose technologies. This entails front-staging the material politics, power struggles, and professional and ethical issues of advanced tech-adoption as always already ingrained in hybridisation and indeed not frictions that are smoothened by hybridisation.

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