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Money as a computational machine

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Abstract

This article presents a speculative philosophical account of money as a computational machine. It does so by leveraging a computational and machinic framework, drawing primarily from the work of Philip Mirowski and Jean Cartelier. The argument is focused on a specific level of abstraction, i.e., the monetary operations involved in the creation and transfer of units of account, asking whether it is possible to view these operations as computations that mediate economic relations. As the primary function of such a machine would be one of social coordination, the article also highlights the political consequences of its implementation across society.

Keywords

Money, computation, machine, hierarchy, Mirowski, Cartelier

Introduction

There are clear advantages to thinking about money as a legal institution or as a creature of law (Desan, 2014), rather than as a special kind of commodity. Nevertheless, there are also risks associated with limiting the focus of analysis to legal rules and definitions. Equally, thinking of money as a social relation provides an extremely valuable vantage point (Ingham, 2004; Dodd, 2014), but it also makes it more difficult to take into account the technical aspects of money. While monetary operations are of course social relations that coordinate human behaviour (Aglietta and Orlean, 1998), they are also highly technical and constructed. This article attempts to chart a different path by taking seriously the idea that money is a kind of technology. What would happen to our understanding of money were we to cast it not simply as a legal or social tool that human beings use to express their economic relations, but as complex machine in its own right?

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The first two sections articulate what we call a *machinic perspective*, which thinks money first and foremost as a machine. To achieve this, the article leverages a cross-disciplinary theoretical framework in general, and the work of Philip Mirowski and Jean Cartelier in particular. Aimed at a specific level of abstraction, i.e., the operations involved in the creation and transfer of units of account, we ask if it is possible to study such operations as computations that mediate economic relations. The focus is both on the rules and procedures of monetary operations as well as on their material substrate, not unlike the software and hardware of a machine. This perspective entails the speculative deployment of a computational frame of reference, identifying inputs and outputs, rules and procedures, executed or instantiated through a variety of physical media.

The subsequent three sections then provide a sketch of the basic architecture of monetary machines, including the main component parts or modules. For each module, we highlight what it computes – that is to say, the functions that it performs – the rules, axioms, or principles that implement these computations, as well as their physical materialization. The first module we outline refers to the *numeraire* or the unit of account. As argued by Mirowski, this is in fact a formal algebraic structure allowing for commodities to be expressed in units of account. Rather than seeing this as just a social convention, Mirowski understands the *numeraire* as an invariant system based on a set of axioms. If this first module imposes the unit of account, the other two modules we outline deal with its actual use. The second module comprises axioms that govern the issuance of units of account. The inputs of this module are requests for units and the outputs are the validated balances. As Cartelier (2010: 29) argues, this module entails the algorithm that inputs numbers in individual accounts. The third module we outline deals with the settlement of units of account. The inputs here are requests for transfers of units and the outputs the resulting settlement balances. In other words, this module validates changes to individual accounts.

From a theoretical perspective, adopting a machinic framework attempts to chart a course between theories of money that are overly naturalizing and those that place too much emphasis on its social constitution. It enables money to be grasped synthetically as a complex coordination device that solves a certain social function based on multiple layers of rules and imposing on society the rigid discipline of an abstract algebra. At the level of its users, the functioning of the monetary machine is experienced as a set of constraints, a "straitjacket", as Mirowski (1990: 712) puts it. Moreover, as Cartelier points out, there are substantial asymmetries between different classes of users in terms of how they experience and manage their straitjacket.

By way of conclusion, we argue that the functioning of monetary machines is both a technical question of computational design as well as one of power and governance. In separating out the computational function and its algorithmic implementation, the machinic perspective allows for a kind of critical realism about how money operates and how it could be organized differently. That is to say, both the normative rules and their material realization in physical media and social institutions could be otherwise.

The machinic perspective

While the idea of a monetary machine might seem outlandish at first, it may be conceptually useful in our contemporary context, where technology and finance have closely intertwined trajectories. In a certain sense, one cannot begin to think about finance, or money more broadly, without being struck by the high level of technological sophistication. Nevertheless, what seems to be a recent development could also be understood as just a modern realization

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of a set of features that were present from inception, i.e., that money has had a technical or machinic nature from the very beginning.[1]

Before unpacking this line of argument, it is important to note that we use the term 'machinic' as understood through the ancient Greek notion of *tekhne*, which is a wider category than tools since it includes behavioural dispositions and socially instituted practices and conventions. To a certain extent, this is compatible with philosophies inspired by Deleuze and Guattari (1983, 1988), where complex assemblages are made up of physical, biological, social, or technical components.[2] Amongst others, the work of Hayles (2016, 2019) represents an attempt to bring these philosophical insights from assemblage theory together with the theory of computation and cybernetics. While all these perspectives are useful in moving away from the notion of technology understood as just a tool and of the human as a tool-bearer, they remain to a certain extent focused on a constitutive dialectic between human beings and their prosthetics (Stiegler, 1998) that fails to think the specificity of either the human or the technical system.

Moving beyond various strands of posthumanism or antihumanism, a machinic perspective requires us to think of both the social and the technical as systems in their own right. One way to understand their entanglement would be in terms of the inhuman elaboration of what it means to be human (Negarestani, 2014). In this perspective, one can think of the first machines as not made of bolts or cogs, but of flesh and blood, comprising human beings as component parts (Mumford, 1967, 1971). These were inhuman machines in the sense that they constituted apparatuses of social coordination whose power also depended on being plugged into something outside of and indifferent to the human. Over time, as Simondon (1989) explains, the evolution of these machines follows an autonomous trajectory, reaching a high degree of automation and self-regulation with the advent of cybernetic machines, which can be said to be inhuman in the further sense of this autonomous mode of existence.

Therefore, our understanding of machines in general is framed within the paradigm of computation and information theory, and particularly those approaches originated by the likes of Shannon (1936), Turing (1937), von Neumann (1951) and Wiener (1965). This allows us to think about monetary machines as rule-based information processing systems, defined in terms of the medium independence of a set of rules and instructions from the physical media that implement them (Piccinini and Bahar, 2013). This is sufficient for the purpose of this article, where inputs and outputs are completely and precisely specified, and processes are sequential, deterministic, and output-oriented. Nevertheless, as we will touch on later, if one was to try and address the monetary phenomenon in its full complexity, one would need to expand this notion of computation to include ongoing multi-agent interactions that are parallel, concurrent, asynchronous, and non-deterministic (Goldin et al., 2006).

While bearing in mind this limitation, one can nevertheless begin by recognizing the value and usefulness of computation as a functional analogy for information processing systems in general. In this regard, consider those historical accounts of computation and technology where Victorian institutions such as the Railway Clearing House or the Post Office Savings Bank are seen as complex computational machines whose 'hardware' was the Victorian clerk (Campbell-Kelly, 2010, 1998). Charles Babbage was intrigued by the complexity and efficiency of the London Clearing House, characterizing it as a well-designed machine. His fascination with the clearing and settlement of payments is described in a chapter of his book, *On the Economy of Machinery and Manufactures* (Babbage, 1833). In fact, as Yuval Millo has recently argued, Babbage's description of the London Clearing House is surprisingly similar to the architecture of modern computers:

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> It is striking how the structure of the Bankers Clearing House, as described by Babbage, resonates with modern computer architecture: input and output, some kind of memory (the clerks, books), and a proto-CPU organised around the inspector. (Millo et al., 2005: 235)

In a certain sense, our general framework argues in a similar way for the usefulness of studying money as if it were a type of rule-based machine. In our case, that means looking at monetary operations (i.e., the arithmetic operations performed on units of accounts) and describing them along the lines of a computational machine.

The monetary machine

Our claim that money can be seen as a computational machine does not mean that the whole monetary phenomenon can be reduced to a Turing machine. There is no grand monetary totality that can be described as a closed-box recursive function, transforming inputs into outputs. And nor do we wish to imply a kind of Hayekian thesis that what is computed is the correct price. Putting aside for now any critique of political economy, these points are evident by looking at just one of the many different aspects of money – namely, the variety of 'hardware' solutions that support its material instantiation.

The hardware of the monetary machine can take many different forms, comprising both human beings and technical artefacts. At first glance, these artefacts would need to have certain characteristics, such as durability and divisibility, in order to act as viable memory supports and facilitate the execution of arithmetic operations. This is why Searle (2017: 1459) argues that "money is essentially digital". In addition, whatever is positioned as money must already have some form of value in the sense of being an object of trust or in virtue of a collective acceptance of status (Lawson, 2016; Searle, 2017). Therefore, the question of what qualifies as an adequate monetary token is by no means trivial, and the way in which a certain group of users finds a suitable solution is the result of all sorts of complex processes.

Furthermore, monetary operations are executed by a complex web of interactive agents (e.g., human beings and their tokens), which means that they are not easily reducible to the operations of a Turing machine. As one continues to look at the monetary phenomenon more broadly, other pockets of complexity become immediately apparent, such as the standardization of commodities, units of measure, validation of monetary tokens, or accounting and taxation. All of these could be seen as relevant to the working of monetary machines, but they also at the same time add to the aforementioned complexity. This would perhaps be best understood as a system of increasing computational complexity, which "includes arbitrary procedures and processes that may be open, non-terminating, and involving multiple inputs interleaved with outputs" (Goldin, 2008: 2). In fact, as has been recently argued in the context of multi-computation, this type of complex system is one that exhibits a high degree of formal and material irreducibility. Nevertheless, one should still be able to parse these computationally irreducible systems using specific reference frames, allowing us to identify aspects that are "computationally simple to describe" (Wolfram, 2021). In other words, although the broader monetary phenomenon is highly complex, by focusing on a specific level of abstraction (i.e., the arithmetic operations performed on units of account), one can attempt to draw a schematic cross-section of its computational functions. As mentioned above, such a description would highlight the different component parts of the machine, the functions they perform, as well as the algorithmic processes that transform inputs into outputs. The remainder of the article will focus on elaborating this schematic or computational architecture of the monetary machine.

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From a historical perspective, one could look at the core 'hardware' of such a machine (i.e., the arithmetic unit/CPU of the day), which over time has included ancient scribes and their clay tablets, medieval merchant-bankers and their bills of exchange, bank clerks and their checks, metal coins, or paper bills. The hardware is not just the physical thing that is exchanged as money, but the whole socially instituted infrastructure that makes that exchange possible. When switching to the 'software' side of the machine, it is important to note that we are not talking here about literal lines of executable code; we use 'software' in a broader sense, referring to the general set of rules that govern the operations of the machine.

As we noted previously, following Cartelier, we distinguish between three different software modules, each with their own specific set of rules or axioms. The first module deals with the creation of units of account "enabling the calculation of values in terms of numbers, with no principled limitations to the respective arithmetical operation" (Carsten Herrmann-Pillath, 2016: 9). The second and third modules open and close accounts. When the machine receives a request to transfer units of account, it computes the required arithmetic operations and provides validated transactions, i.e., final changes to accounts (settlements). Therefore, the output of monetary machines is executed transactions, where a transaction is understood as a formal procedure executed over an information-processing medium (Castelle, 2015).

Money is such a core aspect of sociality that some have described it as the embodiment of our common humanity (Dodd, 2014). The various ramifications of what this means for our day-to-day lives are not always straightforward to identify. For instance, from the point of view of its individual users, money can be seen as a way to make objective valuations, being conducive to more abstract and rational modes of behaviour (Simmel, 1978). On the other hand, money can be seen as a form of memory (Kocherlakota, 1998), allowing for the reduction and exploitation of uncertainty (Esposito, 2011). From a more general perspective, given these very specific computational capabilities, monetary machines can be seen to regulate the way in which resources are mobilized (Desan, 2014) and coordinate the way in which people relate to each other economically (Cartelier, 2018). Most crucially, then, money is also a form of power or means of exploitation, domination, and oppression. Although money is ancient and common to most cultures, it is not a natural given, but an artifactually constructed machine. It is not universal and transhistorical, but has been diversely instituted and is open to further technical, social, and historical transformations. The rest of this article will be devoted to elaborating on the specificities of the three software modules, as well as highlighting some of the political consequences attached to the use of such a monetary machine in mediating socio-economic relations.

Money as computation: (1) The unit of account

This section focuses on the first module, the nominal unit of account, which we can begin to think of as the core protocol of the monetary machine. As is well known, Keynes (1971) singled out the unit of account as the primary concept of the theory of money. From a machinic perspective, it is therefore crucial that we unpack the precise workings of this central component. In this context, we can leverage the work of Philip Mirowski, which stands out as a radical attempt to provide a computational or algorithmic understanding of markets, particularly in his theory of *markomata* (Mirowski and Somefun, 1998; Mirowski, 2002, 2007, 2010).[4] His earlier articles on money are equally insightful. In this regard, he begins by noting the extraordinary effect of money in the context of market exchange, which allows us to compare different objects by reducing them to a *numeraire* (Mirowski, 1986, 1990, 1991). This, of course, is not a natural phenomenon but a socially constructed operation, as Marx

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among others clearly grasped. In Mirowski's (1990: 695) terms, "irreducible differences are dissolved in the acid bath of market exchange". With this comes the question: What precisely is it about money that allows for this anonymous accounting interface which expedites the proliferation of exchange? What allows us to treat exchange as if it were a quantitative phenomenon (subject to arithmetic operations) with prices expressed as rational numbers? His answer is the imposition of "an artificially instituted invariant" by way of a formal algebra (Mirowski, 1986: 229-31; see also Mirowski, 2014). This machinic or inhuman apparatus entails a number of formal properties that are usually taken for granted in daily monetary operations (Mirowski, 1991: 572-79). To be more precise, these are as follows:

1) Any monetary operation should have no effect on the identity of the commodity. Commodities are standardized and abstracted from reality; prices are expressed as rational numbers.
2) These prices become symbols in a computation. They can be added and subtracted.
3) The set of prices conforms to the property of additive identity, which is the same as saying "buying nothing is treated as costing me nothing" (Mirowski, 1991: 579) or that zero is the identity element.
4) Adding prices conforms to the properties of associativity and commutativity. The order in which prices are added should have no impact on the total sum.
5) It is possible in principle to reverse sale or purchase without any loss.
6) Finally, transacting in money-denominated prices should in principle provide no arbitrage opportunities. Everybody pays the same price for the same commodity.

Mirowski (1986) goes to great lengths in providing a formal description of these conditions in mathematical vocabulary, which he posits as the basis for the *numeraire* or unit of account. At the same time, he also argues that the above set of axioms represents an ideal abstract design, and while probably never true for most economic actors, their imposition does nevertheless provide a "transpersonal transtemporal index" (Mirowski, 1991: 571), a benchmark for legitimate or equivalent exchange. That is to say, while it is highly unlikely that these conditions can ever be perfectly implemented in reality, they do ensure the "imposition of rational numbers (in the guise of prices) upon exchanges" (Mirowski, 1986: 231).

On the one hand, this first module seems to be the most natural solution to problems of exchange, but on the other hand, it has a complex formal or constructed character that obfuscates the socially instituted conditions of power it inscribes. This double feature is perhaps best described by Simmel when he notes that our real monetary experience is quite machinic indeed:

> The money economy enforces the necessity of continuous mathematical operations in our daily transactions. The lives of many people are absorbed by such evaluating, weighing, calculating, and reducing of qualitative values to quantitative ones. (Simmel, 1978: 482)

Simmel here highlights the importance of the unit of account as it imposes homogenization, generalization, and quantification. In the words of Mirowski (2014), it is the creation and imposition of an invariant out of nothing, generating the possibility of prices expressed as rational numbers. The immediate consequences of this new technology are well known from the earliest designs in the ancient world, representing a huge efficiency leap in accounting as well as a transformation in the forms and conditions of power (Hudson, 2004).

Nevertheless, while the invention of a reversible, symmetric, frictionless, and orderly unit of account seems to be an elegant solution, it does not provide a fully functioning payment system by itself (Cartelier, 1996). This seems obvious when one considers that "nothing in human experience is perfectly invariant, perfectly identical, or perfectly reversible" (Mirowski, 1990: 694). It might be sufficient when prices and flows are administrated and imposed by

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some form of central authority, but not under the more complex conditions of decentralized multilateral exchange.

In fact, one of the crucial points made by Cartelier is that in the context of market exchange, economic agents can initiate transactions irrespective of their mutual compatibility and their receipts, which means disequilibrium is the norm. As he argues, only a more complex monetary machine could ensure the viability of this out-of-equilibrium form of exchange. Consequently, additional components are needed, namely modules that manage and keep track of the issuance and settlement of units of account.

Money as computation: (2) Payments

In the previous section, we focused on the first module of the machine. In terms of the hardware required to run this module, human beings and specific technical objects seem to be sufficient in terms of implementing the basic conditions for Mirowski's formal algebra of exchange. In fact, one could say, echoing Simondon's (1989) account of technical evolution, that until the advent of digital computers, the unit of account was supported solely by the arithmetical capabilities of human beings and their monetary artefacts, which served as the material substrate for the representational units of computation, and only later was this concretized with the advent of networked infrastructures of digital computation.

While the first module sets the conditions for exchange as a quantitative phenomenon, the crucial question is how these representational units are issued and manipulated. For instance, is it possible for any individual account (or user of the machine) to simply start spending, irrespective of their material situation? Can any individual account create units out of thin air? What seems to be the case is that a fully functioning machine requires a second module specifying the rules and instructions that grant access to units (or means of payment). For instance, if one was to think of the monetary machine of Ancient Mesopotamia, a simplistic description of the rules of the second module could be the following:

1) Silver and barley are commodities standardized by the state.
2) There is a unit of account defined as shekel-weight of silver equal to a bushel of barley (Hudson, 2004: 111).
3) Issuance of units of account is conditioned by the possession of these standardized measures of silver or barley (monetizable wealth).

The first point to make about this set of rules is that, as Cartelier explains, some procedure is required for the initial issuance of unit of accounts, which also coincides with the opening of individual accounts and the assignment of specific quantities of units to these accounts (Cartelier, 2018: 89). That is to say, the second module regulates the way in which an individual account is recognized as a valid user as well as the overall distribution of units of account to specific users (Cartelier, 2018: 108). This is achieved by way of some form of wealth assessment, i.e., the procedure for opening an account (or being issued units) is based on possession of something that is counted (or accounted for) as wealth, such as standardized measures of silver or barley in Ancient Mesopotamia. In that case, possession of specific money tokens is the way in which the machine comes 'on-line' from the point of view of individual accounts. At that moment, valid users gain access to the algebraic language of exchange and being issued units of account (Cartelier, 2010: 21).

Another point made by Cartelier is that these issuance rules seem to be the privilege of some form of public authority. For instance, he abstractly refers to this authority as the "Mint"

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in the case of coinage linked to a centralized sovereign power (Cartelier, 2018: 80). In fact, the rules of the payments module for coinage could be approximated as follows (Cartelier, 1996: 210):

1) Gold and silver are standardized commodities.
2) There is a unit of account based on a standardized measure of gold or silver.
3) The sovereign authority transforms standardized measures of gold or silver into minted coins.
4) The possession of minted gold or silver coins (means of payment) equates to an issuance of units of account.

In this second example, it is clear that the design of the monetary machine is controlled by some form of sovereign political authority (for example, in the case of coinage, the ancient city-states of the Mediterranean). In other words, as exchange becomes essentially a transfer of units of account, one shouldn't be surprised that the issuance of those units becomes a crucial aspect of the exercise of power.

In any case, for individual accounts, adopting the algebra of the *numeraire* and fulfilling the conditions for access to means of payment grants the power to take economic initiative. Exchange is performed by transferring "determinate amounts of nominal units in their accounts" (Cartelier, 2010: 20). Consequently, the lack of accountable wealth, including for instance one's inability to commit labour time in a capitalist economy, is equivalent to being denied access to the monetary machine, which translates into a severely limited ability to act in society.

As the second module affords enhanced capacities for economic initiative, the distribution of the monetary machine across society leads to a decentralized payment system where payments can be initiated irrespective of receipts – that is to say, in the absence of any price equilibrium or mutual compatibility. This is a critical development in terms of expanding the scale and scope of desired transactions and their effective execution. It also raises the prospect of an interwoven web of transactions in which final payment is not assured. Certain individual accounts could easily be put in a position where they spend more than they receive from other accounts, leading to a prevalence of non-zero balances (Cartelier, 2010: 25-27). Therefore, the two sets of rules described so far seem to be necessary but not sufficient for a functioning monetary machine in an environment characterized by disequilibrium.

Money as computation: (3) Settlement

As we have seen, the normal functioning of the first two modules immediately requires a third one, usually referred to as balance settlement, allowing the machine to cope with various forms of disequilibrium. In fact, there are many historical examples in which one can observe this need for a complex architecture, comprising different sets of rules for regulating the functions of unit of account or pricing, payment or circulation, and settlement or safety.[5] Users can complete their desired transactions because the machine opens accounts and issues means of payments but also, perhaps more importantly, because it imposes settlement and closure of accounts. For the 'math to work' and for there to be equivalence in exchange, every account must come to terms with their balance of payments. From the point of view of the overall schematic of the machine, this entails adding additional axioms or rules, and thereby adding to the constraints of the system. If one were to continue with the example of metal coinage, rules 5 and 6 would have to be added to the design:

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1) The physical exchange of minted coins equates to a transfer of units of account (settlement).
2) Accounts must close and balances must be settled (based on Benetti and Cartelier, 1996: 45).

The normal functioning of the monetary machine requires the six conditions of the unit of account and the above-mentioned six rules for payments and settlement to be fully integrated. One can breakdown the abstract functioning of the machine along the lines of the three different modules, such as in the table below (which is based on the work of Jean Cartelier).

Module	*Function*	*Rules*	*Inputs*	*Outputs*
Unit of account	Creating accounts	Formal algebra of exchange	Disparate and incommensurable commodities	Prices expressed in units of account; Individual users interact through accounts
Payment	Opening accounts	Issuance means of payment	Requests for units of account	Distribution of units of account based on wealth assessment; Validated balances
Settlement	Closing accounts	Balance settlement	Requests for transfers of units of account	Validated settlement balances; Post-trade reassessment of wealth

Table 1. Basic input-output architecture of a monetary machine. *Source*: Authors' own, using Cartelier.

The above highlights how the different modules of the monetary machine accept certain inputs, process them according to a set of rules, and provide specific outputs. This can be understood from a computational perspective in terms of solving a specific problem, i.e., performing a function. The first module creates the possibility of units of account, the basic units of representation. The second module allows for the opening of accounts and issuance of units. The third imposes the closure of accounts and the settlement of completed transactions. Along this path, what the monetary machine computes are various arithmetic operations over these units of account. We propose this abstract functional description, based on the work of Mirowski and Cartelier, while making no claims about the various ways in which the architecture is realized. If there is a certain globally shared structure to this machine, the details of its material, social, and historical implementation are significant and locally specific.

To be more precise, as we have seen, the first module takes a set of incommensurable commodities and imposes an algebraic structure that generates a common unit of account. In the case of a machine based on metal coins, it is obvious to see that these quasi-identical, durable, and discrete objects provide a clear material representation for the units of accounts (analogous to digits in computation) and allow for the straightforward execution (or memory support) of arithmetic operations.

The second module receives requests for the issuance of units of account and opens accounts based on some form of wealth assessment. In simple terms, for the case of coinage, providing bullion for minting is the procedure by which the machine issues units of account to respective individual users. From a formal computational perspective, one could encode this module as a simple finite state machine that either accepts the input or does not. One can think here of the machine as having two states (valid and invalid) and a simple transition rule

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for the issuance of units. If the machine reads the correct inputs (legally minted coins) then it switches from invalid to valid. Consequently, the outputs of this module are the validated balances of units of account for each user.

Now, if one considers a simple bilateral situation, then the validated balances of the buyer and the seller together with the amount that must be transferred represent the inputs for the third module. One could also encode the third module as a formal automata capable of executing addition and subtraction.[6] For the sake of simplicity, one can think of two separate Turing machines, one implementing binary addition and the other subtraction. Essentially, one machine would read the inputs on the tape (e.g., the balance of the buyer and the amount that must be transferred) and have as transition state a function that subtracts the two numbers. The other Turing machine would take the balance of the seller and the amount to be transferred and implement the addition of the two numbers. In our example, this is achieved physically thanks to the arithmetical capabilities of the human buyer and seller. The outputs on the tapes would be the resulting balances, or post-trade settlements. Finally, the transfer of units of account is implemented physically by the exchange of metal coins between buyer and seller.

In any case, once settled, every transfer of units then becomes a way to update the 'database' of the machine, effectively instituting changes to the balance sheets of individual accounts and the resulting restructuring of wealth and power. Therefore, when all three modules are in place and streamlined, one can say that the monetary machine is functioning properly as a viable payment system. A 'well-oiled' machine is one that computes a path where decentralized multilateral exchanges are initiated and executed.

One consequence of this perspective is that it could suggest a notion of liquidity that is somewhat different from the usual interpretation. It is obvious that liquidity can have a plurality of meanings, as it can refer to the quality and characteristics of an object or commodity, to the relative position of a market participant, or, more broadly, to the overall state of a market. In the context of this article, we would argue that liquidity is not some intrinsic property of a useless token, as Menger (1892) suggested, but a proxy for the degree to which the monetary machine functions properly, i.e., the degree to which it maintains something like a functioning and viable payment system.

This ideal state of functioning is one where all three modules are integrated and work together in a seamless way. From a day-to-day perspective, this state of liquidity is experienced as the capacity for all accounts to have continuous access to everything by simply matching the currently available price. This could be called the illusion of liquidity, insofar as it is of course an illusion that the machine never breaks-down, that the machine allows for the processing of a limitless number of transactions (Herrmann-Pillath, 2011). That for those with access, commodities will always be available in a seamless and frictionless way.

This is perhaps what is meant when one thinks of the classical function of money as a medium of exchange. The medium of exchange function is an operative feature of the normal state of the machine, where the invariance of the unit of account holds and payments between accounts can be initiated, cleared, and settled. The degree of liquidity of the machine is then linked to the level of interdependence, compatibility, and commensurability of individual balance sheets, as well as the ease with which everything or anything can be moved on the invariant 'plane' of money.

Moreover, one can also perhaps interpret the store of value function in a similar way, whereby it is an operative feature of the machine functioning properly over time, i.e., maintaining this state of liquidity over time.[7] While the monetary machine can by and large maintain this state, this is never assured and is always subject to all sorts of complex

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contingencies. A liquidity crisis would therefore be understood as a state where the monetary machine can no longer cope with transactional demands and where notions of medium of exchange or store of value become meaningless.

Finally, all of this reinforces the idea that it was not the emergence of markets that led to the development of money but that "the evolutionary emergence of an artefact with the properties of early money made the further growth of markets possible" (Herrmann-Pillath, 2011: 40).[8] One could even say that the market-based transactional function of money is a side effect, being only secondary in relation to this primary role of maintaining a viable and functioning payments system, which is also and maybe primarily a matter of social coordination or power.[9]

Political economy of money and hierarchy of access

As we have seen, monetary operations on units of account can be described in terms of a computational machine that shapes and structures socio-economic exchange. At the same time, it is obvious that this machine does not operate in a vacuum but is dependent on social relations that coordinate human behaviour at a basic level (Aglietta and Orlean, 1998), where questions of power, conflict, and recognition become paramount. In other words, monetary machines are part and parcel of the development of fundamental social institutions, where monetary operations are a means "through which social relations of interdependence and conflict are resolved" (Dodd, 2014: 44-45).

In this last section, we will further speculate on the political economy of money through the lens of computation. In particular, we will focus on the fact that although money can appear to be a machine affording superior transactional freedoms, it also deploys several constraints that generate substantial asymmetries between different sets of users. For instance, how does one come to recognize that one is doing better than others, that one's balance sheet is 'healthier' than another's, or that one individual is more 'liquid' than someone else? Moreover, how do these questions relate to an individual's freedom to act in the market and their daily economic existence? While all these points might seem self-evident, it is worth trying to partially articulate them in light of the machinic perspective developed above.

We have seen that, in a certain sense, the architecture of the monetary machine is a layering of specific sets of rules and procedures receiving inputs and requests from its users. At the same time, we have stressed that one should not think of the monetary machine as one great totality. Money is not a universal Turing Machine that produces a correct and predictable output for a given input, either for the individual economic agent or for the economy as a whole. While based on a specific algorithmic architecture, it is a highly distributed multi-agent concurrent process defined by the ongoing social interactions that constitute it (Goldin et al., 2006).

In light of this, we could say that the monetary machine is a set of discrete computations functioning in a user environment made up of a complex web of continuous concurrent computations. The environment in question is our daily socio-economic 'noise', where accounts (individuals or households, corporations, public institutions) attempt to transact, price, account for, and manage their inflows and outflows. The monetary machine itself does not necessarily deal with this entire (computationally irreducible) complexity, but what it can do is accept certain inputs derived from our social interaction. This necessary reduction is done immediately as users plug-in to the machine, moving from discrete input values (prices, quantities of units of account) to discrete outputs (payment settlements and effective changes

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to balance sheets).[10] While this general dynamic has worked as our frame of reference, it is important to break it down and focus on the specific ways in which individual users interact with the machine throughout the monetary 'lifecycle', so to speak.

As we have seen already, the first major constraint imposes itself through the *numeraire*, which essentially functions as the grammar of exchange (Shaikh, 2016: 167), a rule-based form of mediation, or as the "mode of expression and computation of individuals in their relationships with one another" (Cartelier, 2010: 1). In the case of this first module, the ability to seamlessly deal with basic arithmetic seems to be the first and most basic condition for being able to use the monetary machine. Moreover, access is also defined by extra-economic factors such as force (e.g., appropriation and domination of a resource) and norms (e.g., privileged access granted to men over women). While at first money seems to be a universally distributed decentralized machine, it is nevertheless most often historically linked to some sort of centralized public authority (with a capacity for, or monopoly on, violence), as highlighted in the case of money in ancient Mesopotamia (Graeber, 2011). That is not to say that, as in the case of cigarettes in POW camps or ramen soup in US prisons (Gibson-Light, 2018), much more decentralized designs could not emerge under specific environmental constraints. The point is simply that these instances are always likely to be (spatially and temporally) local occurrences, while also having embedded power relations structured by norms and force.

Throughout human history, imposing a stable monetary language – particularly with the advent of coinage – seems to be the purview of some sovereign authority with the power to enforce and maintain the monetary machine, which can be seen as a key aspect of its wider rule-setting ability across all domains. The central constraint that emerges at the level of the unit of account is that without accepting or learning this monetary 'language' or 'code', agents cannot express themselves economically. Furthermore, it also changes the way in which individuals can be described and related to, namely as a set of accounts and their balance sheets (Mehrling, 2001). As Cartelier (2007: 228) puts it, "an individual is an account in which numbers are written according to a well-defined procedure". Outside of this regime, without the seamless anonymity and invariance of the monetary algebra, the capacity for exchange becomes much more limited in scope. Therefore, becoming an account, so to speak, is part and parcel of being socialized through the monetary machine.

Nevertheless, as Cartelier argues repeatedly, the simple adoption of a standardized unit of account is not by itself sufficient for a fully functioning machine. Specifically, it doesn't allow for individuals to take economic initiative in conditions of disequilibrium, where purchases can happen irrespective of receipts and independent of other individual initiatives. For the machine to allow this superior transactional freedom and maximize flows, it must somehow regulate and organize the issuance of units of account. Therefore, the second module brings an additional layer of enabling constraints by recognizing and authorizing valid users of the machine, the so-called active accounts. As we have seen, this requires some form of assessment or accounting of individual wealth, which is needed to underwrite the issuance of means of payment (Cartelier, 2018: 114).

For Cartelier, these rules for regulating means of payments instantly generate a divide that is formal and functional. Non-active accounts are those that are not issued means of payment directly as they lack the minimum level of wealth and therefore need to rely on transfers (e.g., wage payments) from active accounts (e.g., entrepreneurs) (Cartelier, 2018: 84). To access the machine and spend freely, non-active accounts are dependent on the 'generosity' of active accounts (Cartelier, 2007: 223). In other words, this differentiated access to means of payment, a specific parameter of the capitalist form of the monetary machine, can

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be seen as determining and maintaining a deep socio-political asymmetry that is normatively structured. This remains the case even if in capitalist societies, access to means of payments can also be granted based on wealth from future expected profits, such as those generated by entrepreneurial risk taking. Therefore, even if we think in terms of a plurality of means of payment, which in turn generates a complicated hierarchy, the inability to act as an active account in the market is still probably the core asymmetry. In more simple terms, while the machine might be universally accepted (or imposed) and open to all in principle, non-active accounts are nevertheless severely dependent and subordinated in terms of their ability to act in the market and therefore in society in general.

While the function of the first two modules is to manage the relative transactional independence of accounts (expanding it for active accounts and limiting it for non-active ones), the third module imposes a form of interdependence. Through the enforcement of balance settlement, the monetary machine forces the clearing or settlement of obligations and the squaring of accounts. Perry Mehrling (2001: 82) calls this the "survival constraint", describing the need for individual accounts to clear and settle after the trading period, or when asked. For Mehrling (2015), every economic agent is constantly facing the double bind of monetary elasticity and discipline, where ultimately outflows cannot be greater than inflows without some form of resolution. Deficit accounts must either defer final settlement or liquidate part of their wealth to make up the shortfall in respect to surplus accounts. Therefore, another type of asymmetry is created in the case of the settlement module, where not everyone is equally subjected to this discipline. To be more precise, wealth imposes a distinction between those who can relax this constraint on favourable terms and those who have to bear it immediately as a constant feature of their daily existence. Like the payment module, one can also distinguish between a plurality of settlement procedures linked to specific hierarchical structures.[11]

Module	*Function*	*Rules*	*Constraints ('Straitjacket')*
Unit of account	Creating accounts	Formal algebra of exchange	Wealth and social position expressed in numerical form; Individuals are described as accounts; Social interaction through arithmetic operations
Payment	Opening accounts	Issuance means of payment	Opening of accounts conditioned by initial wealth assessment; Asymmetry between direct and indirect access
Settlement	Closing accounts	Balance settlement	Difference in ability to relax the straitjacket; Asymmetry between surplus and deficit accounts

Table 2. Asymmetric constraints of the monetary machine. *Source*: Authors' own, using Cartelier.

Bringing all these points together, we can say that every time an account is plugged-in, the machine effectively computes a balance sheet and sets a level of access. Moreover, by enforcing settlement, it restructures the distribution of wealth at the level of individual accounts and continually shapes what these can and cannot do, as well as what they must do. Mirowski provides us with an ingenious metaphor for the way in which individual accounts

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experience the monetary machine, namely as a ‘‘straitjacket”. We can and indeed are obliged to anticipate and cope with the “consequences of our actions in the economic sphere” at every turn: “So I have opted to purchase this stereo system? The price system then provides a way for me to ‘read’ the consequences of this action for any other actions I may take” (Mirowski, 1991: 579).

The straitjacket metaphor therefore summarises one of the central tensions of the monetary machine. It expresses the way in which, whether we are part of the monetary machinery or are excluded from it, the churning of its cogs is exterior to us. It allows accounts to take initiative independent of *a priori* compatibility and equilibrium constraints, as well as defining and instituting their place in society (Ulgen, 2010: 15). While everyone wears the straitjacket, so to speak, there is a clear difference in how tightly it is felt, as perhaps not all accounts are equally subjected to its strict discipline (Mirowski, 2014). While everyone knows that wealth and power grant certain privileges, it is important to recognize that this is not a given but a question of normative and technical design, where specific models of monetary machines effectively formalize, generate, and entrench these asymmetries. The political economy of monetary machines revolves around this tension between the individuated users and the management protocols of the monetary operating system:

> The institutions that bear responsibility for the integrity of the monetary unit are thus always at odds with the actors’ intent upon the expansion of their own balance sheets. (Mirowski, 1990: 713)

Once the monetary machine is in place, there is a continuous drive by all users towards balance sheet expansion (Gabor, 2016) with the aim of loosening the ligatures of the straitjacket, within or against the norms that regulate movement. For instance, profit seeking, gambling, speculation, stealing, or debasement can all be seen as ways of slackening the ‘straitjacket’.[12] In our machinic perspective, the accumulation of units of account is not simply a form of hoarding liquidity. In fact, the desire to accumulate units of account should be seen as a way to secure better access to the machine. We should perhaps even understand the ‘safe asset’ aspect of money (Boy and Gabor, 2019) in terms of a need to gain superior access to the machine or as a way to guarantee continued access to its capabilities. Losing access amounts to being unplugged from society and the tighter the ‘straitjacket’, the greater the uncertainty around this continued access, the less control a user has over their ability to act in society.

Pushing the metaphor even further, the struggle over balance sheet expansion may be understood to induce an arms race in a computational war over control of the hardware and software of the monetary machine, whether by sanctioned access to the programming language or by illegal hacks. One of the possible outcomes of this conflicting dynamic is the degradation of the specific state of socio-economic relations that we have previously referred to as liquidity. At the extreme, a breakdown of the monetary machine is a situation where the validity of the unit of account is lost, there is no interdependence of balance sheets, commodities are no longer commensurable, and the accounting coherence of the economy is lost.

It should not be surprising to see that the response of public institutions throughout history has been to control the machine and thus attempt to deal with the complex dynamics of conflicting balance sheets. Utmost power would then be defined by what we would call ‘administrative level’ access to the machine, such as the kind associated with the sovereignty of modern central banks. This entails the ability for balance sheet expansion at will or what is generally called the ‘lender of last resort function’ (Mehrling, 2011), i.e., the power to “enter a

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limitless number of transactions" (Herrmann-Pillath, 2011: 36). It could even be said that modern capitalist economies are based, amongst other things, on the dilution of this level of authority in the interest of commercial banking institutions (Desan, 2014). By remaining at all times plugged-in to the monetary machine in an infrastructural entanglement (Braun and Gabor, 2020), banks can cut across the various monetary hierarchies and profit from them (Mehrling, 2017; Gabor and Vestergaard, 2016).

Therefore, in as much as it is clearly the locus for complex social conflicts (Ingham, 2004: 207-208; Dodd, 2014: 109), the thesis according to which money is a neutral transactional medium does not bear much weight. As Searle (2017: 1463) has argued, the essential feature of money is that it is best understood as power itself. In fact, one can say that while money appears to be a naturalistic solution to the problem of resource distribution, its primary function is that of social coordination, which structures and is structured by normative relations of power. Perhaps this is why temples and palaces were the dominant socio-economic institutions for millennia and why in our modern world, global banking conglomerates still compete, in a certain sense, with central banks for the privilege of managing the parameters of the machine.

Conclusion

The proposal for a machinic and computational perspective on money provides a synthetic framework, a speculative attempt to complement legal or social perspectives on money with a machinic one. In practice, it is an invitation to explore the formal aspects of money as a social institution through the lens of computation. The article has therefore attempted to understand money not simply as a tool that human beings use, but also as a machine in its own right. More specifically, we have posited money as a computational machine that mediates social relations and directly shapes and constrains the behaviour of its users. This is relevant today in the context of new digital assets and cryptocurrencies, where communities of users build and experiment with different money-like designs and where one of the crucial working assumptions is that it is possible to change the workings of money by computational means, rather than through political debate and legal reform. While we are aligned with the idea that money is something we can build and reconstruct, we nevertheless remain anchored in the legal and sociological tradition wherein the code of money is essentially a mode of governance.

In developing this argument, we have employed a number of metaphors, including the assumption of a software/hardware functional analogy. By distinguishing between its abstract function at the level of computation and the various ways in which this is implemented (social rules, institutions, and physical systems), a machinic perspective on money allows for a pragmatic grasp on the possible transformation of monetary operating systems. At the level of software, while operative features include formal algebra, rule-based book keeping, and transaction processing operating in a symbolic culture, many coding details of the machine remain open to revision. Moreover, while the hardware of these machines was historically made up of human beings and their tokens, many other different solutions are possible. Following primarily the work of Mirowski and Cartelier, we see monetary machines as having certain invariant properties but being by no means a neutral technology.[13] In fact, their code can be seen to institute and formalize specific hierarchies and asymmetries, both in terms of level of access and the ability to evade its most rigid constraints. Bound by the straitjacket of the machine, individual accounts strive to upgrade their relative position in the hierarchy of access and try to hack or reprogram the parameters of the machine in their favour.

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Notes

1. The link between our basic technical abilities for language, writing and arithmetic, and money is explored by Herrenschmidt (1999).
2. As is well known, at the core of their first book together, *Anti-Oedipus*, is the idea that capitalism itself should be viewed as a "social machine" based on the "axiomatic of abstract quantities in the form of money" (Deleuze and Guattari, 1983: 139).
3. Responding to Kocherlakota's general claim that money is memory, Cartelier argues that we should think of money as the inscription of accounts: "Money is to wealth what the RAM of a computer is to its ROM, that is, the totality of orders and instructions allowing the operator to write information on hard disks. Money, like the RAM, is active only when the computer is active (when transactions take place) whereas wealth, like the ROM, exists independently" (Cartelier, 2010: 19).
4. Mirowski's computational understanding of markets defines them as a "set of rules which facilitate the conduct of exchange and the conveyance of information between buyers and sellers" (Mirowski and Somefun, 1998: 13).
5. For instance, one can reference the transactional practices dating back to ancient Greece, particularly the use of tokens and stones for validating commitments as well as securing and maintaining equivalence (Boy and Gabor, 2019).
6. In his theory of *markomata* (markets + automata), Mirowski shows how it is possible to encode different auction types. For instance, a posted-offer fixed price market could be modeled as a finite state machine; the sealed-bid auction as pushdown automata with two stacks; and the two-sided auction as linear bounded automata or as pushdown automata with 4 stacks (Mirowski, 2002).
7. As Mirowski (1990) has argued, any measurement or conservation of value is dependent on maintaining the invariance of the unit of account. Or as Cartelier (2010: 21) puts it: "What matters here is not the more or less durability of commodities (given by assumption) but the validity over time of the unit of account, which is the real problem obscured by the misleading expression (when applied to money) 'store of value'".
8. As Weber (2019) argues, money is necessary in order to move from certainty of exchange to specialisation and finally division of labour, i.e., the idea of money as the foundational institution of a market economy (Ulgen, 2010).
9. Chavas and Bromley (2008) argue that money probably originated from solving collective coordination problems in the context of hierarchical social relations. For John Searle (2017: 1455-63), money is essentially a status function, part of a complex web of status functions that make up social reality.
10. This understanding of the monetary machine as reducing the complexity of human interaction is very much consistent with broader perspectives on the economic system, such as when the economy is seen as a way to reduce the randomness of "humans as 'free agents' by reducing differences to complete events manifesting as transactions" (Cunningham and Curtis, 2020: 67).
11. In his hierarchy of money, Mehrling (2013) distinguishes between four levels: gold, national currency, deposits, and securities. Operating higher up the hierarchy provides greater security in terms of being able to settle balances. From our perspective, we would say that operating higher up the hierarchy grants superior access to the functionalities of the machine.
12. This propensity to loosen the 'straitjacket' can be reduced to the basic operations of debt creation and profit (Mirowski, 1990: 712).
13. As Mirowski (1991: 572) observes, this invariance is neither natural nor assured but "must be continually maintained by further social institutions, such as the development of double-entry accounting and financial institutions such as banks".

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References

Aglietta, M. and Orlean, A. (1998) *La monnaie souveraine*. Paris: Jacob.

Babbage, C. (1833) *On the Economy of Machinery and Manufactures*. Third edition. London: Charles Knight.

Bawa-Cavia, A. (2022) *Logiciel: Six Seminars on Computational Reason*. Triple Ampersand.

Bell, S. (2001) The role of the state and the hierarchy of money. *Cambridge Journal of Economics*, 25(2): 149-63.

Benetti, C. and Cartelier, J. (1996) Money and price theory. *Lecturas de Economia*, 44(44): 37-54.

Boy, N. and Gabor, D. (2019) Collateral times. *Economy and Society*, 48(3): 295-314.

Braun, B. and Gabor, D. (2020) Central banking, shadow banking, and infrastructural power. In: Mader, P., Mertens, D. and van der Zwan, N. (eds.) *The Routledge International Handbook of Financialization*. London: Routledge, 241-52.

Campbell-Kelly, M. (1998) Data processing and technological change: The Post Office Savings Bank, 1861-1930. *Technology and Culture*, 39(1): 1-32.

Campbell-Kelly, M. (2010) Victorian data processing. *Communications of the ACM*, 53(10): 19-21.

Carruthers, B. and Stinchcombe, A. (1999) The social structure of liquidity: Flexibility, markets, and states. *Theory and Society*, 28(3): 353-82.

Cartelier, J. (1996) Payments systems and dynamics in a monetary economy. In: Deleplace, G. and Nell, E.J. (eds.) *Money in Motion*. London: Palgrave Macmillan, 200-37.

Cartelier, J. (2007) The hypostasis of money: An economic point of view. *Cambridge Journal of Economics*, 31(2): 217-33.

Cartelier, J. (2010) Money is the scribe of a market economy. In: Amato, M., Doria, L. and Fantcci, F. (eds.) *Money and Calculation*. London: Palgrave Macmillan, 16-33.

Cartelier, J. (2018) *Money, Markets and Capital: A Case for Monetary Analysis*. London: Routledge.

Castelle, M. (2015) Making markets durable: Transaction processing in finance. Working paper available upon request.

Chavas, J.P. and Bromley, D. (2008) On the origins and evolving role of money. *Journal of Insititutional and Theoretical Economics*, 164 (4): 624-51.

Deleuze, G. (2006) *Foucault*. London: Continuum.

Deleuze, G. and Guattari, F. (1983) *Anti-Oedipus: Capitalism and Schizophrenia*. Minneapolis: University of Minnesota Press.

Deleuze, G. and Guattari, F. (1988) *A Thousand plateaus: Capitalism and Schizophrenia*. London: Athlone Press.

Desan, C. (2014) *Making Money: Coin, Currency, and the Coming of Capitalism*. Oxford: Oxford University Press.

Dodd, N. (2014) *The Social Life of Money*. Princeton, NJ: Princeton University Press.

Esposito, E. (2011) *The Future of Futures: The Time of Money in Financing and Society*. Cheltenham: Edward Elgar.

Gabor, D. and Vestergaard, J. (2016) Towards a theory of shadow money. Available at: <https://www.ineteconomics.org/uploads/papers/Towards_Theory_Shadow_Money_GV_INET.pdf/>. Accessed 12 March 2022.

Gibson-Light, M. (2018) Ramen politics: Informal money and logics of resistance in the contemporary American prison. *Qualitative Sociology*, 41(2): 199-220.

Goldin, D., Smolka, S.A. and Wegner P. (eds.) (2006) *Interactive Computation: The New Paradigm*. Dordrecht: Springer.

Goldin, D. and Wegner, P. (2008) The interactive nature of computing: Refuting the Strong-Church Turing thesis. *Minds and Machines*, 18: 17-38.

https://doi.org/10.2218/finsoc.7762 Published online by Cambridge University Press

Graeber, D. (2011) *Debt: The First 5,000 Years*. New York: Melville House.
Hayles, K. (2016) Cognitive assemblages: Technical agency and human interactions. *Critical Inquiry*, 43(1): 32-55.
Hayles, K. (2019) Literary texts as cognitive assemblages: The case of electronic literature. *Interface Critique Journal*, 2: 173-95.
Herrenschmidt, C. (1999) Writing, money, and networks: Inventions, ancient and modern. *Le Débat*, 106(4): 17-36.
Herrmann-Pillath, C. (2009) Outline of a Darwinian theory of money. Frankfurt School of Finance and Management Working Paper Series 128. Available at: <http://dx.doi.org/10.2139/ssrn.1468118>. Accessed 11 March 2022.
Herrmann-Pillath, C. (2011) Naturalizing institutions: Evolutionary principles and application on the case of money. Frankfurt School of Finance and Management Working Paper Series 182. Available at: <http://dx.doi.org/10.2139/ssrn.1960392/>. Accessed 11 March 2022.
Herrmann-Pillath, C. (2016) Institutional naturalism: Reflections on Masahiko Aoki's contribution to institutional economics. Available at: <http://dx.doi.org/10.2139/ssrn.2727716/>. Accessed 11 March 2022.
Hudson, M. (2004) The archaeology of money: Debt versus barter theories of money's origins. In: Wray, R. (ed.) *Credit and State Theories of Money*. Cheltenham: Edward Elgar, 99-127.
Ingham, G. (1996) Money is a social relation. *Review of Social Economy*, 54(4): 507-29.
Kocherlakota, N. (1998) Money is memory. *Journal of Economic Theory*, 81(2): 232-51.
Lawson, T. (2016) Social positioning and the nature of money. *Cambridge Journal of Economics*, 40(4): 961-96.
Mehrling, P. (2001) Minsky, modern finance and the case of Long Term Capital Management. In: Bellofiore, R. and Ferri, P. (eds.) *Financial Keynesianism and Market Instability*. Cheltenham: Edward Elgar, Chapter 8.
Mehrling, P. (2013) The inherent hierarchy of money. In: Taylor, L., Rezai, A. and Michl, T. (eds.) *Social Fairness and Economics: Economic Essays in the Spirit of Duncan Foley*. London: Routledge, 394-404.
Mehrling, P. (2015) Elasticity and discipline in the global swap network. Institute for New Economic Thinking Working Paper Series, no. 27. Available at: <https://www.ineteconomics.org/uploads/papers/WP27-Mehrling.pdf/>. Accessed 10 March 2022.
Mehrling, P. (2017) Financialization and its discontents. *Finance and Society*, 3(1): 1-10.
Menger, C. (1892) On the origin of money. *The Economic Journal*, 2(6): 239-55.
Millo, Y., Muniesa, F., Panourgias, N. and Scott, S.V. (2005) Organised detachment: Clearinghouse mechanisms in financial markets. *Information and Organization*, 15(3): 229-46.
Mirowski, P. (1986) Mathematical formalism and economic explanation. In: Mirowski, P. (ed.) *The Reconstruction of Economic Theory: Recent Economic Thought*. Dordrecht: Springer, 179-240.
Mirowski, P. (1990) Learning the meaning of a dollar: Conservation principles and the social theory of value in economic theory. *Social Research*, 57(3): 689-717.
Mirowski, P. (1991) Postmodernism and the social theory of value. *Journal of Post Keynesian Economics*, 13(4): 565-82.
Mirowski, P. (2002) *Machine Dreams: Economics Becomes a Cyborg Science*. Cambridge: Cambridge University Press.
Mirowski, P. (2007) Markets come to bits: Evolution, computation and markomata in economic science. *Journal of Economic Behavior & Organization*, 63(2): 209-42.
Mirowski, P. (2010) Inherent vice: Minsky, markomata, and the tendency of markets to undermine themselves. *Journal of Institutional Economics*, 6(4): 415-43.

https://doi.org/10.2218/finsoc.7762 Published online by Cambridge University Press

Mirowski, P. (2014) Modern shadow banking as Schmittian 'exception': Meditations on a constructivist approach to the theory of money and debt. Paper presented at the Money and Finance Workshop, 11-12 August. University of Sydney, Australia.

Mirowski, P. and Somefun, K. (1998) Markets as evolving computational entities. *Journal of Evolutionary Economics*, 8(4): 329-56.

Mumford, L. (1967) *The Myth of the Machine: Technics and Human Development*. London: Secker and Warburg.

Mumford, L. (1971) *The Myth of the Machine: The Pentagon of Power*. London: Secker and Warburg.

Negarestani, R. (2014) The labour of the inhuman, part I: Human. *e-flux journal*, 52. Available at: https://www.e-flux.com/journal/52/59920/the-labor-of-the-inhuman-part-i-human/>. Accessed 11 March 2022.

Orlean, A. (1992) The origin of money. In: Varela, F. and Dupuy, J.-P. (eds.) *Understanding Origins: Boston Studies in the Philosophy and History of Science*. Springer: Dordrecht, 113-43.

Parry, J. and Bloch, M. (eds.) (1989) *Money and the Morality of Exchange*. Cambridge: Cambridge University Press.

Piccinini, G. and Bahar, S. (2013) Neural computation and the computational theory of cognition. *Cognitive Science*, 37(3): 453-88.

Piccinini, G. (2007) Computing mechanisms. *Philosophy of Science*, 74(4): 501-26.

Pistor, K. (2019) *The Code of Capital: How the Law Creates Wealth and Inequality*. Princeton, NJ: Princeton University Press.

Searle, J. (2017) Money: Ontology and deception. *Cambridge Journal of Economics*, 41(5): 1453-470.

Shaikh, A. (2016) *Capitalism: Competition, Conflict, Crises*. Oxford: Oxford University Press.

Shannon, C. (1938) A symbolic analysis of relay and switching circuits. *Transactions of the American Institute of Electrical Engineers*, 57(12): 713-23.

Simmel, G. (1978) *The Philosophy of Money*. London: Routledge and Kegan Paul.

Simondon, G. (1989) *Du mode d'existence des objets techniques: Aubier philosophie*. Paris: Aubier.

Stiegler, B. (1998) *Technics and Time*. Stanford, CA: Stanford University Press.

Turing, A. (1937) On computable numbers, with an application to the Entscheidungsproblem. *Proceedings of the London Mathematical Society*, 42(2): 544-46.

Ulgen, F. (2010) La coordination en économie: un essai sur la monnaie. Available at: <https://mpra.ub.uni-muenchen.de/35468/>. Accessed 10 March 2022.

von Neumann, J. (1951) The general and logical theory of automata. In: Jeffress, L.A. (ed.) *Cerebral Mechanisms in Behavior: The Hixon Symposium*. Oxford: Wiley, 1-41.

Weber, I. (2019) On the necessity of money in an exchange-constituted economy: The cases of Smith and Marx. *Cambridge Journal of Economics*, 43(6): 1459-83.

Wiener, N. (1965) *Cybernetics or Control and Communication in the Animal and the Machine*. Cambridge, MA: MIT Press.

Wolfram, S. (2021) Even beyond physics: Introducing multicomputation as a fourth general paradigm for theoretical science. Available at: <https://writings.stephenwolfram.com/2021/09/even-beyond-physics-introducing-multicomputation-as-a-fourth-general-paradigm-for-theoretical-science/#the-path-to-a-new-paradigm/>. Accessed 10 March 2022.

https://doi.org/10.2218/finsoc.7762 Published online by Cambridge University Press