Evaluating and Selecting Digital Payment Mechanisms

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Abstract: The Internet is growing rapidly as a marketplace for the exchange of both tangible and information goods and services. Numerous payment mechanisms suitable for use in this marketplace are in various stages of development. Because their development is so recent, it is difficult for potential participants in electronic commerce to evaluate and select payment mechanisms. We characterize the properties of 10 highly visible mechanisms according to 30 criteria. We show how a decisionmaker might follow a systematic rational choice approach to select or evaluate a mechanism The selection process typically leads to a solution in a few iterations or less; it is generalizable; and it requires relatively little information about each alternative, reducing the cost of evaluating and selecting payment mechanisms. The evaluation approach guides payment mechanism designers and researchers by the needs of *users* who desire particular *bundles* of characteristics. We then apply the analysis to the University of Michigan Digital Library (UMDL), a large-scale intelligent-agent commerce-based system. We show how the user-centric approach may lead to the use of more than one payment mechanism within a commerce system, and how the evaluation criteria could be used to determine mechanisms for different UMDL needs.

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Money is not an invention of the state. It is not the product of a legislative act.

The sanction of political authority is not necessary for its existence.

--Carl Menger

1. Introduction

The Internet is growing rapidly as a marketplace for the exchange of both tangible and information goods and services. Numerous payment mechanisms suitable for use in this marketplace are in various stages of development.[4] A few have been implemented; most have been merely proposed or are undergoing trials.

Potential participants in electronic commerce are having difficulty evaluating and selecting payment mechanisms because the field is in constant flux. To begin with, there are many methods for making payments. Consider the tremendous variety of familiar

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[4] For a listing of dozens of proposals and links to further information about them, see the Net Commerce page on the Telecom Info Resources Directory (URL: `http://www.spp.umich.edu/telecom/net-commerce.html`). Payment protocols currently in use include: DigiCash, NetCash, NetCheque, First Virtual, CyberCash, NetBill, and traditional credit cards using PGP and other encryption.

mechanisms: coin, bills, personal checks, cashier checks, money orders, credit cards, debit cards, and so forth.[5] Each of these has multiple digital analogues. Information about the alternatives is limited and costly to obtain; even implemented mechanisms have been in use for only a short period of time. Further, all mechanisms, including those already in use, are being continually modified. With conventional money we may “know it when we see it”[6], but most decision makers have only just begun to see digital money, and they don’t know much about it yet.

We offer both information and a decision strategy to assist decision makers evaluate and select digital payment mechanisms. The information is in the form of two matrices that characterize numerous payment mechanisms according to about 30 characteristics. We have prepared this characterization for ten leading digital mechanisms, and also, for comparison and benchmarking, for seven different conventional payment mechanisms.

The decision strategy we discuss is not very sophisticated. However, it is fully consistent with rational choice theory, feasible and generalizable. It also has the advantage of focusing costly information gathering on those aspects of the mechanisms that are relevant to the decision, therefore limiting wasteful efforts.

[5] In the 19th century multiple banks issued their own cash, and cotton bills (invoices) were used as currency [Temin 1969]. The variety of alternatives increases the further back we look.
[6] Apologies to Justice Potter Stewart.

We apply the decision method to the problem of selecting payment mechanisms for the University of Michigan Digital Library (UMDL) project.[7] This application supports our view that:

- user-centric mechanism evaluation may lead to different preferred mechanisms for different users, even within a single project;
- the simple selection approach can reach a conclusion quickly; and,
- the information burden is modest.

2. Selection Process

A payment mechanism is only as good as its users perceive it to be. Therefore, we take a decisionmaker-centric approach to comparison and selection. This may seem tautological, but in fact other authors have followed an ad hoc approach, which may lead to unproductive infrastructure investment, frustration of potential clients, damage to the organization's reputation, and thus foregone sales of goods and services.

Each of the bewildering array of possible mechanisms can be identified by its performance on a number of characteristics that affect the decisionmaker. Thoughtful selection of a digital money mechanism requires a way to compare and evaluate different systems in terms of these characteristics. Previous authors select an arbitrary subset of the possible criteria on which to evaluate their proposed mechanism. In fact, the selection and application

[7] The UMDL is a research project to develop a distributed digital library that facilitates commercial document transactions, as well as cost recovery for system resources. A digital payment mechanism is an essential component of its architecture.

of criteria is the decision maker's prerogative, and thus should reflect the decision maker's circumstances and preferences.

After identifying the relevant characteristics, the decision maker needs a method for selecting one or more mechanisms based on their performance on the characteristics. We show that a generalized form of prioritizing characteristics provides a workable method for selection. In many cases, prioritization will be a simple ranking of characteristics. In more complex cases the method is consistent with rational choice theory (maximizing a utility function).

The problem of selecting from among many novel mechanisms based on a large number of characteristics is not trivial. However, in practice, decisionmaker-centric selection may be simplified for two reasons:

- *Different attributes may be important to various parties in a transaction, but only those that affect the decisionmaker (either directly or indirectly) are relevant to selection; and*
- *Only a few high priority attributes may be sufficient for making a selection from available mechanisms.*

We find it useful to distinguish between two types of mechanism characteristics: those that affect the decisionmaker directly, and those that affect other users of the mechanism directly, and thus affect the decisionmaker indirectly. For example, suppose the person (or organization) deciding what mechanism to implement is a seller: She might care directly if the mechanism is *non-refutable* (see Appendix Table I). In addition, her potential customers might care about the one-time setup costs to be able to use a mechanism (e.g., account creation and software installation). Thus, the seller-decisionmaker cares about buyer fixed costs indirectly, because they may affect the number of potential buyers.

The approach is quite general. A user, and thus a decisionmaker, could be a seller, a buyer, or an intermediary. All parties relevant to a decision are either users or decisionmakers. This simple dichotomy is exhaustive: everyone who matters is either the decisionmaker, or someone whose views the decisionmaker cares about.[8] For our UM Digital Library examples below, the decisionmaker is an intermediary (the library), and the users are buyers and sellers (and possibly other intermediaries, as digital libraries may interoperate with each other).

We now proceed through the steps of the selection method. First we define the master vector of possibly relevant characteristics. We then narrow the vector of characteristics to those relevant to the decisionmaker. The final step is to identify a set of sufficiently well-ordered preferences, and to apply them to the characteristics matrix to reach a decision.

A. Characteristics of Payment Mechanisms

The idea of evaluating digital payment mechanisms based on a set of desirable characteristics is not new. Several papers on electronic currency include a discussion of characteristics the authors consider desirable.[9] However, none of the papers recommend the *same* characteristics; our literature review yielded about 30 different desirable characteristics. The characteristics are defined in Appendix Table 1. Though quite long, the vector of characteristics is not exhaustive, and illustrates how complex the task of characterizing and

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[8] To be truly complete, the decision maker may also care about regulators or others with authority to impose *constraints* on the decisions. The legal environment is underdeveloped currently, so we ignore regulators in this paper.

[9] These papers include: [XIWT 1995], [Camp 1994], [Chaum 1987], [Neuman and Medvinsky 1995], [Matonis 1995], [Neuman and Medvinsky 1993], [Mao 1995], [Manasse 1995], [Neumann 1995].

comparing payment mechanisms may be.[10] Compiling such a list is an important first step in making a selection between competing proposals, because it forces the decision maker to explicitly think about how to distinguish mechanisms, and about which characteristics are important from his or her perspective.

To test the usefulness of the criteria for discriminating between payment mechanisms, and to offer a familiar point of departure, we first evaluated seven forms of conventional money. The results are shown in Appendix Table 2. Because these payment mechanisms are quite familiar, it is easy to understand the table and to observe how the vector of characteristics can be used to discriminate.

We now turn to digital payment mechanisms. We evaluated 10 popular payment mechanisms on 30 characteristics.[11] See Appendix Table 3.[12]

B. Narrowing the List: The Decisionmaker's Perspective

To evaluate and compare every possible characteristic before selecting a mechanism would be expensive and impractical. The literature to date lacks any reasoned argument on which subset of characteristics to base the selection and evaluation of digital payment

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[10] The task is further complicated because some characteristics themselves have several dimensions. As an example, we collapse a number of considerations into a single characteristic: "privacy". In fact, there are a number of different pieces of information about each transaction that may or may not be private (e.g., identity, value of transaction, item transacted), and there are a number of different potential observers from whom the information may be obscured (e.g., buyer, seller, law enforcement, third party). [Camp 1994] explores the privacy attributes of payment mechanisms in depth; she suggests about 20 distinct privacy characteristics that might independently matter to decisionmakers.

[11] We evaluated each mechanism on all 30 characteristics as a public service. One of the main points of our approach is that a decision maker not need to go through the entire time-consuming, costly exercise. The cost-conscious decision maker will first narrow the list of relevant characteristics, as we describe below, and *then* evaluate the candidate payment mechanisms on the reduced list of characteristics.

mechanisms. In fact, using the characteristics advocated by any particular author may be quite misleading. Several of the discussions of desirable characteristics are conducted by developers of payment mechanisms that of course possess all of the characteristics advocated. Instead, we recommend selecting from the master list by focusing on the needs of the *actual* decisionmaker (or the organization she represents).

Consider two characteristics for digital payment mechanisms. **Low financial risk** or default risk is frequently proposed as desirable, and is important, for example, to UMDL for the agent transactions in which it takes a direct interest.[13] **Monetary value** is also frequently cited as a desirable characteristic (see, e.g., [XIWT 1995]). However, for its own transactions, the UMDL cares about monetary value only insofar as it reduces default risk; it is but one of several aspects of a payment mechanism that may affect financial risk.[14] The UMDL may be willing to accept a mechanism that does not have monetary value (e.g., a “credit”) if for other reasons the mechanism has sufficiently low financial risk. Therefore, only *low financial risk,* not *monetary value*, should be retained in the vector of decision characteristics (for this particular decisionmaker).

To illustrate, we have applied this dimension reduction approach for our example decisionmaker, the UMDL (with respect to infrastructure transactions in which UMDL takes

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[12] All of the digital mechanisms we examine are still under development, and limited information is available. Thus, at any time our characterizations are likely to have some inaccuracies. Each decision maker should therefore be responsible for determining the validity of a particular characterization.

[13] Different decision makers will tolerate different degrees of risk.. Generally in market economies there is a trade-off between risk and expected return. Some decision makers will choose to bear higher risk in exchange for higher expected returns.

[14] Others include the risk that the digital money or other sensitive financial information will be stolen or "overheard" by parties outside the transaction and used fraudulently; risk that digital money is being double-spent; and risk of non-payment or other customer fraud.

a direct financial interest). Obviously, the procedure is subjective, as is any model-building exercise.[15] We conferred with UMDL researchers (including ourselves) to first eliminate irrelevant characteristics, and then to determine which characteristics were subsumed by others. We then evaluated a variety of digital payment mechanisms for their performance on these characteristics. The reduced set of characteristics is presented in Table 1 below.

[15] It is not so obvious to us, however, that the process is more subjective than is forming the initial master list of objectives, for example, or than any other aspect of the decision making process. The problem is not the subjectivity of decision-making — indeed, we are trying to focus the decision process on the responsible subject, or decision maker — but the extent to which the decisionmaker forms explicit objectives, methods and assumptions at each stage of the process.

Table 1: Reduced Evaluation of Digital Payment Mechanisms

	First Virtual	NetBill	Millicent	Ecash	CyberCash
Easily exchangeable	**N/A**	**yes**	**yes**	**yes**	**N/A**
Locally scalable	**yes**	**limited**	**yes**	**yes**	**yes**
Acceptable to users	**yes**	**?**	**?**	**yes**	**yes**
Low transactions delay	**no**	**yes**	**yes**	**yes**	**yes**
Low transactions cost:					
for micro transactions	**no**	**no**	**yes**	**no**	**no**
for large transactions	**yes**	**yes**	**no**	**yes**	**yes**
Low fixed costs (for seller)	**yes**	**no**	**?**	**no**	**?**
Non-refutable	**no**	**yes**	**no**	**no**	**yes**
Transferable	**no**	**limited**	**no**	**no**	**no**
Financial risk					
Buyer subject to risk?	**no**	**low**	**low**	**low**	**low**
Seller subject to risk?	**yes**	**low**	**low**	**low**	**no**
Unobtrusive	**no**	**yes**	**no**	**yes**	**yes**
Anonymous:					
for buyer	**no**	**no**	**no**	**yes**	**no**
for seller	**no**	**no**	**no**	**no**	**no**
Immediately respendable	**no**	**no**	**no**	**no**	**no**
Privacy	**some**	**high**	**some**	**high**	**some**
Two-way	**no**	**no**	**no**	**yes**	**no**

C. Prioritize Characteristics and Select a Mechanism

We now have a reduced set of characteristics on which we have scored the various alternatives. We propose an axiomatic approach to mechanism selection. By axiomatic selection we mean that a mechanism will be acceptable (to the decisionmaker) only if it satisfies certain a priori conditions, taken as given This approach is trivial and non-controversial if there exist one or more mechanisms that perform adequately on all of the characteristics important to the decisionmaker.[16] We are interested in the harder case, for which no mechanism exhibits all of the desired characteristics (but there is at least one mechanism that performs well enough overall that the decision maker prefers to choose such a

[16] If too many mechanisms perform “adequately” on all of the relevant characteristics (perhaps too many because the costs of implementing each incremental mechanism outweigh the benefits of having multiple mechanisms),

mechanism rather than forego digital payment altogether). In this case, the decision maker must make a judgment about which characteristics are axiomatically *required*, and which are not. In a simple world, the decisionmaker will be comfortable prioritizing the relevant characteristics, and establishing independent thresholds for each.[17] The decision procedure is then straightforward, and can be quite illuminating. Each characteristic serves as a screen: the set of candidate mechanisms is passed through each screen in priority order until the desired number remain. A useful by-product of this procedure, especially for digital payment designers, is guidance on which absent or inadequate characteristics are critical for particular mechanisms (at least for the decisionmaker in question).

Of course, decisionmakers may not have a strict preference ordering across all characteristics; e.g., there may be "ties". Then the screens can be applied in sets. A problem arises if applying a set of "equally important" screens eliminates all remaining mechanisms. This could indicate one of three different states:

- None of the considered mechanisms performs sufficiently well, and the decisionmaker chooses to forego digital payment.
- The decision maker is willing to forego all of the equally important characteristics in the subset, and accepts the set of mechanisms remaining before applying the set.
- The decision maker realizes on further reflection that the criteria in the subset are not equally important, and arrives at a partial ordering that leads to a successful selection.

The last possibility suggests the usefulness of the approach in helping the decision maker to refine her selection method *efficiently*. If it is difficult (costly) to strictly order a subset of

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then the decision maker needs either to tighten the sense of "adequate", or develop some way to otherwise (partially) rank order the surviving mechanisms.

criteria, it makes sense to first see whether such an ordering is necessary. If it is necessary because no mechanisms survive the subset of screens, then the decision maker can choose whether to invest the extra effort required to refine the ordering. Thus, rather than an inflexible decision support tool, the approach is interactive and flexible: the decision maker is confronted with the need to make decisions that trade off certain characteristics against others only when such trade-offs are critical to the selection. We will show an example below in which such a trade-off is explicit, and is reached surprisingly quickly (that is, after only two screening characteristics are applied).

There may be cases in which the decisionmaker does not have a simple preference ordering with well-defined, independent thresholds for each characteristic. The method admits the use of a much more complex class of preferences. Any independent sequence of criteria that can be formed as logical operations on the decision maker's list of characteristics can be applied. For example, the following could be a (sub)sequence of screens:

1. exchangeable
2. (financial risk ≤ "medium" AND anonymous) OR immediately respendable
3. low transactions delay, etc.

By the use of generalized screens, the axiomatic approach is made fully general. Indeed, generalized screens support a continuum of metrics, from the simplest lexicographic

[17] In the simple case of an independent rank-ordering of characteristics that must be satisfied, the axiomatic approach is *lexicographic*.

prioritization to a complete cardinalization that selects the mechanism with the maximum weighted score.[18]

The basic insights from our formulation of the decision process are that:

- hard decision problems necessarily involve trade-offs between multiple desirable features
- good decision making requires that the trade-offs be made explicit
- a good decision support method assists the decision maker in finding which screening criteria can be applied at low cost, and which must be more carefully defined in order to discriminate between acceptable and unacceptable choices.

3. Applying the Selection Approach in a Diverse Environment

We shall use the University of Michigan Digital Library (UMDL) to motivate and illustrate the usefulness of our method. The UMDL architecture is built on multiple specialized information agents. Each agent can reason about its resources and objectives, communicate and negotiate with other agents, and choose its actions autonomously [Birmingham 1995; Wellman et al. 1996]. Agent types include user interface agents, collection interface agents, task planners, information service agents (providing, for example, thesaurus look-ups or searches), and system service agents (providing, for example, registration, notification, and auctions). These agents agree on terms of *exchange* before providing services to each other, as intermediated through decentralized auctions, and thus are engaged in continuous, real-time electronic commerce.

[18] Maximum weighted score could be implemented to any desired degree of precision. Call the weighting function F(x). Construct a sequence of screens of the form: (1) $F(x) > e_1$, (2) $F(x) > e_2$, etc., for e_i an increasing sequence with small increments.

A system with many autonomous, goal-oriented agents acting on their own behalf is an excellent setting in which to emphasize the importance of approaching the payment mechanisms selection problem from the *decision maker's* viewpoint. Each agent is an autonomous decision maker, and may have different preferences over payment mechanisms than do other agents. Further, the UMDL architecture is self-consciously modeled on a distributed, *human* agent economy, and so this example also illustrates our method for the broader context of free-market electronic commerce in general.

Within the UMDL, various agents may prefer different digital payment mechanisms for at least two reasons: diversity of *transactions*, and diversity of *trust*. We first consider transaction diversity. A distributed digital library requires the performance of a wide variety of functions. With a distributed agent architecture, these functions are provided in the form of transactions between autonomous agents. For an example, a collection agent will *register* with the registry agent; the registry agent will *notify* users of the availability of a collection; a user and a collection agent may negotiate and contract to *exchange* a digital document for monetary compensation. Transactions may be large (document delivery) or small (notification); they may be occasional (bibliographic search) or frequent (registrations and notifications); etc. Agents may prefer different money mechanisms for different transaction types, much as we each do in familiar daily transactions: sometimes we use cash, sometimes checks, credit cards, bank checks, and so forth. Frequent, small transactions are best served by a low-overhead, lightweight mechanism; irregular, large transactions may benefit from a more secure, but higher overhead mechanism.

User preferences for a payment mechanism may also vary due to *trust*. UMDL is designed to be an open system, in that autonomous human agents may participate merely by providing their own software interface agents that meet the interface requirements of the UMDL.[19] Each autonomous agent in an open distributed system will trust other agents to a varying degree. For example, many agents in the initial implementation of the UMDL will be "owned" by the UMDL itself, and although each seeks to maximize its own objective function, they are known to each other and ultimately are part of a system designed to accomplish a unified goal.[20] When trusted agents engage in commerce, they may be willing to rely on a lightweight protocol with low peer-to-peer security, analogous to merchants who accept checks only if drawn on a local bank. When these same agents transact with unrelated agents (e.g., with the agent of a commercial book publisher), they may prefer a stronger payment mechanism, despite the higher overhead cost (cf. checks versus credit cards with immediate authorization but a 3-4% service charge).

The diversity of preferences for a payment mechanism, together with differences in mechanism overheads, may have important implications for the participant configuration in a distributed agent architecture. In the UMDL, for example, there are many infrastructure services that must be provided continuously, resulting in a heavy transactions load (examples include registry, notification, auction setup and operation). The architecture is open, so any

[19] For example, a publisher unaffiliated with the University may offer access to its collection through a collection interface agent. This is quite different from some computational market agent systems in which all of the software agents are designed and owned by the same organization, and thus can trust each other.

[20] The fact that self-interested individual agents can achieve a result that maximizes an overall, social objective follows from the First Welfare Theorem in economics, see, e.g., [Varian 1992]. This result motivates the use of a distributed agent architecture based on economic exchange for solving complex system objectives.

participant *could* write a competing agent to provide some of these infrastructure services. But frequent low-value transactions may not be feasible if monetized with a heavyweight protocol. Thus a single provider of a cluster of different infrastructure agents may have a decided competitive advantage over a configuration with multiple competing providers, each offering only one or two infrastructure agents, because the single provider can use a lightweight protocol for exchanges between its chain of agents.[21]

For less frequent, higher value transactions, such as an extensive bibliographic search, the value of the transaction may be sufficient to support greater payment mechanism overhead. Then we would expect to see multiple, competing agents with different (untrusted) owners who offer search. The case is clearer still for the content providers: the overhead of a secure payment mechanism is small relative to the value of content, and thus we should expect to see a diversity of content providers, even though a single integrated provider of content and library services would have a lower overhead cost.

A similar effect of payment mechanism overhead in conventional commerce can be observed in near-border trade. Retail establishments situated near national borders often accept currency from both sides of the border at approximate exchange rates, bearing some risk of exchange rate fluctuation and the transactions cost of later performing an exchange in order to lower the overhead costs to the customers of changing currency for frequent, small transactions. However, this behavior is more likely to be seen for exchanges of modest value

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[21] The question of which functions are most efficiently provided as clusters of trusted agents is closely related to the question of which functions should be provided by a single agent, and which should be distributed to separate agents. The boundaries of agent functionality and trust relations involve a trade-off between the

(e.g., a newspaper or restaurant meal), and almost never for purchases of consumer durables (e.g., home appliances, automobiles).

Therefore, we expect that in UMDL the selection of acceptable payment mechanisms will affect the configuration of participants and the agents they offer, and that there is likely to be considerable demand for more than one payment mechanism within the system. Diversity in transaction types and in trust are two reasons for choosing one payment mechanism over another, and these reasons are likely to diverge significantly within an open, distributed agent economy. However, as we shall see, there are a number of other considerations in choosing a digital payment mechanism, and the selection problem can be quite complex.

4. Examples: Payment in a Digital Library

To illustrate our method, and some of the helpful by-products of following the process, we present two simplified examples of how payment mechanisms might be selected for different transaction types in the UMDL.[22]

A. Example 1

Many transactions in the UMDL distributed agent environment will have low value, will occur frequently, and will require low transaction delay. For example, a notification agent will poll the registry to check for new events (such as new collections being added), and a new auction service will register with the registry agent. Some of these high-frequency, low-value

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efficiencies of more centralized control and the efficiencies of market-mediated transactions. See, e.g., [Williamson 1975].

[22] The UMDL has not reached any final decisions about digital payment mechanisms. The examples presented here should not be viewed as an endorsement or criticism of any particular mechanism.

transactions will take place between trusted agents, such as agents that are owned by a single entity. We suppose that these transactions, the agents require a payment mechanism that satisfies three properties (in priority order):

1. low transactions delay;
2. low transactions cost for micro transactions;
3. unobtrusive.

By referring to the characteristics matrix in Table 1, we conclude that only Ecash, NetBill, Millicent, CyberCash, NetCheque, Mondex, MicroMint and PayWord pass through the "low transactions delay" screen.[23] Millicent, NetCheque, MicroMint and PayWord also pass the "transaction cost" screen. Of these four, only PayWord and MicroMint also pass the "unobtrusive" screen. See Figure 1. If the UMDL wishes to select only one mechanism, it can now determine which further criteria are important, and start applying those until one PayWord or MicroMint is eliminated. In the alternative, the UMDL might decide to accept both forms of digital money if the costs of setting up and handling two types are sufficiently low.

B. Example 2

To illustrate a different type of outcome, consider now a document exchange transaction in which a collection agent delivers a substantial document to a user agent. We presume that these agents do not fully trust each other (any more than a conventional bookstore fully trusts its customers and vice versa). Suppose that for this low-trust, high-

[23] To save space we did not include columns for all of the payment mechanisms in Table 1; the underlying information is available in Appendix Table 3.

value, relatively infrequent transaction agents require a payment mechanism that satisfies the following properties (in priority order):

1. low financial risk for buyer and seller;
2. low transactions cost for large transactions;
3. non-refutable; and,
4. atomic transactions.

By again applying our evaluation matrix, we find that NetBill, Millicent, Ecash, CyberCash, NetCash, MicroMint, PayWord and Mondex all pass the first screen. Of those, NetBill, Ecash, CyberCash, Mondex and NetCash also pass the “transactions cost” screen. Only NetBill, CyberCash and Mondex also pass the “non-refutable” screen. When we further impose “atomicity”, only NetBill survives.

One striking observation from this example is that the bewildering variety of digital money characteristics (and the size of the decision matrix) is not very important, at least in this application. The decision makers needed to identify only the top four criteria in order to eliminate all but two of the options. The next dozen or more criteria of interest don’t affect the decision, and thus no effort need be devoted to evaluating those criteria or attempting to determine their strict ordering or interdependent rates of trade-off.[24] This is not to say that the decision is easy; but the decision method limits the effort and focuses it on the hard part: determining the priority of the most important characteristics.[25]

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[24] Indeed, if it is expensive to fill out the characteristics matrix, it would make sense to fill it out in priority order, researching the distinctions between the mechanisms only up to the point necessary to make a decision.
[25] A second observation is that if our sole purpose in this example is to select a mechanism, then the third criterion was redundant. That is, if we apply only screens (1), (2) and (4), we arrive at the same conclusion: NetBill.

5. Discussion

We have emphasized that when the analysis of payment mechanisms proceeds from the decisionmaker's viewpoint, only a very few of the many possible characteristics may be needed to make a selection. We expect, however, that some readers may be uncomfortable with what may seem to be too intensive an emphasis on individual decisionmakers, making independent decisions. Have we missed the most important consideration: that digital money users will want to adopt a mechanism that others are adopting? Won't the only characteristic that matters to most decisionmakers be that they adopt the "standard" mechanism?

We have no quibble with this prediction, but our purpose is not to predict which characteristics will be important to users. If widespread adoption is important to a decisionmaker, then that can be a characteristic in her vector, and it can be given a high rank when the vector is prioritized. Indeed, if this characteristic is dominant for some users, then one of our main points is reinforced: the list of characteristics needed for any particular decisionmaker to select a mechanism may be very short, and a careful quantification and weighting of numerous factors may be irrelevant when some characteristics are axiomatic (e.g., "must be a widely adopted standard").

On the other hand, it is well to remember that to date, no payment mechanism has been widely adopted as a standard. Unlike the speed with which Web browsers and HTML language modifications have become de facto standards, some payment mechanisms have been in use for over a year without critical mass gathering behind any of them. At present, every adopter is an early adopter, and by definition early adopters are those for whom selecting the successful standard is not as important as the value of selecting *some* mechanism and moving forward. We think it is almost surely true that payment mechanisms will exhibit **positive network externalities** ¾ that is, that users will value a mechanism more, the more other users who also use the mechanism ¾ and thus that payment mechanisms will be subject to the phenomena of critical mass and "tipping" (rapid standard adoption) that has characterized so many other software applications (see, e.g., [Katz and Shapiro 1994] for a discussion). But along the way, each individual decisionmaker needs to make her own decision, and for now, those decisions necessarily must depend on at least some criteria other than adoption of a standardized mechanism.

We propose an axiomatic approach to selecting a mechanism. The approach is designed to focus effort on information collection and analysis only to the extent needed to make a decision. But the method is fully general and includes cardinalization and selection by maximizing a weighted score as a special case. We have shown that trade-offs among desiderata are typically necessary, and that for the mechanisms currently available, the selection process reaches an outcome quickly. Further, although we have emphasized the selection problem, following our method will guide researchers to further development based on the needs of *users* who desire particular bundles of characteristics.

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Appendix Table 1: Characteristics of Payment Protocols

Easily Exchangeable: Easy to exchange as payment for other electronic tokens, paper cash, deposits in bank accounts, etc. Well-accepted and relatively fixed mechanisms exist for converting between various forms of money. Interoperable, fungible. *Example:* A transit fare card *is not* exchangeable for a money order; a money order *is* exchangeable for cash.

Private: Some or all of the elements of transaction information are hidden from some parties, either involved in or observing the transaction. Transaction elements include: amount, date, time, location, product, and identities of the buyer and seller.

Locally Scalable: The payment protocol supports many customers simultaneously buying goods; adding users does not create a bottleneck that slows transactions. In addition, the protocol does not place a limit on the total number of a given seller's customers or the number of transactions that can be made with a given seller.

Acceptable to Users: The payment protocol has (or has the potential to have) a large number of users. Acceptability is a function of: portability, no account required, buyer earns pre- and/or post-transactions float, easy to use, hardware independence, no encryption required, software installation not required, low fixed cost.

Low Fixed Costs: Average cost per transaction of adopting the payment protocol are low. Fixed costs is a function of hardware costs, hardware installation costs, software and software installation costs, account start-up costs.

Low Transactions Cost:

For micro transactions: The payment protocol is suitable for use in transactions with a value of one cent or less. Such efficiency may involve a tradeoff with security; may allow only the use of lightweight encryption or no encryption.

For large transactions: Fees charged by financial intermediary are low per transaction (as a percentage of the amount of transaction); the payment protocol is secure enough for use in large transactions.

Non-refutable: Parties can verify that a transaction took place, the data and/or amount of the transaction. A record may be produced. Non-refutability may involve a tradeoff with privacy.

Transferable: The payment instrument is not bonded to a particular individual; i.e., it can be used by someone other than the original owner. May involve a tradeoff with security.

Low Financial Risk: Is the buyer, seller, or financial intermediary subject to risk? The risk of financial loss to each party involved in the transaction is low/acceptable. The level of risk involved with use of a payment protocol is a function of its security. Loss to buyers can be limited by maximum amount transactions, false positive passwords in case of theft, approval required for large transactions. May involve tradeoff with unobtrusiveness.

Unobtrusive: The buyer does not need to frequently initiate new actions or pay; few steps are required to complete a transaction. May be particularly important in small transactions.

Anonymous: The identity of one or more parties in a transaction is hidden.

Immediately Respendable: A payee does not have to take an intermediate step after receiving payment to respend it. *Example:* A check must be deposited in a bank account before the money can be respent; it is not immediately respendable.

Two-Way: Peer-to-peer payments are possible. The payment instrument is transferable to other users without either party being required to attain registered merchant status. *Example:* A check is two-way; a credit card is not.

Low Transactions Delay: The time required to complete a transaction is low.

Portable: Security and use of payment mechanism are not dependent on any physical location.

Operational Today: Payment mechanism is available for use immediately.

Security Against Unauthorized Use: The device is not easily stolen and used. May be secure because of encryption, false positive passwords, etc.

Accessible: Users find process to be accessible, easy to effect, and quick. No special expertise required.

Tamper-resistant: Hard to tamper with, copy, forge, double-spend.

Monetary Value: A payment protocol has monetary value if it represents cash, a bank-authorized credit, or a bank-certified check. Acts as a medium of exchange. *Example*: A traveler's check has monetary value because its value is guaranteed by the issuing bank. A credit card does not because its use simply represents a promise to pay sometime in the future.

Off-line Operation: Use of the payment protocol does not require a network and/or real-time third-party authentication. This characteristic may be important if infrastructure reliability is an issue. A payment protocol requiring on-line operation may be subject to time delays during periods of network congestion; in addition, if the network goes down, the payment mechanism may not be acceptable. On-line operation may also limit scalability.

Divisible: Allows for the exchange of multiple low denomination instruments for a single high-denomination instrument.

Hardware Independent: For buyers, for sellers. Users do not need specialized hardware.

Storable: Able to be stored and retrieved remotely. Facilitates asynchronous exchange, allows payment mechanism to act as a store of value, adds stability to value of payment mechanism. Retrievable.

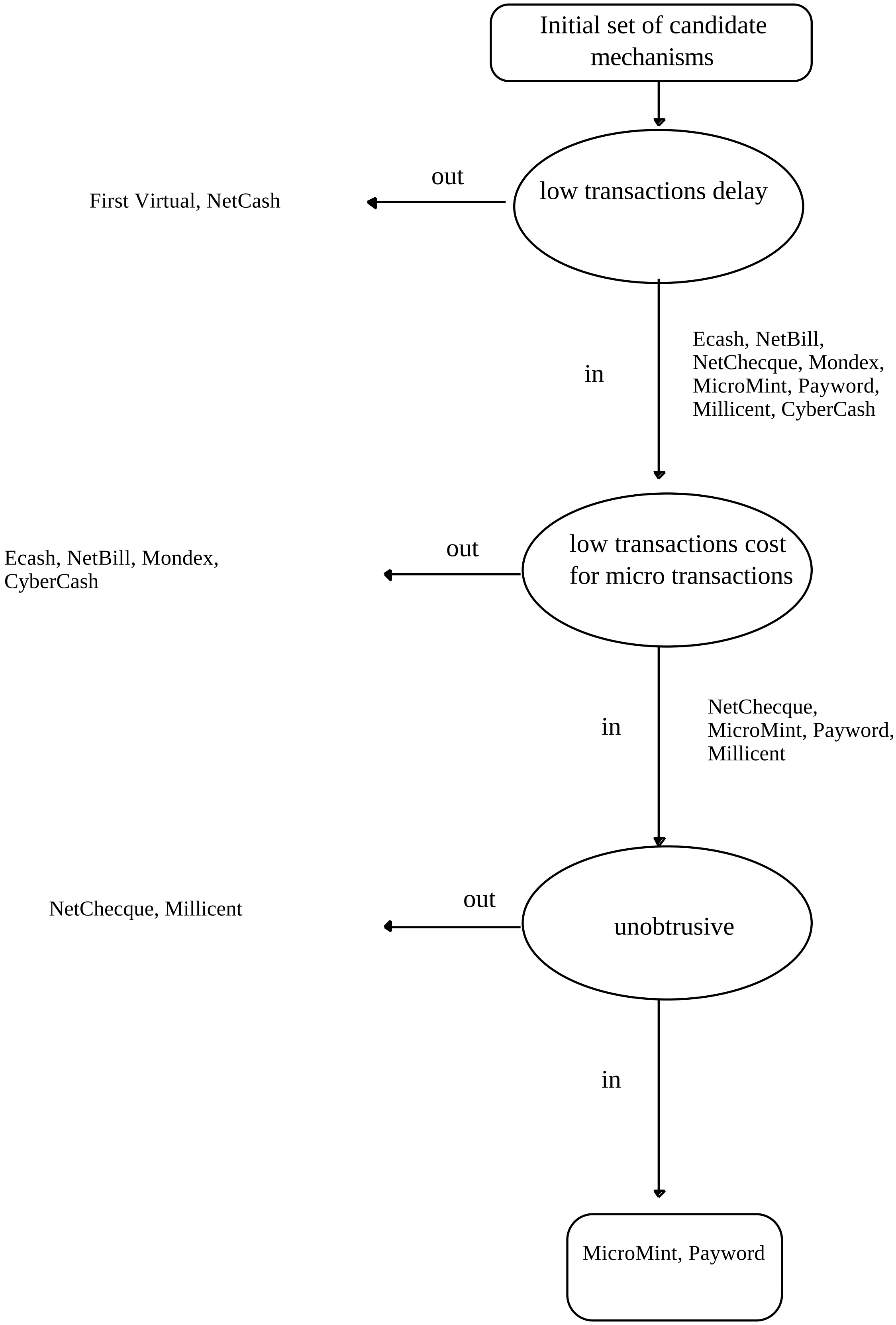
Float: Pre-transaction, post transaction. Does the buyer keep the float generated before the transaction occurs? After the transaction occurs? *Example*: Buyer keeps interest generated in an interest-bearing checking account before and after checks are written. Does not keep interest when using cash because no float is generated.

Account Required: Payment mechanism requires that users maintain an account with a vendor or payment mechanism provider; implies a lack of universality. May limit customer base for vendors accepting only this method of payment.

Appendix Table 2: Characterization of Conventional Payment Mechanisms

	Cash	Check	Credit Card	Debit Card	Money Order	Traveler's Check	Prepaid Card
Easily exchangeable	yes	somewhat	no	no	yes	yes	no
Locally scalable	yes	yes	yes	yes	yes	yes	yes
Acceptable to users	yes	yes	yes	yes	somewhat	somewhat	somewhat
Low transactions delay	yes	yes	yes	yes	yes	yes	yes
Low transactions cost:							
for small transactions	yes	no	no	no	no	no	?
for large transactions	no	yes	yes	yes	yes	yes	?
Low fixed costs (for seller)	yes	yes	yes	no	yes	yes	no
Non-refutable	no	yes	yes	yes	no	no	no
Transferable	yes	no	no	no	yes	no	no
Financial risk:							
Buyer risk?	yes	no	Up to $50	Limited	yes	no	yes
Seller risk?	no	yes	no	no	no	no	no
Unobtrusive	yes	yes	yes	yes	yes	yes	yes
Anonymous:							
for buyer	yes	no	no	no	yes	no	yes
for seller	possible	possible	no	no	possible	no	no
Immediately respendable	yes	no	no	no	possible	no	no
Security against unauthorized use	no	some	some	yes	no	some	possible
Two-way	yes	yes	no	no	yes	yes	no
Retrievable	yes	yes	yes	yes	yes	yes	yes
Tamper-resistant	yes	no	no	yes	yes	yes	yes
Off-line operation	yes	yes	no	no	yes	yes	no
Divisible	yes	yes	yes	yes	yes	somewhat	yes
Installation of software required	no	no	no	no	no	no	no
Operational today	yes	yes	yes	yes	yes	yes	limited
Hardware independent:							
for buyer	yes	yes	yes	yes	yes	yes	yes
for seller	yes	yes	no	no	yes	yes	?
Portable	yes	yes	no	no	yes	yes	no
Accessible	yes	yes	yes	yes	somewhat	somewhat	yes
Encryption required:							
for buyer	no	no	no	no	no	no	no
for seller	no	no	no	no	no	no	no
Buyer keeps pre-transaction float	no	yes	n/a	yes	no	no	no
Buyer keeps post-transaction float	no	yes	yes	no	no	no	no
Account required	no	yes	yes	yes	no	no	no
Monetary value	yes	no	no	yes	yes	yes	yes

Figure 1: Payment Mechanism Selection Example



Appendix Table 3: Characterization of Digital Payment Mechanisms

	First Virtual	NetBill	Millicent	Ecash	CyberCash	NetCheque	Mondex	NetCash	MicroMint	PayWord
Conventional Analog	Credit Card	Debit Card	Transit farecard	Coins	Credit Card	Check/Debit	Smart Card	Foreign Currency	Coins	Credit-based
Status	In Use	Trial	Proposed	In Use	In Use	Trial	Trial	In Use	Proposed	Proposed
Easily exchangeable	N/A	yes (4)	yes	yes	N/A	yes	yes	no	yes	N/A
Locally scalable	yes	limited	yes	yes	yes	yes	yes	limited	yes	yes
Low transactions delay	no	yes	yes	yes	yes	yes	yes	no	yes	yes
Low transactions cost:										
for micro transactions	no	no	yes	no	no	yes	no	no	yes	yes
for large transactions	yes	yes	no	yes	yes	yes	yes	yes	no	no
Low fixed costs (for seller)	yes	no	?	no	?	?	no	yes	?	?
Non-refutable	no	yes	no	no (7)	yes	?	?	no	no	no
Transferable	no	limited	no	no	no	no	no	yes	yes	no
Financial risk										
Buyer subject to risk?	no	low	low	low	low	low	low	low	low	low
Seller subject to risk?	yes	low	low	low	no	yes (8)	no	low	low	low
Unobtrusive (1)	no	yes	no	yes	yes	no	no	no	yes	yes
Anonymous:										
for buyer	no	no	no	yes	no	no	no	weak	no	no
for seller	no	no	no	no	no	no	no	no	no	no
Immediately respendable	no	no	no	no	no	no	yes	yes	no	no
Two-way	no	no	no	yes	no	?	yes	yes	no	no
Secure from theft	yes	limited	yes	yes	limited	limited	somewhat (9)	variable (10)	limited	yes
Secure from eavesdropping	yes	yes	yes	yes	yes	yes	limited	variable (10)	limited	limited
Divisible	yes	yes	yes	yes	yes	yes	yes	limited	yes	yes
Atomic transactions	no	yes	no	no	no	no	no	no	no	no
Suitable for information goods?	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Suitable for tangible goods?	no (3)	no (5)	no	yes	yes	yes	yes	?	no	no
Privacy	some	high	some	high	some	some	low	high	low	some
Acceptable to buyers:										
Portable (2)	no	no	no	no	no	no	yes	no	no	no
Account required	yes	yes	yes	yes	yes	yes	yes	no	yes	yes
Buyer keeps:										
pre-transactions float	yes	no	varies	no	yes	no	no	no	no	yes
post-transactions float	yes	varies (6)	varies	no	yes	no	no	no	no	yes
Low fixed costs	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Globally Scalable	limited	yes	yes	limited	limited	yes	yes	limited	yes	yes
Version of Mechanism Analyzed		debit model	secure w/o encryption	Mark Twain Bank	0.8	debit model	Swindon trial	2.0a4	debit, w/o variations & extensions	w/o variations & extensions
Company	First Virtual Holdings	Carnegie Mellon	DEC	DigiCash	CyberCash	USC-ISI	Mondex Int'l.	Software Agents, Inc.	MIT/Weizmann Institute of Science	

Notes:

(1) The payment mechanism's obtrusiveness is evaluated on the transaction size for which it is optimized.
(2) Payment mechanisms are considered not portable even if they ***could*** be portable if used on a laptop computer.
(3) First Virtual's current implementation is most suitable for information goods; however, in a few cases, tangible goods are being sold using First Virtual.
(4) When the user's NetBill account is linked to a credit card account, the characteristic "Easily Exchangeable" is not applicable.
(5) NetBill is optimized for transactions involving information goods; however, it may also be possible to use NetBill for exchanging tangible goods.
(6) If the NetBill account is funded through a credit card, it is possible to earn post-transactions float.
(7) Ecash is non-refutable if anonymity is given up.

(8) The seller is subject to lower risk if the option of clearing the check in real-time, which may require an extra charge, is exercised.
(9) The card can be locked, and if stolen would be useless.
(10) The level of security depends on the security of the email program being used.