BoLT: Building on Local Trust to Solve Lending Market Failure

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Abstract

Accessible and fair lending markets are essential for an economy to work for everyone. Unfortunately, lending markets are riddled with issues of asymmetric information, imperfect competition, and systemic bias making it hard for small businesses, the unbanked, and those who are already marginalized or economically disadvantaged to obtain capital; which leads to increased income inequality.

These systemic and long-standing problems in lending markets have been exacerbated by the unprecedented slowdown created by Covid-19. Small businesses everywhere have been shut down and are threatened as lending markets are not able to provide the liquidity needed to survive the crisis. Government assistance has been slow, uncertain, and inadequate. In response, many communities and businesses are creating new systems to help ride out the storm: e.g., towns and businesses are issuing their own scrip and companies are offering discounted gift cards that can be redeemed in the future. These systems face significant challenges including information hiding, liquidity, fraud, problems with valuation, and acceptance.

Building on Local Trust (BoLT) is a universal solution that generalizes the existing ad hoc proposals and eliminates the problems of asymmetric information, imperfect competition, and systemic bias. BoLT is a bottom-up, community-based system that uses a public ledger to create a transparent and universally accessible system where businesses can raise money by selling claims to their future goods and services at a discount. Furthermore, the claims are immediately tradeable and can function as a medium of exchange within the community.

1 Introduction

It is well recognized that the mainstream banking system has continually failed to meet the needs of disadvantaged communities [24]. Recently emerging evidence shows it also fails to meet the needs of small to medium-sized businesses [31]. The inability to access capital is a huge barrier to growth. Times of crisis exacerbate this problem.

The failure of traditional banks to adequately and equitably loan money can be attributed to their aversion for risk [28] and the lack of accepted methods for evaluating the risk of small businesses or borrowers in disadvantaged communities. Combined with the high transaction costs of borrowing, these issues result in an inadequate supply of capital [28]. Furthermore, as borrowing has become an institutionalized service, personal reputation and relationships, once the most important signals for loan-making, have seen little use in determining "credit scores" or the likelihood of repayment. The days of the Bailey Building and Loan [7] are long gone.

Sourcing funds in the community for the community seems like the solution to this problem. Local members of the community can vote with their feet by "investing" in the businesses they care about. However, there needs to be an infrastructure to raise those funds. To this end, we propose BoLT, a system that builds on local trust to create a transparent, equal access, bottom-up funding and exchange system that can create liquidity and increase access to capital for all.

To make BoLT more concrete, we present a simple use case. Consider that Alice's Bakery is currently closed because of the pandemic. Even though the bakery is closed, Alice still has to pay rent, her employees, etc. Luckily, Alice has a local following for her baked goods. She contacts her customers and offers to sell them Alice bolts. For this introductory example the reader can think of bolts as digital gift cards which her customers can use in six months. In the meantime, as a bonus, her gift cards will pay 10%/year interest. Let us say that Bob bought \$20 worth of Alice bolts (or 20ϟAlice); in six months he will be able to buy \$21 worth of baked goods and Alice gets the funds to keep her bakery going.

With BoLT, the story doesn't end there. Bob has given up some versatility (since dollars are more widely accepted than ϟAlice), but the interest he gains should compensate for his acceptance of risk and temporary loss of versatility. However, because Alice has a local following and a good reputation, her bolts are in demand. Unlike a traditional loan where the lender's funds are completely tied up, Bob still holds a liquid asset. Bob can use his ϟAlice immediately to trade with anyone else on the BoLT system. For example, when Bob goes into Charlie's Corner store to buy something his wallet software and Charlie's Point-of-sale (POS) terminal will select a bolt they both agree on to complete the purchase. Why would Charlie (or, his POS terminal) take an ϟAlice from Bob? Because, Charlie believes someone else will accept them from him. In other words, Charlie expects to buy baked goods from Alice (and Alice is required to take her own bolts) or he expects he can trade his ϟAlice with someone else who (1) wants to buy baked goods from Alice, or (2) will give him another bolt, or (3) he can find a market for ϟAlice in US\$ (We use US\$ as a stand in for the government issued fiat currency in which the bolt was originally issued.) BoLT uses a public ledger to make all transactions visible which will allow users to see and evaluate the web of trust in their community. In this example, the web of trust shows that Bob and Charlie have some trust in Alice. Over time, overlapping trading circles should allow bolts to trade beyond the community in which they were created.

More abstractly, a bolt is an electronic IOU (which may be, but does not have to be, backed by collateral). It is a promise that if presented to the writer of the IOU that they will accept it at full value. Similarly, a US dollar (like any fiat currency) represents a promise by the United States government that it will accept said dollar at full value. The promise that an IOU will be accepted by its issuer is enough to make it valuable to anyone who wants to do business with the issuer. Additionally, if enough people believe that a sufficient number of agents will accept the IOU, then it becomes a medium of exchange [22, 23]. BoLT uses the public ledger to allow everyone to evaluate who is willing to take issued bolts.

Going back to our example, in the end, Charlie will be willing to take ⚡Alice, not because he plans to go to Alice's bakery in the future, but because he sees that other people are willing to take Alice's bolts. As we show later in the paper, various metrics can be used to evaluate the data on the ledger to determine the acceptability of bolts. Furthermore, these metrics can be used to account for the risk of acceptability by setting interest rates on bolts. All of which can be done automatically by a user's wallet software.

In the rest of this paper, we review the issues facing lending markets which have been exacerbated by the pandemic, outline the historical inspirations behind BoLT, and describe how BoLT works and its underlying implementation. We then evaluate BoLT in terms of its scalability and how effective it is under different social networks. Finally, we discuss some of the challenges in rolling it out and then conclude.

2 Issues in Traditional Lending Markets

Here we review some of the issues with lending markets, some of which are made even starker in disadvantaged communities and during economic crises. We then examine the features of a fairer and more accessible lending system.

2.1 Traditional Banks

Traditional liquidity tools provided by financial institutions are often inaccessible to many businesses. This is due to factors including but not limited to asymmetric information [44], imperfect competition [10], systemic racial bias [24], and avoidance of small-sized loans (i.e., size bias) [9, 28]. As a result, many businesses deemed valuable and important by local communities are unable to grow, let alone survive economic crises, as they cannot secure loans from commercial banks [2]. Additionally, commercial banks are less and less eager to make loans in the 50-200K range [9], the critical amount needed by small and medium-sized businesses [19]. Furthermore, commercial banks are the main supplier of non-usurious loans for small to medium sized businesses. Thus, when demand for loans increase (as in economic downturns), banks possess inordinate power to raise the cost of borrowing and push out financially struggling borrowers [10].

Following the seminal work of Stiglitz and Weiss modeling the negative impact of asymmetric information on lending markets [44], others have shown that lack of competition is also an important issue as it leads to increases in the cost of borrowing, while asymmetric information pushes financially struggling businesses out of lending markets [10]. These findings make it clear that many businesses struggle to raise money due to the structural issues in lending markets.

Another issue within lending markets is systemic bias. The 2020 US Federal Reserve data indicate that less than 47% of financing applications filed by African American business owners are approved [27]. This figure is in stark contrast with the national loan approval rate of 88.2% [11]. The systemic discrimination experienced by African Americans is also very present in mortgage markets within which Black and Latinx applicants face lower approval rates and higher interest rates [24]. These studies suggest that significant economic value is lost due to the failure of lending markets.

2.2 Lending Market Problems Exacerbated by Covid-19

The problems that lending markets face have been further aggravated by the downturn caused by the Covid-19 pandemic. Never before have over 50 million Americans filed for unemployment in just three short months [25]. With businesses shut down, not only are workers out of a job, but the businesses are fighting for survival [32]. The government has responded with the largest stimulus bill in the history of the United States [20]. These measures, however, have not been enough to alleviate the damage caused by the crisis [32].

It has been demonstrated that economic crises can further exacerbate issues such as adverse selection within lending markets [29]. Indeed, as the current crisis unfolds, more evidence has come to light that suggests that lending market issues have been aggravated as lenders have become increasingly risk-averse due to a grim economic outlook [31].

2.3 Link to Income Inequality

As the previous sections have established, lending inequality deters small and medium-sized businesses from accessing capital. The consequences of lending inequality, however, do not stop there as lending inequality is significantly associated with income inequality [35]. Loan availability for micro, small, and medium-sized businesses all contribute to reducing income inequality, while loans to larger-sized businesses exacerbate the issue. Additionally, the labor intensive nature of smaller businesses provides job openings to the unemployed which contributes greatly to the reduction of income inequality [35]. The lack of loans approved for smaller businesses thus directly contributes to income inequality.

2.4 Lessons from the Literature

The discussion above provides a framework for designing a better lending market. First, it is clear that any engineered solution should increase transparency to eliminate the problems of asymmetric information (e.g. a public ledger storing the financial transactions of the community). Second, the solution should increase lending opportunities for all by reducing imperfect competition (e.g., increasing the supply of loans by allowing the average person to lend money to local businesses). Third, it should be community-based in order to reduce systemic bias (e.g., disadvantaged communities can get access to funds by effectively raising money through their local community members who are less likely to discriminate). Finally, the proposed alternative should increase the supply of smaller loans in order to overcome size bias (e.g., by allowing the average citizen to lend smaller loans).

3 Historical Precedent

Many communities and businesses have created systems to help overcome the issues present in lending markets and the current economic downturn: E.g., communities are issuing local business supported currencies, towns are issuing their own scrip, companies are offering bonuses on gift card purchases which can be redeemed in the future, and community oriented crowdfunding sites are offering gift cards with a premium.

These approaches are trying to solve some of the issues existing in lending markets at a local level, but they face significant challenges including information hiding, liquidity, fraud, and problems with valuation and acceptance. While not perfect, ad hoc local systems can alleviate the issues within lending markets by allowing local businesses to raise funds based on a system of trust even in grim times and serve as a source of inspiration for any solution that aims to make lending markets fair and accessible.

3.1 Irish Banking Strikes

Between 1966 and 1976, Irish banks went on strikes that lasted about a year in total. During the strikes, almost all Irish citizens were locked out of their savings and not able to use the banks. Up to 80% of the country's money supply was inaccessible. In response to the strike, the Irish replaced the tasks that the banking system would normally handle with a system based on trust. For instance, instead of depositing checks, people started to circulate checks written by each other as cash. Essentially, these checks were backed only by "good faith." Contrary to expectations, the crisis ended up having little negative impact on the Irish economy. In fact, the GDP of Ireland grew during each of the strikes, as much as 2.7% in the longest one, despite the financial downturn brought on by the 1970s energy crises [26].

Antoin Murphy, a professor at the Trinity College of Ireland, explains the success by the ability of people to assess risk "based on a vast pool of information available to transactors on the credit-worthiness of other transactors" [30]. In particular, the local publicans were considered a trust authority. If they signed the back of someone's check, it essentially became as good as cash. The highly reliable nature of this trust system was proven out once the banks ended their strikes and almost every check written during the strike period successfully cleared [18]. The system was so successful that many economists cannot point to any of its failures other than its rather opaque nature. That is, the amount of checks written by people was not publicly available making it hard to evaluate whether a check was backed by actual assets.

The ability of the Irish to overcome the bank strikes demonstrates the potential of trust based systems, however, not all communities are close to achieving perfect information about the risk profile of its members nor do other communities trust their publicans as much as the Irish. This seems to suggest that in order for community-based approaches to be effective they have to promote a level of transparency that can allow a correct assessment of the risk of borrowers.

3.2 Berkshares

In 1989 Frank Tortoriello ran a deli in Great Barrington, MA [21]. He needed a loan of $4,500 to expand his deli but could not get a loan from his local bank. Instead, he issued "Deli Dollars," a scrip that he personally guaranteed. A customer could buy $10 worth of deli dollars for $8. The deli dollars could then be redeemed for $10 of goods at Frank's deli at a future date. Within a month he raised $5,000 and successfully moved his deli.

Notably, Deli Dollars circulated beyond their original purchasers and the notes began to circulate as regular currency:

> "Parents passed them on to their student children to make sure they were eating properly [. . .] Employers passed them to workers as Christmas gifts [. . .] The minister ate at the deli and soon notes started turning up in his collection box. Even the bank which refused Frank a loan in the first place circulated deli dollars." [21]

Tortoriello's small business was able to succeed because locals became loan suppliers. The high velocity of the Deli Dollars was a direct result of the high local trust in Tortoriello's business. Tortoriello's reputation effectively overcame the problem of asymmetric of information (i.e., between commercial banks and Mr.Tortoriello) by going to a source that was aware of his reliability. It also effectively solved the problem of imperfect competition and size bias, since Mr.Tortoriello was able to increase the supply of small loans for himself by sourcing it from his customers.

Frank's success eventually led to the modern day Berkshares [3]. Berkshares are a locally issued scrip that can be redeemed at nine banks in the region. The exchange rate is 95 cents per Berkshare and they can be redeemed at stores for their dollar value. As in Ireland in the 1970s, the Berkshares experiment shows the importance of trust in overcoming asymmetric information. Additionally, Berkshares demonstrate how crowdfunding can increase competition and solve the issue of size bias. However, the problems that come with opacity suggest that transparency is required to allow the system to expand organically beyond a single community.

3.3 Honeycomb Loyalty Bonds

The Honeycomb loyalty bond program [19] is a gift card system with the purpose of raising money for businesses during the Covid-19 lock down. The program works as follows: customers buy gift cards that are sent to them in 4 installments over a period of 24 months; since the gift cards are not directly redeemable the businesses compensate the customers by sending a total gift card amount that is 1.3x the face value of the gift card.

The Honeycomb Loyalty Bond program has successfully raised thousands of dollars for many businesses. It overcomes the problems of imperfect competition and size bias by allowing customers of businesses to effectively become small loan suppliers. However, despite increasing competition, the Honeycomb system fails to lower borrowing costs; reducing the benefit to the borrowers. This suggests the importance of a decentralized lending system which can reduce the high transaction costs exhibited by the presence of middle-men.

3.4 Local Exchange Trading Systems (LETS)

Local Exchange Trading Systems (LETS) are democratically-operated community enterprises that allow community members to trade goods and services by using a local currency not backed by the government [36]. The main characteristics of LETS are 1) equivalence of the LETS currency to the local currency, that is one unit of the LETS currency is equivalent to one unit of the local currency, 2) full disclosure of all interactions, that is all interactions are stored and are available for everyone to see, and 3) members earn and spend credits that stay within the trading community [33]. LETS encourages those who lack currency to participate in the trading system, primarily by allowing currency to be exchanged for jobs/services. In effect, people are allowed to spend even when they don't own any credits because the negative balance can be repaid in the future.

The nature of LETS allows members to become lenders and borrowers of small loans thus increasing competition, reducing the cost of borrowing and overcoming size bias. Additionally, the requirement of disclosure on all interactions reduces issues with asymmetric information since the financial standing of all participants to the system are available to all. LETS is an example of a pre-internet public ledger. By making all transactions public, local community members were able to both advertise their goods and services as well as ensure that local members in the community stayed within reasonable bounds in terms of their debt. LETS seem to suggest that public ledgers storing all transactions are essential in fostering trust in alternative lending systems.

3.5 Wooden Currency in Tenino City

In the midst of the Great Depression, Tenino issued wooden currency to counter the economic downturn. When the local bank closed, residents agreed to pay the city with legal tender in exchange for the wooden currency once the banks reopened [42]. Now, the pandemic has pushed the city to take on similar measures [17].

Low-income local citizens are being given scrip from the city, to be used at local retailers. The retailers can exchange the scrip for US currency with the city. In addition to granting "stimulus" money to residents, the issuance of the wooden currency encourages money from the city to stay within the Tenino community. The city clerk, Millard, highlighted, "Tenino citizens paid this money into the city, and the city has the money to use for the benefit of Tenino citizens" [41].

In creating this system, the Tenino local government has emphasized the strength of local support. Local support overcame information asymmetries because citizens had a full picture of how local retailers were doing. Though the support is restricted within the local community and does not offer much help to outsiders, it capitalizes on local trust in communities to prevent a major economic crisis [41]. Furthermore, Tenino's experiment seems to suggest that alternative medium exchanges (i.e., scrips) can increase the welfare of communities.

3.6 Creditos during 2002 Argentina Great Depression

In 1998, Argentina entered a recession that would last until the summer of 2002. During this recession, inequality and unemployment greatly increased leading to the rise of alternative currencies. Exchange clubs emerged and grew in popularity. At these clubs, members would exchange goods and services for the club's private fiat currency, the credito. At the time of joining, members would pay a small acceptance fee in exchange for a one time credito loan. The members could then use their acquired creditos to buy goods and services. To attend meetings, members had to bring products or services to sell [8].

These exchange clubs were able to isolate their members from the economic crisis happening in Argentina as members exclusively used exchange clubs to sell and buy goods and services effectively creating an alternative economic system independent of the Argentine economy. The nature of these local meetings eliminated asymmetric information between members as the club managers ensured that every member provided enough goods and services to be part of the club making all members financially reliable. The success of this system was measured by comparing credito users and non credito users with same characteristics. Results showed that the average benefit for people accepting creditos in trade was around 100 pesos per month. Additionally, the adoption of creditos by users throughout was estimated to raise Argentina's income by an amount equal to 1.17% of their share in the Argentine GDP. Argentina's experience with creditos demonstrates that alternative currencies can increase welfare and shield communities from economic shocks affecting their countries [8].

3.7 Lessons from Experiments in Alternative Lending Markets

Community-based solutions give us insights on the properties of efficient alternative lending markets, but also point to potential issues that such an alternative must overcome. First, previous alternative lending markets suggest that a public ledger and community based lending system can overcome asymmetric information. Many businesses can raise funds by leveraging their reputation within their community since locals who deal with the business and its owner on a daily basis have a fuller picture of the value of the business to the community.

Second, when the local community become suppliers of loans competition in lending markets is increased, the cost of borrowing is reduced, and local businesses get more access to capital. Local businesses can rely on previously-established trust in their local communities to generate loans. Note how this differs from global-based micro-lending platforms, e.g., Kiva.org, since the lenders there have neither direct contact with the borrowers nor is there a public ledger which can be used to export local trust.

Third, allowing loans to be backed by the goods and services of the borrower rather than strictly as claims to the future wealth of the borrowers increases the supply of small loans. Customers who deal with their local businesses regularly are incentivized to give small loans to businesses since this is indistinguishable from buying a gift card.

Despite the positive outcomes of community-based financing, current solutions are still lacking. Most of the transactions in these community-based systems are designed to be executed in-person. Furthermore, most of the community solutions we discussed do not publicly disclose the amount of "loans" circulating in the market making it hard for community members to trust or evaluate such systems. LETS attempts to solve this issue with weekly communication of people's balances and exchanges. As a further consequence, the lack of transparency prevents the trust-based system to easily expand beyond the immediate, local community.

Insights from the economic literature and previous alternative lending markets suggests that any solution that aims to fix issues within lending markets needs to be 1) community and trust-based, 2) allowing regular individuals to become supplier of loans, 3) backed by goods and services, 4) transparent/public ledger based, 5) secure and 6) easily implementable and scalable to any community.

4 Peer-to-Peer Scrip Systems

4.1 P2P Scrip Systems

So far, we have reviewed the literature exposing issues within lending markets and have studied historical examples of lending and scrip systems that emerged to meet a pressing economic need. Using these foundations, we described guiding principles and insights to design an alternative scrip system that could provide an efficient alternative to traditional lending markets. In this section, we will study the economic efficiency of scrip systems such as BoLT from a game theoretic perspective.

In a 2006 paper, E. Friedman, J. Halpern, and Ian Kash, model a game over a peer-to-peer (P2P) network where agents offer services to each other. The paper shows that welfare in P2P exchange systems increases as scrips are added into the system. That is, the authors show that when users are able to use the scrips they have earned to purchase the services of other users in the system, the utility derived by the users of the system as a whole increases [16]. Although BoLT is a more complicated game then the one described in the authors' paper, the P2P scrips system and exchange model that the authors analyze is at the core of BoLT. The authors' findings seem to corroborate the welfare improving aspects of a system like BoLT.

Furthermore, the game-theoretic literature also provides us with clues on the design of the incentive structures of BoLT. Although BoLT is a community focused solution, we hope that the system will be used by any user to invest into any communities. However, this also implies that users outside of the community will have to grow trust into businesses outside of their community artificially through the data available on the public ledger. As a result, due to assymetric information investors might be taking on too much risk putting BoLT's stability into danger. Recent works have explored ways to limit the propagation of loss caused in credit network when users default.

4.2 Incentives: Theoretic Insights

A 2020 paper Geoffrey Ramseyer, Ashish Goel and David Maziers, analyzes different constraint types on agents and groups of agents in order to bound the total amount of a loss in the case that an agent defaults. In particular, the authors show that by introducing solvency guarantees for each agent, i.e., that if the agent default creditors will be paid back partially or totally, the combinatorial structure of the credit network is not affected and the total amount loss in case of default is bounded [39]. This result is important because it means that by introducing solvency guarantees to BoLT we effectively make the BoLT network safer and we do not affect the interactions between users (i.e., the combinatorial structure of the social graph of BoLT).

This result motivates our introduction of a solvency guarantee system for each user issuing BoLTs that we call trustlines. Trustlines essentially allow other users to guarantee that they will accept another user's BoLT up to a certain amount no matter the state of the world. One might critique that the trustlines system is only dependent on the assumption that users will use the trustlines system. [14] analyze the formation of credit lines (what we call trustlines) and prove that in large networks, users' best response strategies on how to extend credit lines converges to a social optimum. This implies that one

```
typedef uint BoltId;            // Unique identifier of a Definition
typedef uint Date;              // Calendar date and time
typedef uint FixedPoint;        // a fixedpoint number with 20 binary digits after binary point
typedef uint OfferId;           // unique identifier of an offer

class BoltDefinition {            // The underlying definition of a Bolt issued by `issuer`
  address issuer;
  BoltId ID;                      // UUID of this bolt definition
  Date maturity;
  Interest interest;
  BuyBack buyback;
  BoltId redeem;
}

// A certain `value` of bolt's with definition `ID`
class Instance {
  BoltId ID;                    // ID of underlying bolt definition
  FixedPoint value;
}

// Declaration by `truster` to accept all Bolts of the class `trusted` upto `amount` until
// `expiration`.
class Trust {
  address truster;
  BoltId trusted;               // any at least as good as 'trusted'
  FixedPoint amount;
  Date Expiration;
}

// A bid of `value` of `bider`'s bolts made by `offerer` for upto `value`*`exchangeRate`
// bolts that meet the `wants` specification.
class ExchangeOffer {
  address offerer;
  OfferId id;
  BoltId selling;
  FixedPoint value;
  FixedPoint exchangeRate;
  BoltId wants;               // any at least as good as 'wants'
}

// specification of the buyback for a bolt.
class BuyBack {
  FixedPoint fee;               // Fee (per bolt) for executing buyback (in buyback bolts)
  BoltId[] bolts;               // A list of BoltId's that can be used (or better) for buyback.
}                               // Only 1 BoltId per issuer is allowed.

// Simple interest specification
class Interest {
  FixedPoint rate;      // percentage paid per day of SIMPLE interest.
  uint number;          // total number of payments (after which no more interest will accrue)
  Date start;           // date that interest will start to be paid, i.e.,
}                       // start+1day at 0GMT will be first time interest is paid.

// Approval by issuer for minter to be able to mint a BoltDefinition created by issuer
class MintApproval {
  address issuer;
  address minter;
  FixedPoint mintLimit;
  Date expiration;
}
```

Figure 1: *The data structures used for the BoLT API and Ledger entries.*

would expect the creation of enough trustlines for the system to bound the loss that might be caused by the default of another user.

Although trustlines allow us to alleviate the impact of defaults caused by solvency issues (i.e., agents have more liabilities than assets) on the BoLT system, they might not help with liquidity crises and even exacerbate them. That is, the trustlines system does not bound the loss of value that might be caused by users defaulting because the BoLTs they own are not easily tradable. That is, as opposed to real world transactions where we know that fiat currencies are guaranteed to be existed by everyone, in BoLT this is not the case. However, it turns out that liquidity in systems such as BoLT is indeed similar to real-world centralized currency systems. This issue is one taken into consideration by [13]. The authors of the paper consider the risk of default that might arise in a system in which users can issue their own IOUs. They prove that the transaction failure probability in a number of well-known graph families goes to 0 as the size, density and credit capacity of the network increases. The authors then compare liquidity levels in systems such as BoLT and centralized real world currency systems and prove that liquidity in both systems is comparable.

In this section, we have reviewed the theoretic aspects of P2P credit network systems. We have shown that the introduction of scrip in P2P credit networks systems increases welfare. We then analyzed risks within P2P credit network and discussed some mechanisms to limit these risks.

5 BoLT: A Bottom-Up Solution

BoLT combines ideas from past implementations of local currencies and discounted gift cards with modern cryptographic primitives and cryptocurrencies to create a low friction, bottom-up funding and exchange system focused on local communities. BoLT uses digital objects to represent "gift-cards" which can be redeemed for goods and services and optionally fiat currency. We call these digital gift-cards *bolts*. Each bolt is issued by a user of the system for a particular dollar amount. If the bolt can be redeemed for goods and services now, then we call it a *certificate*. Certificates are contracts that are defined by a dollar amount which can be redeemed for the goods and services of the business that issued it. *Commitments* are bolts that do not have to be accepted by the issuer until the maturity date is reached, i.e., after the maturity date a commitment becomes a certificate. Bolts may be issued with the option to redeem them for fiat currency, in addition to goods and services.

The enabling technology behind BoLT is the public ledger on which all bolts are issued and traded. Wallet software is used to make changes to the ledger. By making all transactions visible to all users the ledger serves as a distributed Irish Publican; allowing users to determine for themselves which bolts are useful.

5.1 Overview

Businesses can raise funds by incentivizing customers or investors with an interest rate attached to their bolts. For instance, if a business needs to raise $1000 to pay its expenses but knows that it is going to be shutdown for the next year due to a pandemic, it can sell commitments that will mature in one year. To entice users, who are probably its local customers, the business can attach an interest rate to the commitments so that they are worth more than their original amount at maturity. During the next year, the commitment can be traded for other bolts, or used to purchase goods and services from anyone in the system who will accept it. The key idea here is that the customer was able to help its local business, but not tie up their money—they can spend or trade the commitment with anyone else who will accept it.

5.2 The Nuts and Bolts

The public ledger underlying BoLT supports seven basic transactions (see Figure 2) that implement the creation, transfer, and exchange of bolts as well as the extension of trust. These seven basic transactions are created and manipulated by wallets using the BoLT API (see Figure 3). For example, `createBoltSpecification` is called by a user to create a new kind of bolt that can be issued by that user. Once a specification for a bolt has been created, the user (or her wallet) calls the `mint` function to create new instances of the specification, i.e., new bolts issued by the user. The `mint(id, amount)` function results in the user having `amount` of bolts as specified by `id` deposited in her wallet. As shown in Figure 3, only the issuer of the `id` (or anyone the issuer authorized with a `mintAuthorize` call) can mint new bolts based on that bolt specification.

Once there are bolts in a user's wallet, they have four options. They can:

1. Transfer the bolts to another user (using the `transfer` function) in exchange for a goods, services, or currency.
2. Offer to exchange their newly created bolts for other bolts in the system with `offerExchange`.
3. Accept an an outstanding offer (if any) for the user's bolts with `acceptOffer`.
4. Or, destroy the bolts using `destroy`.

Beyond these basic mechanisms there are three additional API calls to buybacks bolts (`buyback`), to indicate the acceptance of bolts issued by someone else (`extendTrust`), and to delegate minting authority (`mintAuthorize`).

Creation

Each bolt is defined by its issuer, a maturity date, how much (if any) interest it pays, whether or not it is redeemable for fiat currency, and whether or not the issuer can buy it back. The maturity date specifies when the bolt can be used to purchase goods and services from the issuer. The only difference between a certificate (i.e., a bolt past its maturity date) and a commitment (a bolt with a future maturity date) is that the system requires that an issuer must unconditionally accept any certificates which they issued. Before the maturity date, all bolts are treated equally and can be traded and exchanged with any user willing to accept them. After the maturity date a commitment becomes a certificate. A bolt can optionally have an interest rate specification associated with it. If so, then the value of the bolt will include any accrued interest. An issuer can optionally specify a set of other bolts that can be used to buyback the bolt.

Note that the interest rate specification is independent of the maturity date. As shown in Figure 1, the issuer can determine the simple interest rate, the start date (which can be in the future) at which interest will begin to accrue, and the length of

```
Create:     <address issuer, BoltId id, Date maturity, Interest interest, BuyBack buyback>
Mint:       <BoltId kind, FixedPoint value>
Transfer:   <TransferId id, address from, address to, BoltId kind, FixedPoint value>
Trustline:  <address truster, BoltClass kind, FixedPoint value, Date expiration>
Offer:      <OfferId id, address bidder, BoltId kind, FixedPoint value, FixedPoint exchRate, BoltId wants>
Revoke:     <OfferId id>
Authorized: <BoltId id, address minter, FixedPoint mintLimit, Date expiration>
```

Figure 2: *The seven different kinds of ledger entries used by BoLT.*

```
createBoltSpecification(Date maturity, Interest interest, BuyBack buyback, BoltId redeem)
   ⟹ Create <sender, fresh(), maturity, interest, buyback, redeem>

mint(BoltId kind, FixedPoint value)
   requires: sender == kind.issuer
             OR (kind.minters[sender].mintLimit >= value
             AND kind.minters[sender].expiration > now)
   ⟹ Mint <sender, kind, value>

transfer(address to, BoltId kind, FixedPoint value)
   requires: value of kind ∈ sender
   ⟹ Transfer <sender, to, kind, value>

destroy(BoltId kind, FixedPoint value)
   requires: (sender == kind.issuer
             OR (kind.minters[sender].mintLimit > 0 AND kind.minters[sender].expiration >
                 now))
             AND value of kind ∈ sender
   ⟹ Transfer <sender, 0, kind, value>

offerExchange(BoltId kind, FixedPoint value, FixedPoint exchRate, BoltId wants)
   ⟹ Offer <fresh(), sender, kind, value, exchRate, wants>

revokeExchange(OfferId id)
   requires: sender == id.offerer
   ⟹ Revoke <id>

acceptOffer(OfferId offer, BoltId kind, FixedPoint value)
   requires: value of kind ∈ sender
             kind ≥ offer.wants
             value == offer.value ∗ offer.exchangeRate
   ⟹ Transfer <offer.offerer, sender, offer.selling, offer.value>
   ⟹ Transfer <sender, offer.offerer, kind, value>

buyback(address owner, BoltId buy, BoltId pay, FixedPoint value)
   requires: pay ≥ b for some b ∈ buy.buyback.bolts
             buy.buyback.fee * value of pay ∈ sender
   ⟹ Transfer(owner, sender, buy, value)
   ⟹ Transfer(sender, owner, pay, value * buy.buyback.fee)

mintAuthorize(address minter, BoltId kind, FixedPoint mintLimit, Date expiration)
   requires: sender == kind.issuer
   ⟹ MintPrivilege(kind, minter, mintLimit, expiration)

extendTrust(BoltId kind, FixedPoint maxValue, Date expiration)
   ⟹ Trust <sender, kind, maxValue, expiration>
```

Figure 3: *The BoLT ledger API calls. The first eight API calls are used to manage the creation, destruction, transfer, and exchange of bolts. The last call is used to record a trustline. Each function, if its requirements are met, will cause the entries after the* $\Longrightarrow$ *to be recorded on the ledger.* $\mathit{fresh}()$ *generates a unique identifier of the appropriate type. The types listed here are defined in Figure 1. Not shown here are the cryptographic primitives that ensure, for example, that the* `sender` *is the user issuing the API call. We abuse the dot notation by allowing a '.' to be applied to an id when we mean the underlying structure identified by the id.*

time it will accrue. Interest accumulates automatically on a daily basis.

Buybacks

The buyback option is included so that an issuer whose circumstances have changed can reduce their interest burden. For example, suppose Frank currently cannot get anyone to accept his bolts unless the bolts pay 3% interest. Also, suppose that George is considered a risk free issuer whose bolts are in wide circulation. Frank creates new bolts which pay 3% interest, but can be bought back with George bolts. Frank's customers are happy with this, since George's bolts are accepted everywhere. Sometime in the future Frank's situation has changed and he has access to more funds, in particular, George bolts. Now, Frank can issue a `buyback` which automatically swaps the Frank bolts for their current value (plus any fee originally specified when the bolts were created) in George bolts. Frank can then `destroy` his reclaimed bolts which reduces his interest costs. Without the buyback option, Frank would be penalized permanently, since his only option would be to sell his bolt for a discount.

Offers

There are three primitives that support the exchange of one kind of bolt for another. `offerExchange` posts an ask for one kind of bolt for another. The exchange can be canceled at anytime with `revokeExchange`. Another user can accept any portion of a posted offer using the `acceptOffer` call. A small detail with respect to offers is that when the offer is posted a **`BoltId`** is used to specify the bolt being bid for. The actual bolt which will be used to accept the offer can be any bolt from the same issuer which is $\geq$ (at least as "valuable" as) the bolt specified in the offer. More technically, $\geq$ is a partial order on bolts, such that, $x \geq y$ means that the BoltDefinition x has a maturity date no later than that of BoltDefinition y, that x pays at least as much interest as y, that the buyback fee (if any) in x is no more than that in y, that the set of buyback bolts in x is a subset of the buyback bolts in y, and that $x.\text{redeem} \neq 0 \implies x.\text{redeem} = y.\text{redeem}$. The same logic applies to bolts used in buybacks and trust agreements.

Trust

The final primitive on the ledger is the trustline. A trustline is an explicit agreement that a user of the system will accept a bolt issued by another user as if it were their own. (Contrast the trustline which guarantees acceptability with the concept of a "web of trust" which just signals trust based on historical acceptance.) Once a user executes an `extendTrust` call, they agree to accept (up to the specified value) bolts from another user up until the trustline expires. It has already been shown that systems with trustlines and multiple agents each issuing their own currency can be as robust to centralized currency systems [13].

5.3 Using a BoLT wallet

The system specified here is very general and as a result BoLT appears very complex. To manage that complexity users will use wallet software which will handle the details of determining what bolts they will accept and which of the bolts in their wallet they will use to purchase goods and services (or trade for other bolts). For example, evaluating whether or not a particular bolt has value will require the user (or more likely, the user's wallet) to understand whether their future trading partners will accept it or not. This will be determined by things like the bolt's interest rate, maturity date, and what other bolts it might be bought back for, among other things. To handle this complexity, wallets will have to process the ledger to build a web of trust from the point of view of the wallet holder. In Section 5.5 we discuss some of the possible metrics and methods that might be used for this evaluation. Here we describe the basic process by which wallets will be used to carry out transactions.

Purchasing Goods and Services

The primary task of any wallet will be to use bolts to purchase goods and services. As in any traditional sale, the seller will present the buyer with a bill. The buyer's wallet (most probably implemented as an app on a smartphone) will propose various bolts to the seller's point of sale (POS) terminal until they agree on a bolt to be used for the sale. It is up to the wallet software to pick the bolt that the buyer would most prefer to use. BoLT requires (and certified wallets will enforce) that the seller must accept (1) their own bolts and (2) any bolts to which they have issued a trustline. If the buyer has neither (or doesn't want to use either), then the buyer can exchange one of the bolts she holds for one the seller will accept or a negotiation will be carried out. As we describe in Section 5.5, the seller[1] will determine which bolts and at what interest rates they will accept based on the transaction graph derived from the ledger combined with whom they intend do business with in the future. If none of the bolts in the buyers wallet are acceptable to the seller, the buyer can propose to use their own bolts (and mint them on the spot) or the buyer could use the offer mechanism to purchase the seller's bolts doing a bolt exchange.

Bolt Exchange

BoLT has a built in auction mechanism in the form of `offerExchange`, `acceptOffer`, and `revokeExchange` API calls. The wallet software would either query third-party exchanges or could perform a P2P exchange by posting an ask (i.e., `offerExchange`) for the seller's bolt using one or more of the bolts currently in the buyer's wallet.

Liquidity and Bridge Bolts

One potential problem is that the trading graph might be too sparse for there to be a liquid market in every bolt at all times. While certain bolts may become ubiquitous enough to serve as a common medium of exchange, we introduce the notion of a bridge bolt to ensure tradability. There are at least two possible choices for a bridge bolt: (1) an on-chain bolt created for this purpose, as Ripple does with XRP [45], or (2) an on-chain representation of a government currency. We briefly describe

[1] In general, we expect users (especially for low value transactions) to use the algorithms in their wallet to do the negotiation.

the second approach. A trusted entity creates a bolt for the local fiat currency, e.g., a ϟUS, which represents one US$. It can delegate authority to mint this bolt to other entities (e.g., banks). The authorized minters are allowed to mint one ϟUS for each dollar that is deposited. Depositors can get their US$ back only by trading them for ϟUS. Auditing of the issuers is facilitated by tracking how much each issuer mints, trades, and destroys.

Terms of Service and Risk of Default

The BoLT system requires that users accept their issued bolts and those to which they extended trust. Previous approaches for enforcing the rules of ledger-based cryptocurrency systems have been to assess a penalty, recorded on the ledger, against the non-cooperating party such that they lose more value than the party they hurt (E.g, [37]). BoLT takes a different approach towards resolving the tension between failure to honor a bolt in the real world and the ledger. It relies primarily on market forces to price the interest rates of bolts to reflect the reputation of the issuer and the perceived risk that the issuer might not honor their agreement. Of course, holders of bolts could decide to seek legal redress based on the contract law of their local jurisdiction.

5.4 The Ledger

BoLT is agnostic about whether the ledger is distributed or centralized as long as the ledger is publicly readable. The main requirements are that the ledger support high throughput, quick transaction confirmation, and that the cost to record a transaction be minimal. If the ledger is distributed, then miners need to be incentivized with bolts they will accept. The obvious choice is to use the bridge bolts we describe above.

5.5 Evaluating Risk of Acceptability

Fundamental to the working of BoLT is that users can easily determine whether or not a particular bolt will be useful to them, i.e., whether someone else will accept it as payment. If they decide that it is likely to be accepted, then they will in turn accept it as payment. An accurate assesment of acceptibility is thus key to BoLT working and replacing the “Irish publican.” Here we present various metrics that could be used as the basis for making such an assessment and forming the core of the negotiation part of a good wallet.

Traditional measures such as velocity, money supply, etc. will be useful in evaluating general risk of bolts. In addition, metrics such as Pagerank [34] can be adapted to determine if a person randomly trading bolts will accept a particular bolt. This can also help eliminate sybil attacks. Of more interest to particular users will be metrics that can evaluate the risk of acceptability with respect to her own trading circle, e.g.: might include:

Shortest path The minimum length path between the issuer of a bolt and a member of the user’s trading circle.

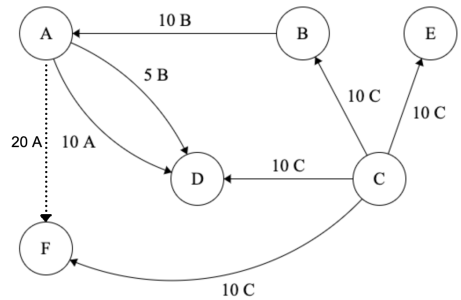

Figure 4: *A graph representation of trades on the ledger.*

Max Flow The maximum value of all paths between an issuer of a bolt and a member of the user’s trading circle.

Let us present an example to make this concrete. Assume that six people have created and minted 100ϟeach and then carried out the transactions shown in Figure 4. Each solid edge in the graph is a transaction between two parties, e.g., (B,A) with weight 10B is included because Betty paid Alice 10ϟBetty. The dotted edge represents a trustline (in this case Fiona extends a trustline for 20ϟAlice). Assume George, who frequently trades with Fiona and David, wants to determine the acceptability of everyone’s bolts.

- The money supply of each currency is the same, as each person has issued 100ϟ.
- ϟCharlie has the highest velocity, 40ϟ.
- ϟEric has zero velocity and zero reach since no user has accepted his bolts.
- ϟCharlie has the highest reach (Since David accepted them from Alice, who accepted them from Betty, who accepted them from Charlie).
- Outside of David and Fiona, Aliceϟand Charlieϟhave the shortest paths for George. (Note, this includes the trustline extended by Fiona to Alice.)
- For George, the max flow to his trading circle for ϟAlice is 30, ϟBetty is 10, and ϟCharlie is 30.

With this information, George would certainly take (up to the amount he expects to trade) ϟDavid and ϟFiona. He would also take ϟAlice (given the trustline) and ϟCharlie (given their high max flow, low shortest path, and generally high velocity). Finally, he would probably accept ϟBetty (maybe with an attached interest rate), but is unlikely to take ϟEric.

5.6 Outcomes

BoLT harnesses the power of the public ledger and the wallet software to significantly reduce problems with traditional liquidity tools offered by financial institutions. BoLT supports the low-cost creation of loans and allows those loans to be easily traded. By recording all transactions on the public ledger everyone has access to the same information. Alternative methods of generating liquidity, like gift cards, do not provide this transparency. Gift cards cannot be easily divided, traded, can be forged, and can only be redeemed for goods and services

Function	Gas Used (Avg.)	Ether Cost	USD Cost (1 ETH = $240)
createBoltSpec	220,732	0.00441	1.05951
mint (Regular)	66,332	0.00133	0.31839
mint (Delegated)	74,340	0.00149	0.35683
transfer	53,170	0.00106	0.25522
extendTrust	24,855	0.00050	0.11930
offerExchange	159,989	0.00320	0.76795
revokeExchange	25,404	0.00051	0.12194
acceptOffer	40,116	0.00080	0.19256
buyback	50,160	0.00133	0.24077
mintAuthorize	66,736	0.00114	0.27311

Table 1: *The average gas used and cost of each API call in Ether a*

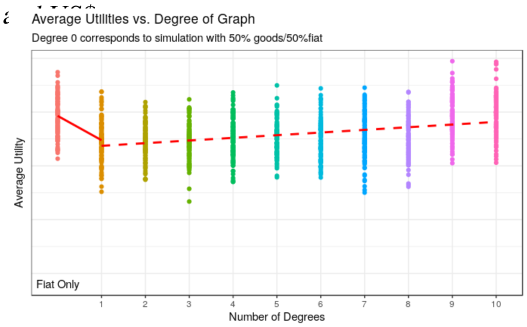

Figure 5: *Average utility for simulations comparing degree of trust extended to claims. 0 represents using only fiat currency. Each point is a run of the simulation.*

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1169.1426	6.6444	-175.96	0.0000
degree	12.3520	1.0708	11.53	0.0000

Table 2: *Regression of the average utilities against degree.*

at a single business. By allowing anyone to create, trade, subdivide, and exchange bolts, BoLT also eliminates monopolistic or oligopolistic tendencies that have arisen from banking mergers and reduced competition of mainstream lenders.

6 Experiments

We have started evaluating BoLT in both simulation and as an Ethereum contract written in Solidity.

6.1 Modeling

BoLT's effectiveness is directly tied to how interconnected the trading relationships are in a community. To understand the impact of interconnectedness we extend the dual currency model proposed by [23] to support claims issued by each type of agent. In the model, goods and claims are indivisible. We look at the shortest path metric described previously. We run simulations where we vary the maximum length path of claims that traders are willing to accept.

As expected, our simulation shows that when traders are only willing to accept their claims 1 hop away, the average utility is worse than in an economy with a fiat currency (which everyone excepts). However, as shown in Figure 5, when traders are willing to extend trust to claims with larger shortest paths, the average utility improves. As shown in Table 2, the positive improvement in utility as the trading circle expands is statistically significant. This simulation is in some sense a worst case for BoLT since claims have no interest, there are no trustlines, and no one can create or mint new claims.

An alternative basis for our modeling could have come from peer-to-peer scrip systems [16, 38] or credit networks [13, 39, 14]. However, because the trustline in bolt (which is similar to a credit line in the above) is just one basis for establishing a trading relationship we chose to base our modeling on search-directed monetary theory.

6.2 Solidity Experiments

We have implemented our specification in Solidity [43] on top of Ethereum [6] and tested it using the Truffle test framework [46]. We have confirmed that all the API calls have constant time complexity. If we allow a variable number of buybacks to be specified, then `createBoltSpecification`, `acceptOffer` are $O(B)$ and `buyback` is $O(B^2)$, where B are the number possible buyback bolts listed when the bolt is created. See Table 1. We expect that usually when a bolt is created there will be no buyback bolts listed, but if there are any, it will generally be no more than one or two.

While the solidity implementation verifies that BoLT is workable, the overhead with Ethereum is too high. Since we want to enable BoLT's use even for micro-transactions, a custom ledger would have to be used in practice.

7 Challenges

In this section we discuss two key challenges facing BoLT. The most significant challenge is how to get a BoLT ecosystem started. Initially, the ledger in a particular community will be blank and there will be no in-system web of trust. We see several possible models to get BoLT started in a community. First, the local government could (as they have done in Tenino, WA) issue bolts which they could distribute to citizens in need while at the same time giving POS terminals to local merchants who agree to accept the bolts. The merchants are likely to do this as the town (by issuing the bolts and obeying the terms and services agreement) has agreed to take the bolts as payment for local taxes. This would immediately create a community of users and let the ecosystem then grow organically. An alternative model is for a chamber of commerce to gather a group of merchants who would invest in POS terminals and all agree to take a fixed amount of each other's bolts. They could then try to raise money by selling commitments to their loyal customers. In both cases, the key is that a group of users form as close to a strongly connected component of trustlines as possible.

Once off the ground, BoLT faces the challenge of being more complex than cash (or credit cards). Wallet designers will have to go to great lengths to create an app that is simple and intuitive in the face of such variable features as interest rates, buybacks, maturity dates, understanding risk of acceptance, etc. Basic defaults will need to be set so that businesses and customers can use the system for what it is intended: facilitating local lending and exchange. To that end, we have established certain default profiles (e.g., low risk, high risk) and tied them to basic formulae to evaluate the risk of acceptance. These formulae will be built into the devices which will carry out transactions. Thus, we expect the point-of-sale terminals and wallet software to carry out the negotiation between a buyer and a seller, picking a mutual acceptable claim for a transaction. For small transactions, this is likely to satisfy most users. For larger transactions, the negotiation and potential minting of a new claim will probably have to be done manually.

There are a host of challenges that we are not touching on here: how to handle bankruptcy (e.g., how to encode insurance and/or credit default swaps on the ledger), how to manage the privacy/reputation trade-off (e.g., [15, 4, 5, 47]), how to prevent sybil attacks (e.g., [40]), how to handle throughput, latency, the high cost per transaction and long confirmation latencies in today's distributed public ledger based systems (e.g., [12, 1]), how to incentivize miners (e.g. using bridge bolts as described in Section 5.3), etc. We are currently assessing and addressing these challenges.

8 Conclusions

Our system, BoLT, builds on local trust to solve structural problems in lending markets. It reduces asymmetric information (by recording everything on a public ledger), increases competition in the lending markets (by providing regular citizens with the ability to crowd-source liquidity for businesses), reduces systemic bias (with its "go local" approach), and reduces size bias (with low overhead loan creation). We believe that the problem BoLT solves are of immediate interest as they also address the economic hardship and inequality being generated by the pandemic. By avoiding traditional banks, BoLT provides a route for disenfranchised businesses to "go local" and secure loans. At the same time, customers of local businesses get to shop, in the future, at a discount. In effect, BoLT creates a friction-less marketplace for local communities to loan money to others in need of temporary support—where trust is built from connections and exchanges.

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