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A stack made in heaven? Exploring AI-blockchain intersections and their implications for labour and value

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ABSTRACT

How have socio-technical practices in blockchain and artificial intelligence (AI) communities shaped one another and society more widely? This article explores the different and overlapping materialities, practices, spaces and places that the two most hyped technologies of the 21st century are impacting and evolving within. Employing the concept and analogy of "the stack", we show how Machine Learning (ML), and crypto-assets each developed separately and yet become deeply interconnected. In doing so, we pluralise the concept of the stack to trace how two techno-communities have cometh, collided and colluded (Three Cs) in ways that pose varying implications for labour and the enactment of value in hyper capitalist tech-driven economic geographies.

Introduction

"Is Crypto-AI Really a Match Made in Heaven?" asked a September 2023 headline in *Consensus Magazine* (Wilser, 2023b) exploring the progressive overlapping of the most hyped technologies of the 21st century, epitomised by frenzied financial speculation around the likes of "AI Cryptocurrencies" (Hooson & Pratt, 2024). Beyond profits potentials from price swings, little research has dug into deeper overlaps and divergences in the material objects and social practices underpinning this new heaven of techno-hype (Ante & Demir, 2023; Sandner et al., 2020). Moving beyond speculative inquiry into the heavens of speculation, this article asks: *how have material components, socio-technical practices, and cultures in blockchain and AI communities shaped one another and society more widely?*

Exploring this question, we provide an initial mapping of the plurality of spaces and places in which AI and blockchain technologies are co-evolving. Through anecdotes and vignettes from qualitative data collected in event ethnographies of industry expos (Moeran, 2011; Sandler & Thedvall, 2017; Høyer Leivestad & Nyqvist, 2017; Rella, 2021), online documents such as press releases, and interviews, we map coevolving intersections of blockchain and AI employing the concept of the stack, which has helped trace topologies of power nested in the materiality of software code (Bratton, 2016). We also build on critiques of the stack as being too metaphorical, singular and removed from spatialities (Hansen, 2024; Straube, 2016) by "grounding" fast changing developments in four layers of each technologies' stack - Hardware, Algorithm, Application, and User. Fewer than the seven dimensions of heaven, our four stack layers echo those of the Internet Protocol (IP) stack and are adapted for analysing the specific material components, socio-technical practices, and cultures considered here.

AI and blockchain have *come* about, *collided* and *colluded* in ways that have important yet under considered implications for labour and the enactment of value in hyper capitalist tech-driven economic geographies. We develop this central contention in four sections. First, we lay out the *hardware*, *application, algorithm,* and *user* layers of our conceptualisation of stacks building on both recent applications and critiques of the concept. Second, we trace the *coming* of ML and blockchain stacks, specifying how activities at each of their four layers shape the labour of their users and their value in broader society. Third, we illustrate the *collisions* as well as the *collusions* between AI and blockchain stacks, interactions made possible by, while also constraining, value and forms of human and machinic labour. Fourth, we summarise the main implications revealed from the 3Cs identified in our mapping of socio-technical stacks: the repositioning traditionally human attributes such as creativity and individuality within new spatial configurations and value extraction methodologies. This finding leads us to conclude with a call for further research less into speculative heavens than into the evolving conditions of labour and value in an era of widespread hybridization (Rella et al., 2024) and blurring distinctions between human practices and non-human objects (Dourish, 2017).

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(Un)Settling the stack

This section lays out the analytic utility and our conceptualisation of stacks as well as their main "layers". We trace conceptual refinements emphasising the material and social relations underpinning a *plurality* of stacks.

Originating in the design of kitchenware (Çalışkan, 2021), stacks became a cornerstone concept in computer engineering, initially as the physical representation of software instructions arranged in "last-in, first-out" piles (Solomon, 2013), and then as hierarchical layers of digital communication protocols, the most famous of which is the Transmission Control Protocol – Internet Protocol (TCP-IP) (Hunt & Thompson, 1998). Popularised subsequently in the social sciences by Benjamin Bratton, The Stack – capital "S" – became widely cited in geography as a diagram for multiple forms of platform power specifically as a new articulation of territoriality and technologies of power over territory. According to Bratton (2016), Stack-inspired analysis "starts with the technologies themselves" in tracing the emergence, across narrowly defined technological domains, of what he calls an "accidental megastructure" super-imposed upon (post)Westphalian political geographies of sovereign states. Bratton's Stack became topological metaphor and analytical device to explain the forms of social power nested in the materiality of software code as:

> *Users*, human or nonhuman, are cohered in relation to *Interface*, which provides synthetic total images of the *Addresses*, landscapes and networks of the whole, from the physical and virtual envelopes of the *City* to the geographic archipelago of the *Cloud*, and the autophagic consumption of *Earth*'s minerals, electrons, and climates that power all the above. (Bratton, 2016, p. 12)

Critiques have sparked useful refinements of the Stack. Geographer Till Straube (2016) advances a notion of the stack – lowercase – that is more closely connected with the materialities underpinning specific technologies and the wider infrastructures facilitating their (re-)design and (re-)use. Straube argues that "the various articulations of relational systems making up the layers found within digital infrastructures should be taken seriously as spaces proper" (Straube, 2016, p. 6). Hence, "[r]ather than imposing spatial metaphors onto digital technologies, the goal should be to engage with and draw out specific spatial articulations encountered within the various inscriptions of digital devices" (Straube, 2016, p. 7). Straube's conception enables generalisation about stacks without losing adherence to the materiality of the technologies that their layers are grounded in. This grounding matters, literally, and informs our selection of AI-blockchain stack layers as not just a random *list* or *pile* but elements in – functional, hierarchical, etc – relationships with other materials and people. As Straube (2016) argues about the stack:

> Each of its layers is an articulation of a specific logic […] 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. […] The hierarchy of layers is real; 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, p. 6)

This first conceptual specification is echoed in the economic sociology literature on platformisation and economisation. Çalışkan (2021, p. 133) deploys the concept of stack economisation to define the "stacked nature of the multiplicity of economisation practices that either draw on or make possible each other as architectures or infrastructures". Here Bratton's Stack as a "megastructure" is critiqued for its totality and disconnected from any individual nodal point or a clearly segregated space, be it virtual of physical. Çalışkan's contribution is also valuable to our analysis of AI-blockchain stacks because it emphasises the need for the stack to be considered as fundamentally *material* arrangements of economic relations that result in multiple, simultaneous, and diverse practices predicated on economisation and other on non-market relations. The materiality of the stack is similarly emphasised by Mackenzie, Çalışkan and Rommerskirchen's (2023) who reveal behavioural data tracking and ad trading as undergirded by AdTech hardware in investigating stack economisation in the advertising industry. Their sensitivity to the materiality of stacks helps emphasise the *when* and *where* computation becomes performed as well as *by whom* or *by what*. This also allows for the kind of vertical and horizontal comparisons of stacks across spaces and across industries recommended by Spears & Hansen (2023) and operationalised by MacKenzie et al. in analysing material political economic constraints, incentives and affordances in AdTech and High Frequency Trading.

A second conceptual refinement informing our approach to stacks and their layers is Hansen and Thylstrup's (2023, p. 2) re-definition of the stack as "[t]he layered components in digital information systems that create a certain hierarchical organisation as well as dependencies and interactions of the respective elements in […] 'the functioning of an infrastructural technology'". Hansen and Thylstrup add further emphasis on the *fluidity* of stacks and the infrastructural dependencies they engender. What they term "stack bricolage" involves a "creative, ad hoc re-use of existing resources", rather than any "grand plan" (s 2023, p. 2). In foregrounding the forms of labour that stacks often hide within them, "stack inversion" developed by Hansen (2024, p. 6) provides a useful approach to unpick "the processes and practices that make complex computational systems tick". Hansen identifies backgrounded activities at four layers of machine learning and quant trading stacks by inverting "the work and negotiations taking place around the adoption and use of complex computational systems and […] toward the variegated and entangled elements of those systems" (Hansen, 2024, p. 4). Stacks produce not only vertical dependencies but also horizontal frictions, as in the expertise and training of the computer engineer and that of the quant trader that can be at odds, further underscoring the need for studying stacks vertically and horizontally (Spears and Hansen, 2023).

In emphasising plurality, materiality and fluidity, conceptual refinements of stacks helps point to relevant stack *layers* to be compared in any given setting. Put simply, there are different criteria in selecting stack layers. More metaphorical uses of the capitalised and singular Stack such as Bratton's are more concerned with layers as political and economic formations. Meanwhile, metonymic approaches like Straube and Hansen stay close to the materiality and spatiality of technology (Cf. Terranova, 2017). Çalışkan as well as Mackenzie et al. (2023) equally stress materiality as core to the layering of practices in stacks that are *part of* but not simply equated with wider infrastructures of finance, production and labour in global economies.

Our mapping of AI and blockchain stacks examines layers that are most similar to Hansen's. Hansen (2014, p. 16) identifies: "a data-collection layer (sources data), a feature-generation layer (makes the data machine processable), an alpha-producing layer (discovers potential market edge), and an execution layer (designed to exploit the discovered edge)" (Hansen, 2024, p. 16). We deviate slightly by analysing AI and blockchain stacks as consisting of first, a *hardware* layer, where instructions are executed as electric impulses on specific microchips and server racks. Second, our *algorithm* layer includes the data that are ingested by algorithms and the transformations that such data is subjected to – e.g. feature extraction and analysis in neural networks, as well as encryption in blockchains. Third, our *application* layer, much like the TCP-IP definition of the term, is "the conduit through which end-users and applications communicate with network services" (Network Encyclopedia, 2021), such as a user sending a payment through a blockchain or running facial recognition on a picture. Lastly, our *user* layer is where the stack directly impacts individuals, be they humans or machines – e.g. a bitcoin mining rig, a content moderator training GPT, a person whose eye is being scanned to establish their "proof of personhood", or an individual prompting a diffusion model to generate a picture of a cat.

Our four layer diagram (Fig. 1 below) closely resembles the original TCP-IP four-layered architecture of Network Access, Internet, Transfer, and Application layer protocols. While widening some layers and

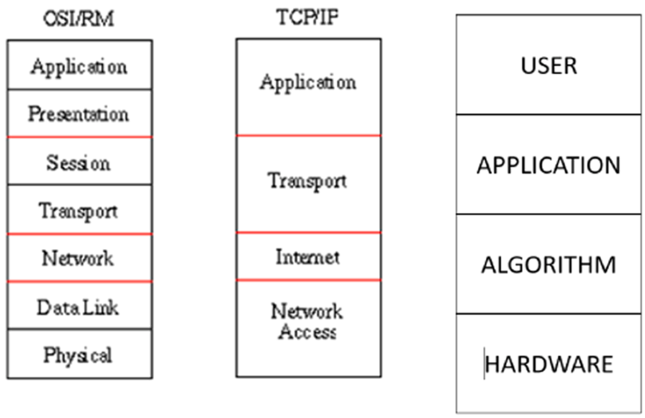

Fig. 1. Open System Interconnection (OSI) Reference Model Stack, TCP/IP Stack, and our version of the AI-blockchain stack. Source: Frystyk (1994) and authors' own.

narrowing others, we retain the hierarchical nature of TCP-IP stack in order to specify how the materiality of a layer influences that of another. For instance, Network Access, concerned as it is with "how data is physically sent through the network, including how bits are electrically or optically signaled by hardware devices that interface directly with a network medium" (Omnisecu, n.d.), maps out quite neatly onto our own Hardware layer. The Transfer and Internet layers merge into our Algorithm layer since the former are concerned with how messages are chopped into packets that can just as easily contain fragments of a picture to be classified by a neural network, or as the content of a block to be added to a blockchain. We do not have a separate Data layer since they circulate on all layers rather than live on a separate layer, in "raw" form (Gitelman, 2013): data are inseparable to the algorithmic process that makes them machine readable. Furthermore, the data fed into each algorithm is algorithm-specific – transactions in blockchain, feature vectors in neural nets, etc. – hence such a separation would have created unnecessary complexity and hindered comparison. Lastly, our User layer enables to see how the Application layer is interacted with by "real-world" Users, and how they themselves are remade through their interactions with the other layers.

Each of our stack layers has its own peculiar spatialities whose unpacking through "stack inversion" (Hansen, 2024) contributes more widely to strands of economic geography scholarship. First, phenomena at the Hardware layer that we identify such as the assembling of distributed datacentres or the migration of hardware from crypto mining to AI training can contribute to the study of spatialities of cloud computing infrastructures and ongoing attempts at abstracting away from, as well as assetisation of hardware through software such as Narayan's (2022) analysis of flexible cloud arrangements, Amoore's (2018) analysis of the spatialities of the cloud, Kinsley's (2014) and Pickren's (2018) analysis of the materialities of the cloud, or Wyeth et al. (2023)'s analysis of the spatialities of crypto mining. Second, the algorithm layer helps "algorithm talk" (Amoore 2020) from becoming generic and abstract, and instead unpacking the different affordances of different software architectures in producing specific political economies of data, both "real" and synthetic (Zook & Spangler, 2023). Third, the application layer is rich with geographical explorations of the platform political economy determined by specific applications, firms, and industries (Haberly et al., 2019; Langley & Leyshon, 2016, 2020). Fourth, examining the user layer opens up contributions to literature on the economic geography of labour in digital environments and platforms (Graham & Ferrari, 2022; Richardson, 2018). Beyond individual layers, our vertical analysis of stacks and of AI and blockchain stacks in horizontal comparison resonates not only with Spears & Hansen (2023) but also with layered understandings of cloud geographies such as those outlined by Furlong (2020). Our mapping of different technologies across spaces in interaction with each other extend ongoing efforts to adapt production network frameworks to the production and circulation of data, algorithmic predictions, software assets, etc (Ferrari, 2023). In sum, our transversal mapping of stack layers resonates with invitations to investigate technologies, actors, and industries such as the "FinTech Cube" conceptualised by Lai and Samers (2021).

Our four layered stack allows for analytical mapping of specific and varied sociotechnical formations. The *hardware* level emphasises the materiality through which value can extracted, as well as the material limits of extraction and extractivism imposed by hardware architectures. It is where the material political economy of semiconductors, microchips, devices and server comes to the fore. The *algorithm* layer exposes different algorithmic orientations towards data and space between privacy and surveillance, decentralisation and centralisation. It is where political economies and ethicopolitical implications of data and computation get foreground. The *application* layer is concerned with platform and assetisation of algorithmic outputs, such as cryptoassets, algorithmically generated images, prompts, etc. It is where platforms and their business models are shown to play out, such as when the data elaborated by one algorithmic architecture, or another are put to use to end users as well as monetised upon to generate network effects and revenue streams. Last but not least, the *User* layer is where connections between value and the labour of human *and* non-human most clearly comes together to reveal what we argue are practical blurring of boundaries in digital networks. What no longer becomes tenable are artificial separations between the labour of content moderators, GPT trainers and crypto miners, as well as the value of LLMs, crypto-assets and unique synthetic personas.

We now proceed to our mapping of the four layers of blockchain and AI stacks structured by what we call the 3Cs analysing how these stacks have *come* about before turning to how they have *collided* and how they have *colluded*. While we recognise overlaps in each of these 3Cs entail that they are not as discrete in practice, our tripartite separation helps draw out implications for value and labour that can be missed when bundling together their initial development (*coming*) with partnerships for profit (*collusions*) and wider socio-economic tensions (*collisions*).

AI arrives and crypto-cometh in separate stacks

Blockchain's stack can be traced back to software applications developed since the 1970s (Narayanan & Clark, 2017). This stack however formally materialised as the Bitcoin protocol emerged in 2009 and other cryptoassets[1] emerged thereafter as digital representations of value operating in distributed, time-stamped, append-only accounting ledgers that are simultaneously held by all users across a decentralised network – the blockchain – which is updated and validated following a set of rules, instructions and procedures called a "consensus algorithm" or "consensus mechanism"[2]; (Rella, 2020). The *hardware* layer of this stack consists of mining rigs and other forms of validating computing equipment that store the agreed-upon version of the ledger and run the cryptographic functions necessary to validate new blocks. The *algorithm* layer involves various sets of instructions encoded into blockchain protocols for determining who gets to decide on new blocks, as well as the "monetary policy" of the asset: how many new units are minted or mined, how they are distributed, and so on. The *application layer* is where blockchain-based assets are deployed, either as representations of

[1] The term cryptocurrency became common in the early 2010s until terms like coins and tokens were recognised to function less like currencies than stores of value.

[2] Proof of Work and Proof of Stake are the two largest consensus algorithm families. PoW requires validators, called miners, to perform algorithmic work in order to qualify to validate the next transaction block. PoS, conversely, rewards cryptoasset holders based on the stake they have in the cryptoasset, as well as how long they held it.

monetary value like Bitcoin, or as a digitalised version of equity like real estate, or used as a digital cadastral register for land. The *user* layer is where humans and non-humans initiate transactions and transfer value on the blockchain, in the form of "tokenised" representations of value.

The ML stack's cometh was far earlier than blockchain's: in the 1940s research on the neuron by McCulloch and Pitts (1943) and their representation in computational form by Rosenblatt (1958). The *hardware layer* grew in scale while also shrinking in physical dimensions from the original 15-meter-long computers. Cloud servers powered by highly-parallel hardware such as NVIDIA Graphic Processing Units (GPUs) or Google Tensor Processing Units (TPUs) have come to execute vast amounts of operations simultaneously (Rella, 2023). While changing quite dramatically over time, from symbolic AI and expert systems to present-day neural networks and reinforcement learning, neural networks and connectionist AI are now widespread. The *algorithm layer* involves analysis of patterns retrieved in large datasets or generating new data based on those patterns. For instance, neural nets are a series of mathematical functions (neurons) that perform operations on data organised as feature vectors and that are organised in layers, each of which has specific functions. The *application layer* is where use cases evolve and the valuation and platformisation of data happens, for example when AI art and prompts are commercialised. The *user* level has AI agents born out of a combination of neural networks and reinforcement learning algorithms. Here the insights extracted from patterns of data are actioned by algorithms, for example when a robot decides on how to navigate a room. Multiple intersections for what counts as human and non-human are at stake here, such as decisions made by border officers based on the output of a ML algorithm flagging travellers as security risks.

Colliding and colluding stacks

Collisions at the intersections of ML and blockchain stacks emerged early in 2010s. We examine here three encounters at different layers of AI and blockchain stacks that have revealed less-than-honest or less-than-legal *collusions* as well as subsequent tensions that have arisen in and across uneven/disparate geographies of value and labour. Our use of the term collusion is purposely intended to be provocatory. The textbook meaning "to work together secretly especially in order to do something illegal or dishonest",[3] helps point towards illicit activities occurring in each ML and blockchain stacks separately[4] becoming mutually reinforcing through combinations of the two technologies. However, we want for "collusion" not to mean solely illicit uses of either technologies or their combination, but rather to mean in a wider sense that the two technologies are combined in a way that magnify each other's capacities for the extraction of value and labour.

Hard(ware) encounters

Cryptoassets that deploy Proof of Work algorithms like Bitcoin require a specific cryptographic process to be generated, called mining. Bitcoin deploys an algorithm called SHA-256 to encrypt the value of the blocks to be appended in the blockchain, and miners add an arbitrary value – called nonce – to the content of a block so that the encrypted value is lower than the current difficulty threshold. The algorithm is quite complex internally and the difficulty is adjusted very frequently, hence larger and larger mining farms using more and more efficient Application Specific Integrated Circuits (ASICs) have been mobilised seeking efficiencies in terms of time, energy, cooling, and taxes. A complex global geography of datacentres and shell companies has emerged (Wyeth et al., 2023). When the second largest blockchain, Ethereum, in 2022 abandoned mining altogether in favour of Proof of Stake (PoS), all the GPUs dedicated to Ethereum mining became worthless overnight. In 2023 both former Ethereum miners and current Bitcoin miners scrambled for new sources of revenue, also due to the need to maintain value during the "crypto-winter," a period of stagnant cryptocurrency prices following the peak in 2020–1 (Gkritsi, 2023a; Wilser, 2023a).

Following this statement, crypto mining firms such as Iris Energy diversified into high-performance computing (HPC) as energy demand from AI firms boomed "insatiably" (Plan, 2024). Iris Energy had a booth at the 2023 AI Hardware Expo that one of the authors attended in Santa Clara, California. This presence reflected the wider crypto mining industry's attempt at diversification into the AI accelerator industry between 2021 and 3. Cross-stack collaborations were promoted as entailing a so-called different "risk appetite" than the well-known rollercoaster price swings of cryptoasset markets (Hut 8, 2021, p. 8; 2022; HIVE Digital, 2023; Wilser, 2023a). Yet this attempt at diversification was far from entirely honest about the persistent risks involved with linking computer hardware from one stack whose speculative tendencies were trending downwards to another stack whose speculative possibilities were on the upwards.

Parallels with previous crypto-asset boom were both superficial and deeper. In the former case, mining firms like Applied Blockchain changed their name into Applied Digital as similar acts of rebranding were welcomed with soaring stock prices and valuations in a process reminiscent of when companies could see their valuation skyrocket just by adding blockchain to it (Applied Blockchain Inc., 2022; Gkritsi, 2023b; Cheng, 2017). In the latter case, mining hardware was "rented out" to so-called "distributed datacentres, which often operate orchestrated computing (Hut 8, 2022) through which "powerful GPUs [and] general-purpose compute resources are commoditised" (IO.NET, n.d.-a). These distributed datacentres allow miners to add their unused GPUs to the network, which are then rented to people who want to train or deploy ML models without relying on in-house hardware or costly cloud providers players like AWS (Qblocks, n.d.). A host of different rental arrangements emerged in which some companies use standardised pricing schemes denominated in dollars that pay by the hour of GPU use, while others create dynamic, "interruptible" arrangement that allow clients to bid for computing power (VAST.AI., n.d.), and other companies go so far as to incorporate crypto as a reward and pricing mechanism. New York City-based IO.NET, for example, uses tokens to "align network incentives" between "IO Workers (GPU providers) [and] AI Engineers (AI and ML workload deployment teams)" and, through "[g]amification mechanics on both the demand and supply side [it] establishes a clear decentralised pricing for a device based on its hardware and network performance via a decentralised and transparent pricing oracle" (IO.NET, n.d.-a). Los Angeles' Vast AI accepts crypto payments through crypto-exchanges Coinbase and crypto.com, but is yet to have a native token to manage incentives (VAST.AI., n.d.).

In the switch to LLM training and so-called "stable" rent income, AI and blockchain stacks often colluded by downplaying the persistently speculative potential of such collaborations. Mining GPUs are all about computing speed, trying to calculate the encrypted hashes of as many candidate blocks as possible, and hoping that one will be first and accrue rewards by making it on to the blockchain. AI training meanwhile is much more memory-hungry: ML models have a large number of parameters that need to be stored in memory in order to be updated based on the data that a given algorithm is fed (Lanz, 2023). When AI models are deployed at so-called inference time – when we for instance prompt GPT to generate a piece of text – users want low latency. Traditional datacentres, and the GPUs they store, provide low latency and high-bandwidth connectivity, whereas "crypto GPU miners may have poor internet connectivity, as the proof-of-work algorithms they use do not require much bandwidth" (IO.NET, n.d.-b). Hence, pivoting to AI without updating the hardware to top-tier chips like NVIDIA's V100,

[3] https://www.merriam-webster.com/thesaurus/collude

[4] For example, copyright theft and training LLMs on unauthorised materials as well as mining and use of crypto-assets for money laundering and terrorism finance.

A100 and H100 chips can save money but might also not provide sizeable returns. Conversely, buying these chips can be prohibitively expensive: Iris Energy's 2023 purchase of 248 NVIDIA's latest generation AI H100 GPUs totalled $10 million (Iris Energy Limited, 2023b). Mining companies, like HIVE, have tried to hedge this risk by buying "multi-use Nvidia cards instead of Ethereum-specific ones which are slightly more efficient" (HIVE Digital, 2023). Speed is also about connectivity: after having approached miners to crypto miners to provide high-performance computing equipment, IO.NET appeared to have encountered issues with miners' apparent lack of high-speed connectivity. Online and streaming gamers became more appealing, yet not necessarily less volatile, markets for firms like IO.NET to source their GPUs. Collusion in such encounters at this layer of stack interactions involved a shared lack of transparency regarding the persistent possibilities for profit loss and volatility potential.

AI-blockchain stacks' collusions may further exacerbate collisions at their hardware layers stemming from how crypto-miners were all of a sudden potentially responsible for bias, exclusion, toxic or illegal synthetic content in running AI models. As Iris Energy put it:

> [A miner's] investments in further developing and offering HPC solutions [...] may result in new or enhanced governmental or regulatory scrutiny, litigation, confidentiality or security risks, ethical concerns, or other complications that could adversely affect our business, reputation, results of operations or financial condition (Iris Energy Limited, 2023a, p. 12).

The persistent volatility of crypto valuations and hardware-level collusions between stacks could aggravate these new legal liabilities for crypto-miners pivoting to AI, which the European Commission's European Blockchain Observatory and Forum (EUBOF, 2024) urged further regulation thereof. Our mapping of these tensions lays ground for further research to investigate collisions emanating from such collusions as stack relations evolve at hardware and other layers we proceed to examine.

Soft(ware) encounters at the algorithm layer

In 2021, the Society for Worldwide Interbank Financial Telecommunication (SWIFT) ran its yearly hackathon on the theme of synthetic data for anomaly detection in payments. Among the winners, was the team of JP Morgan's Blockchain division, Onyx. Their proposal was for a new decentralised ML framework, FedSyn, which combined blockchain technologies, Generative Adversarial Networks (GANs), and so-called Federated Learning – which is a class of ML algorithms where multiple models are deployed on computers near where the data are collected rather than in the cloud. FedSyn anonymises users' financial data while still being able to train AI models on them, all with the aim to detect fraudulent and illegal transactions. Financial institution using FedSyn can own a "data pool" of their customers and their transactions. If they intend to scan those transactions for suspicious activities, in traditional Machine Learning they would have to share with other financial institutions the underlying data to train it. Conversely, in FedSyn, each bank trains a generative AI model on their local data, and uses this model to generate new synthetic data that are then shared with the rest of the FedSyn network. These synthetic data "resemble" the original data that the model was trained on, but they cannot be traced back to actually existing individuals, hence ostensibly preserving privacy (Jacobsen, 2023, 2024). Another American company less connected to finance and blockchain, Hewlett Packard (HP) filed a series of patents for "Swarm Learning". Similar to FedSyn, Swarm Learning manages a global ML model across a network of devices, each of which contribute to the global training of the model with some data and associated weight updates (Manamohan, Garg, Shastry, et al., 2021).

Seemingly productive collaborations of AI and blockchain algorithms involved less socially productive collusions as ethico-political "derisking" issues were downplayed in and across multiple data practices. Synthetic data used in blockchain-AI hybrid projects like FedSyn tried to evacuate ethico-political questions around data and privacy protection by avoiding data sharing and instead sharing "not a trace, copy, or recording, but the product of a computational process" (Steinhoff, 2022, p. 5). Here, "synthetic data enable the de-risking of algorithms, generating a risk-free zone in which algorithmic systems can operate" (Jacobsen, 2023, p. 6). The dispersion of the ML model into multiple partial models, held by FedSyn participants, explodes the relationships between the individual from the dataset representing or standing in for a general population and its feature space. However, compliance and non-compliance, or suspicion around specific transactions may not be calculated around specific behaviours, but through similarity and proximity with behaviour patterns of unrelated others, including datapoints not related to *any* individuals and instead being generated by a Generative Adversarial Network. In short, the algorithmic encounter between stacks downplayed ethical questions, such as: "What is a non-compliant person and how would someone know if they are to be classified as non-complaint? With the advent of machine learning algorithms that generate clusters from data (underspecified in advance), the non-compliant person is whomsoever the clustering model decides they may be" (Amoore, 2021, p. 6). Further collusions and collisions also occurred as stacks met at the application layer.

Application layer: platform political economies of AI and AI tokens

To recall, the application layer is where inputs and outputs of both AI and blockchains are assembled in use-case-specific platforms and their associated business models and political economies (Langley & Leyshon, 2020). The intersection between stacks at the application layer rearticulates collusions between AI and blockchain by further downplaying collisions and tension between data abundance of generative AI algorithms and the scarcity that gives cryptoassets their value. On the one hand, the emergence of generative AI seems to render futile any attempt at algorithmically producing scarcity. On the other hand, the production of scarcity with ostensibly unique and unrepeatable works of art in non-fungible tokens (NFTs) points to not-entirely honest collusions in making scarce the nearly unlimited spaces of digital worlds.

A cottage industry of projects leveraging blockchain-based NFTs for AI-generated art emerged in the early 2020 s. Alethea.ai, for example, was an art NFT marketplace already active before generative AI became the multi-billion industry. In 2021 they sold Alice, ostensibly the first iNFT on the prestigious auction house Sotheby's for $478,800 (Alice and Alethea, 2021). Alice was an animated video avatar powered by Large Language Model AI agent with a specific persona and personality derived from a set of prompts with which the large language model is fine-tuned and a specific set of desired.

Alice illustrates collusions at the application layer of AI and that of blockchain between the agent, the input and the output. First, Alice is an AI agent with their own persona, and it is that persona who is monetised upon in the act of selling Alice at an auction: as Sotheby's described it, "[Alice] offers a tantalising glimmer of a future in which neural net language models will sit on top of decentralised blockchains, allowing true and trustless ownership of intelligent characters" (Alice and Alethea, 2021). Second, Alice's persona is the result of a set of natural language prompts, which in turn can become very granular and unique, and hence directly monetised. A spree of "prompt engineering" hirings in multiple AI companies, created job descriptions tasked with testing how AI outputs change in response to specific inputs and instructions (Harwell, 2023). Over a short period of time, different websites started monetising prompts by allowing people to publish their prompts and other parameters they used to generate some pictures, so that other people could use them to generate similar pictures or texts. Stimulated by a court decision in the United States that prevented people from copyrighting the output of AI models as their own work of arts (Davis, 2023), some firms turned to prompts as a way to commercialise AI art focusing not on outputs but on inputs.

One company focused specifically on blockchain and cryptoasset-based forms of prompt monetisation is Promptsea, a Japanese start-up proposing to prevent "prompt stealing" and to fence copyrighted art material from AI training. Promptsea's diffusion models are trained on art pictures on the open internet the authors of which did often not agree to AI-related uses of their art. This is achieved by creating three distinct networks: the *memory pool*, the *inference pool* and the *utility pool* (Daengthongdee, n.d.). The memory pool maintains a database with the art belonging to the people participating in the network, to prevent those art pieces from being used for AI training unless the people doing the training are willing to pay for the use of the artwork. Prompts are similarly stored, so that prompts similar in nature can be excluded to avoid "prompt plagiarism", and users purchase and use prompts without knowing its content, only its effects, i.e., the image it is capable of generating. This is to avoid prompt engineers from being able to buy someone else's prompts and then reselling those same prompts in other marketplaces. The inference pool is a network storing open-source version of ML models. Through the inference pool, the memory pool is exposed to algorithms for training and fine-tuning, but without "seeing" the actual data and only an encrypted version of it. Finally, the utility pool is the one that provides infrastructural services such as generating cryptographic keys.

The output of a generative AI algorithm like Alice, such as text or images, can be turned into value and revenue, further compounding what Steinhoff calls the "political economy of synthetic data" (Steinhoff, 2022, p. 10). Quite unsurprisingly, the emergence of generative AI initially reinvigorated the NFT market, with the promise of combining the capacity to monetise unique digital objects with the apparently inexhaustible potential for the production of those objects. In so doing, the collusion of the AI and blockchain application stack contributes to "reconfigure the conditions of possibility for data-intensive capital" (Steinhoff, 2022, p. 10) by immediately monetising the ostensibly endless process of synthetic data generation, through the productive tension between the uniqueness in style and subject enshrined in AI personalities and generative AI prompt, on one side, and the seemingly endless abundance of AI outputs that can be generated by the same AI personalities and AI prompts.

At the same time, this collusion also comes with its own forms of collisions and tensions. The introduction of AI-related NFTs promising to protect – and project – an aura of uniqueness onto digital objects (O'Dwyer, 2019) failed to practically fulfil it: several legal judgements by now have declared AI art to be exempt from copyright, meaning that the underlying property rights that would sustain an NFT are largely void (Davis, 2023). This has contributed to NFTs losing most of the value accumulated in 2020. Similarly underlying tensions in generating value is how synthetic data are routinely commercialised using fiat currencies. The additional layer of cryptoassets, with the regulatory attentions they might attract, might be a point of friction that might dissuade companies from using AI tokens to sell synthetic data. Lastly, our mapping points to how wider collisions between scarcity and abundance downplay tensions in the ethico-political issues at stake in the encounters between NFTs on AI art chronicled here.

User layer: more-than-human encounters

A further point of collision and collusion between AI and blockchain is illustrated by the case of Worldcoin, a project muddled in legal difficulties around the world stemming from tensions evolving at the user layers of two stacks encountering one another. Worldcoin was founded in 2019 by OpenAI CEO Sam Altman, Tools for Humanity CEO Alex Blania, and an American tech entrepreneur who left the project in 2021 as it first publicly emerged in beta phase. Worldcoin seeks to establish "proof of personhood" (PoP) in an age of AI-bots: that is, to authenticate unique human-ness. It does so through biometric scanning of retinas with a device called the Orb – a sphere the size of a bowling ball with a sensor specifically designed for mapping the retina and transforming iris scans into numerical codes held on their blockchain. Anti-spoofing mechanisms ensure that irises have not previously been scanned while Zero Knowledge Proofs (ZKP) provide cryptographic verification whereby someone can verify that a message is authentic without knowing the content of the message itself. Worldcoin uses "Zero Knowledge ML" to completely disentangle algorithmic learning from data content.

The value generated for labour by Worldcoin is said to be four-fold. First, is user protection against the rise of synthetic impersonators like deepfakes. Second, is material value in free goods like "unique human" t-shirts (Khalili, n.d.), cash, and Airpods, all of which critics have likened to bribery (Kemp, 2023). Third, is value in the World ID, which is intended to replace government-issued ID lowering the cost and hassle of labour migration to where employed is located. Fourth, is the issuance to "proved persons" of a token (WLD) intended as damage compensation for the paid employment that AI is expected automate away. WLD issuance is conceived as a form of universal basic income (UBI), a longstanding pet project of co-founder Sam Altman who led an ill-fated pilot initiative to provide Oakland families with a monthly stipend of $1500 (Chow, 2023). Altman has argued that because AI "will do more and more of the work that people now do," UBI is needed to combat income inequality (Tong, 2023). World IDs, in turn, are needed to avoid fraud when deploying UBI. Altman's Proof of Humanity projects previously offered $50 to $100 monthly (Chow, 2023) in a project that sought to lay the groundwork for global UBI.

Several collisions at the user level occur in Worldcoin, whose less-than-honest collection and storage of iris data leading to growing legal troubles around the world illustrate collusions between AI and blockchain stacks. Worldcoin (n.d.) asserts that the blockchain-based PoP process is the most fraud secure and privacy preserving option for proving personhood in and across national borders in an age of AI (Levingston & Hammond, 2023;). Yet the privacy of iris scans has been compromised in hacks between 2021 and 3 that allowed the transfer of funds and data out of Worldcoin wallets and accounts that did not require two-factor authentication at the level of login (Guo & Renaldi, 2022).

Worldcoin was also critiqued for experimenting on the poor, a phenomenon more generally underlying both stacks (Howson & de Vries, 2022) but which specifically played out in Kenya, a key jurisdiction for content moderation and Reinforcement Learning from Human Feedback (RLHF) activities underlying in ChatGPT (Perrigo, 2023). Orb operators in this African country, conducting iris scans meant as antidotes to AI pathologies, were remunerated approximately 44 or 88 US cents for each user they enlisted in the World ID project (Guo & Renaldi, 2022). The Kenyan government in 2023 suspended WorldCoin operations reflecting concerns regarding the involvement of private companies in the handling of sensitive biometric data (Nkonge, 2023), particularly due to the fact that once breached, such data cannot be replaced (Kemp, 2023).[5] The country's national government then raided Worldcoin's warehouses, confiscating their equipment and documents (Iyengar, 2024). A parliamentary committee was established to investigate the activities and operations of the Worldcoin, as the project was declared to be a threat to the state and exploiting weak regulations (Miriri, 2023). Worldcoin also came under legal scrutiny in jurisdictions with strong privacy regulations, such as in the European Union where Spain suspended operations of the project in 2024 and the Bavarian State Office for Data Protection Supervision instigated a probe in 2022 on-going at the time of writing (Nwaokocha, 2024).

Despite these user level collisions and increasingly clear collusions between AI and blockchain stacks, Worldcoin continued to attract value. The project secured nearly $100 million in funding just months before its official launch in a 2023 fundraiser, led by now disgraced founder

[5] Subsequently, the UK, France, and Germany investigated Worldcoin for issues of privacy and informed consent (Stacey, 2023).

and former CEO of crypto-exchange FTX, Sam Bankman-Fried (Thaler, 2023). Later in the same year, it raised $115 million during its Series C funding led by Blockchain Capital, a16z, and Bain Capital Crypto (Howcroft & Coulter, 2023). Worldcoin's token price launched in 2023 at $0.3 and soared up to $3.58 only to subsequently decrease to $2.11 (CoinMarketCap, n.d.). Governments like Malaysia adopted WorldID as part of the country's push to identify its citizens and enhance its National Blockchain Infrastructure (Nwaokocha, 2024). The expansions of this project and its persistent ability to raise capital illustrates how collisions and collusions between stacks have uneven implications for value and labour that require further research as they continue to evolve.

Discussion and conclusions

This article mapped four layers of AI and blockchain stacks and identified their coming into being (cometh), coming together in murky manners (collusion) and coming apart as tensions surfaced (collision) between value extraction and conflict over labour and regulation. At the *hardware* level, the two stacks found initial points of contact and collusion around highly parallel hardware like GPUs that promised value for both for AI and blockchain computation. As cryptoassets entered a bear market, crypto miners diversified into AI training leading to competition and conflict over computing power and connection speeds. At the *algorithm* layer collisions surfaced in tensions between the granularity of data analysis and inference of AI and the ostensible capacity of blockchain to preserve privacy. Resolutions to these tensions were sought in decentralised Machine Learning combined with generative AI, which decouples data storage and data analysis and enables for personal data to be transformed into synthetic data, ostensibly disconnected from individuals and hence "devoid" of risk (Jacobsen, 2023). At the *application layer*, the platform political economy (Langley and Leyshon 2021) of NFTs and cryptoassets encountered the political economy of synthetic data (Steinhoff, 2022) with promises of endless proliferation of unique digital assets, prompts, and even AI agents and their personas, on the one hand, and seamless monetisation by earmarking these assets and bringing them to market. Frictionlessness remained a fiction (Pesch & Ishmaev, 2019) as property rights over AI outputs were ruled to be unenforceable, and NFTs as financial vehicles lost nearly all value since 2021. Lastly, at the *user* layer, humanity and human labour, and the increasingly blurred line with non-human labour performed by machines, became sites of monetisation and value extraction through projects like Worldcoin with its monetisation of the iris and efforts at producing a database of "untamperable" identities. Like OpenAI CEO Sam Altman's wider endeavours, Worldcoin's encounters between AI and blockchain relied on both hidden and poorly remunerated or entirely voluntary human labour in the Global South where tensions with privacy laws also emerged. The findings from our mapping are summarised in Table 1 below.

Exploring the intersections of AI and blockchain and whether their merger is a "Match Made in Heaven", for whom, how and where, this article emphasised the value accumulation and extraction possibilities for the varying labour involved in collision and collusion between these technology stacks. In doing so, we have built on literature pushing back on widespread tendencies to obfuscate the multiple forms of human and machinic labour involved into making, but also in resisting, what are presented as "automated" systems. At the hardware level, we traced the similarities and differences between AI training and crypto mining algorithms and their implementation in hardware, identifying, in the process, the human and non-human forms of labour – whether computational or engineering – that is required to repurpose and retrofit hardware used for one task for another. Incidentally, the shifting geographies of AI training hardware can contribute to emerging economic geography literature on flexibilisation of cloud computing infrastructures (Narayan, 2022). At the algorithm and application layers, we have leveraged literature on synthetic data, the connection between data and (more-than-)human subjectivity to extend highly pressing questions in contemporary data production, extraction and valuation regimes (Jacobsen, 2023; Steinhoff, 2022). The remotion of humans in synthetic data – beyond the fact that it is actually impossible to fully achieve – is instrumental in producing the promise of "risk free" algorithmic decision-making, as well as in removing ethico-political and economic barriers to fully unimpeded data production. We have shown that the use of synthetic data in NFTs and blockchain-based distributed machine learning ticks both boxes. Finally, at the User layer, we have stressed how the reworking of human subjectivity assumes a higher salience for the viability of crypto projects like Worldcoin. Here the same reworking of human subjectivity and human creativity wrought by ChatGPT and its disruption of the human author of texts is used as *raison d'être* for the introduction of a crypto token that is at once a digital ID, an instrument to gather and watermark biometric data, and a source of income in compensation for the disruption of labour that algorithms themselves are purported to summon. It is little coincidence that the same economic geography of GPT's "Production Network" (Cf. Ferrari, 2023) strongly overlaps with that of Worldcoin, with Kenya playing a pivotal role in both.

In sum, by providing an initial map of the on-going politics of stack (re-)design and application this article offers pathways for economic geographers to further study the trajectories and implications of seemingly technical decisions and non-decisions. What AI and blockchain stacks might *instead* embody in the future, and under which circumstances they might (re-)emerge (Dourish, 2017) and collude again in ways that present *different* implications for value and labour can be unpacked through the kind of approach we have taken here. In doing so there is much to be gained by integration of posthuman literature in the "canon" of economic geography, as well as by integrating economic geographical and political economic concerns in investigations of the evolving conditions of (post)humanity.

CRediT authorship contribution statement

Ludovico Rella: Writing – review & editing, Writing – original draft,

Table 1
Four Layers and Three Cs in Blockchain and AI Stacks.

Layers	Cometh Blockchain	AI	Collision	Collusion
Hardware (Infrastructure)	ASICs and GPU	GPU, TPU, NPU	Data and algorithmic friction. Unprecedented ethical and regulatory scrutiny.	Monetisation of computing infrastructures to pivot from high-gain, high-risk return of mining to low-risk, low-gain rent from rented hardware.
Algorithm (Data + Software)	Cryptography and consensus algorithms	Backpropagation, matrix-matrix multiplications, normalisation	Ethical risks in privacy and bias.	De-risking of privacy in algorithms. Monetisation of distributed AI computation.
Application (Output)	Cryptoassets, NFTs	Synthetic data	NFTs crashing in value, unenforceability of property rights over AI outputs.	Monetisation of AI agents, prompts and outputs through artificial scarcity.
Users (Labour)	Proof of Humanity, watermarking ID, Zero-Knowledge	Prompting, content moderation, model training	Hack of equipment, data leaks, regulatory and policing interventions.	Monetisation of identity, personhood, data. Unfree labour and experimental subjects in the Global South (Worldcoin tests, GPT training)

Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Malcolm Campbell-Verduyn:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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