Thesis Project Portfolio

Expanding on Multiple Cryptocurrency and Wallet Software

(Technical Report)

Reducing the Environmental Impact of Data Centers

(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Sociotechnical Synthesis

The Digital Age has allowed for the rapid development of complex and computationally intensive technologies. These technologies have become embedded into a societal structure built on communication technology and the movement of data. It is critical to examine how these technologies integrate into society to better manage emerging technologies. Increased complexity in underlying technologies brings challenges in architecting software that is effective, accessible, and useable to a large audience. Furthermore, there are structural challenges in designing, maintaining, and powering these technologies that process, collect, and communicate vast sums of data. The technical report focuses on the software design challenge presented by the complexity of cryptocurrency technologies, while the research paper focuses on the environmental implications of large-scale data usage, especially regarding the power usage that bitcoin is infamous for.

The technical report delves into a project to implement a framework that simplifies the interaction with multiple cryptocurrencies within the same software for developers and users. There is a vast array of cryptocurrencies in circulation, with new types still being created. This increases complexity and creates a barrier for users intending to use multiple types. It also creates a problem of scale for software intending to interact with such technology as each currency is somewhat unique due to the lack of uniformity in implementation, wallet, and developer tools. This framework attempted to tackle this complexity through abstraction. It generalizes a transaction into two parts: connecting to the daemon and interacting with the appropriate software wallet. The framework handled the quirks of a specific currency once it is implemented within the framework so that the user may simply input their currency and wallet.

I worked on this project as an intern along a team of full hires and the technical lead who designed the framework. The technical report details the process of understanding the codebase, fixing bugs within an Ethereum implementation, and further research into a potential implementation of Monero within the framework. The framework was able to successfully manage transaction currencies such as Ethereum and could potentially handle others with more research. Such a framework allows this technology to be more accessible by abstracting away the complexities of software for the user for ease-of-use, while still taking an individual approach to the implementation of each currency.

Computing workloads have become more intensive due to the flood of data from new technologies such as cryptocurrency. This has in turn demanded an increase in power usage in the data centers processing this information over the past decade. The research paper focuses on this societal effect of this technology and how interest groups have worked to reduce the environmental impact of data centers. It reviews the sociotechnical techniques such as the policy, programs, and activism that have contributed to a large-scale effort towards improving data center efficiency. The primary participants in the system surrounding data centers are the technology companies responsible for the centers, the governmental agencies regulating them, and the communities who live around them. This paper utilizes both press releases, policy documents, and first-hand accounts as well as academic articles and new reports to delve into these perspectives.

On the large scale, policy and non-governmental initiatives have promoted data center efficiency. Central to these ideas is the free access to information in sharing designs, promoting research, and developing training programs and standards to close the gap between private stakeholders and governmental policy. Creating policy or plans to manage data centers is a complex affair due to the variety in location, technology, and design of centers. Government policy that takes a voluntary approach over specific restrictions in policy can better manage that diversity and yield more quantifiable results. Similarly, the plans proposed by technology companies to promote sustainability in their centers are often capital intensive and have many complexities in their implementations even as they provide economic benefits. A review of the activism reveals that, like the issue posed by the cryptocurrencies, an individual approach must be taken alongside these large-scale plans. At the smaller scale there can be dissonance between economic policy and environmental initiatives. The environment of the area where data centers are built require special attention to ensure positive outcomes for both the communities living there and the companies stationed there.

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Expanding on Multiple Cryptocurrency and Wallet Software

CS 4991 Capstone Report, 2021

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ABSTRACT

The vast array of cryptocurrencies and wallets available create a problem of scale for any software designed to interact with multiple types. Each potential currency or wallet provides its own unique challenges due to the lack of uniformity in implementation and tools. A technical lead designed a framework to simplify interaction with multiple currencies via abstraction. I worked as an intern along with a team of full hires to understand the established codebase and framework, fix potential bugs, and research the tools necessary to implement the cryptocurrency Monero within the framework.

The framework generalized the interaction into stages that are present across several cryptocurrencies. The project handled the minutiae of each currency and its corresponding wallet individually, so users only had to know their own currency and wallet. As such, bug fixes and research into additional currencies helped expand the potential array of currencies with which the framework, and thus the end user, can interact with.

1 Introduction

There are over 13,000 cryptocurrencies in existence. New types of cryptocurrencies are regularly created, each with its own use case and corresponding design quirks. [6] Many cryptocurrencies utilize blockchain technology to allow transactions without a third-party mediator. The industry of financial cryptocurrency is expected to grow in the coming years, especially as more large institutions such as PayPal and Amazon are making moves to accept cryptocurrency payments. [10] Granting Consumers greater flexibility in their cryptocurrency and wallet of type is essential to this growth, but can present a software development challenge due to the variety inherent in cryptocurrencies.

2 Background

Despite the large number of currencies, 70% of the market in cryptocurrencies is made up of the top 5 coins. There is a subset of crypto-assets that are "payment-focused" coins including Bitcoin, Litecoin, and Ethereum. [6] These are thus the most relevant cryptocurrencies for a transaction-oriented software to be able to handle. It also implies similarities in use case, and thus, potentially transaction functionality exposed for the coins and their corresponding wallets. This does not imply a uniform implementation however. [1]

Cryptocurrencies utilize blockchain technology to perform transactions without the need for a third-party authority such as a bank. A blockchain is a type of distributed ledger and each user has their own copy of the ledger known as a node. Each node must run the relevant blockchain client software in order to exchange assets. To confirm a transaction on the ledger, all nodes must agree on the transaction, a process that can often require a significant amount of time to complete, and must be accounted for in software. [4] Different types of cryptocurrencies are deployed on different blockchains, even using variants of the technology. Transactions using a currency can be made on the network using the appropriate blockchain client. In a multicurrency software this implies the use of multiple clients. [1]

Consumers can participate in the blockchain and make transactions with a digital wallet. Digital wallets are usually designed to store a specific type of coin. Each wallet has a public key that acts as an address for transactions to be routed to and a corresponding private key. The private key is not shared, but is required to approve any transfer of cryptocurrency out of the wallet. [1] Wallets usually have functionality to store, send, and receive a specific type of cryptocurrency. In order to interact with multiple types of currencies, a software must be able to interact with a multitude of wallets.

3 Related Work

Multi-wallet software is directly related to this project. Software such as "FreeWallet" [13], "Exodus" [7], and "Coinomi" [5] provide custom individual wallets for each cryptocurrency they are able to work with (Coinomi Ltd., n.d; Exodus n.d.; Wallet Services Ltd., n.d.). In contrast, this multi-wallet framework works with external wallets of the user's choice. An alternate design for working with multiple currencies is multi-asset wallets like "ViaWallet" which provides a single wallet that stores multiple cryptocurrencies. ViaWallet also exposes some of its blockchain functionality in an API for public use, demonstrating similar developer-oriented design goals. [12] Previous research has explored new methodology for multi-asset system design. Tian et al. [8] investigated an alternative transaction scheme for cross-cryptocurrency transaction using smart contracts. Xu et al. [9] designed a system to maintain privacy and security when managing multi-asset cryptocurrency transactions.

4 Project Design

I worked on a system designed by a technical lead to solve the challenges of multi-currency software. The system abstracts away the minutiae of a transaction by splitting the process into two portions: connecting to the daemon and interacting with the software wallet. The developer implements a standardized set of functionalities for each new wallet/cryptocurrency while the user must only know their own currency and wallet. I was initially tasked with exploring and understanding this system so that I could fix bugs and assist in implementing new cryptocurrencies. I then researched whether the publicly available resources for the coin Monero would allow implementation within the multi-wallet framework as is.

A technical lead built a prototype software to implement and test project features before deployment. I was directed to use test-driven development since functionality for each currency was predefined by the framework. Test Networks were used along with replica currency to test functionality without the risk of using real currency. Project features were split across developers by currencies and/or wallet as each implementation was independent. Planning and general development was handled with a loose agile development style with weekly sprints.

4.1 Framework: Daemon

In order to complete a transaction software must interact with the blockchain to confirm the new transfer, adding it to the "public record" so to speak. A daemon is a program running in the background, and in the case of cryptocurrency, connects a given wallet to the appropriate blockchain. This process requires both the software to have at least a partial record of the current blockchain and the ability to queue up the transaction to be validated via mining.

The program handling the daemon for a given cryptocurrency encapsulated the logic for starting, stopping, and checking if the daemon was still running amongst other functionality. This facilitates switching between cryptocurrencies as each is guaranteed to have the exposed functionality to set up, reset, and tear down its daemon. This encapsulation also included the ability to send specific commands to the daemon. Interacting with a daemon is largely asynchronous since the startup, tear down, and mining each take a variable amount of time to complete.

In order to work with the daemon and the larger blockchain, I also had to investigate whether a potential "Test Network" existed for a given coin. This is a network that follows the same rules as the real blockchain, but works with dummy versions of the currency with no real value. This was essential to the testing phase of the application as working with real money was impractical and potentially expensive in the event of bugged code. The ability to create a Private Regression Test Network, a completely private version of the mentioned Test Network, was also desirable. A private test network allows users to manipulate the conditions of the underlying blockchain and generate fake coins on the fly without connecting to external network and services to acquire coins on the Test Network.

4.2 Framework: Software Wallet

In order to complete a transaction, the program must interact with the user-loaded software wallets to transfer currencies to and from. Software wallets are variable in how they store the relevant public and private keys, their intended functionality in transfers, and protocols. This portion of the framework encapsulates the implementation of the actual transactions, getting the relevant keys from the user's wallet and performing appropriate transfers. Once again, the program should implement some standard set of functions, exposing their functionality to the user and greater software.

This portion required research into the appropriate Remote Procedure Call (RPC) for the given wallet. This is the system by which the software wallet connects to an already running instance of the Daemon. The program uses the RPC in order to actually send any given transaction to the daemon for approval. Many software wallets/cryptocurrencies have an API for a Wallet RPC that already has many basic transaction functionalities implemented, in which case the developer is largely writing a wrapper around them. For example, the Bitcoin API has the ability to load in a wallet, get balances, and transfer coins to an address amongst other things. [3] This process, similar to connecting to the Daemon, isn't instantaneous.

4.3 Understanding the Framework: Ethereum

Once I had a grasp on the framework, I was assigned to fix some issues with the Ethereum implementation. To understand the framework, I studied the given codebase as well as the sample implementations for Bitcoin and the partial implementation for Ethereum. My understanding of the framework is discussed in 4.1 and 4.2. I also performed general research and worked with other team members to gain domain knowledge about cryptocurrency in order to understand why the code was designed as it was.

From there I investigated the implementation for the Ethereum implementation and identified issues causing the code to fail. In particular I studied asynchronous programming concepts in resolving issues of timing within the program. For example, even while using a particular wallet's API, Ethereum in this case, maintaining the node can require a variable amount of time depending of software specifications. As such, the start-up and shut down process of different instances of daemons were leaving behind artifacts due to the timing of the clean-up functionality. I also analyzed program output to identify a faulty genesis block in a private test network, pushed a working version based on additional research.

4.2 New Coin: Monero

I then researched a possible implementation of Monero in the multi-wallet framework. Monero is a privacy-focused coin as opposed to a transaction-oriented coin like the other implemented currencies (Bitcoin, Ethereum, and Litecoin) causing it to have unique quirks in its management of its public and private keys. Even so, Monero has robust documentation of its features and is one of the more popular privacy-focused coins used in transactions, making it a viable option to implement within the framework. [2]

Following the format of the framework, I first visited the official Monero resources to research its daemon. The official website, getmonero.org had both a daemon and associated command line tools, as well as resources to verify those downloads. In addition, they have documentation for a Test Network and faucet to acquire fake Monero to perform tests with. If a Private Test Network is preferred, some modifications have to be made to work with the RPC. [11]

While the framework was created with an assumption of just a private and public key, Monero Wallets have associated "Spend" and "View" keys, of which there are private and public variants. In addition, wallets are required to have an associated "Seed Phrase" that allows the owner to regain their wallet. As such, there are more files to keep track of compared to the transaction-focused currencies.

In addition, Monero has both a Wallet RPC and a Daemon RPC. The former for interacting with the wallet, and the latter for allowing the wallet to interact with the blockchain. This avoids the Daemon RPC having access to the private keys in the wallet. Despite this difference, the Wallet RPC contains similar commands to the transaction currencies including the ability to load a wallet and the ability to start transfers to an address. I also researched open-source libraries that are able put wrappers around the official RPC to wrap together operations involving the two types and use languages such as Javascript. [11]

5 Results

The proposed framework successfully encapsulated the important elements of a general cryptocurrency transaction based on its ability to successfully handle the major transaction cryptocurrencies. I helped expand the potential array of currencies the framework can handle by investigating issues with the Ethereum implementation and researching how Monero, a different type of coin, could fit into the framework. Despite having key differences in file system and RPC, Monero can be implemented using the same general framework.

6 Conclusion

The proposed framework allows multi-cryptocurrency software to interact with a uniform set of functionalities to perform transactions rather than having to deal with the minutiae of each individual cryptocurrency. The encapsulated start up and tear down also allows the software to switch between cryptocurrencies if required. It also allows developers to divide work efficiently as each currency can be implemented independently. The framework is also robust and can interact with privacy-focused cryptocurrencies such as Monero in addition to the transaction-focused.

7 Future Work

To expand on this framework, additional alternative cryptocurrencies could be researched and implemented within the system. This could be done on the basis of the most relevant cryptocurrencies at the time based on transaction metrics. The framework itself could also be expanded in the types of default functionality it exposes in terms of types of addresses it can handle for transactions. This should also be accompanied by research into the most relevant functionalities to implement within the system.

8 UVA Program Evaluation

The University of Virginia CS Program sufficiently prepared me to participate in this project. In particular, the course "CS 3240 Advanced Software Development Techniques" was essential in introducing agile development, gaining experience with source control such as Git, and in using Test-Driven Development. The software design principles introduced in this class such as MVC as well as the general principles of abstraction and encapsulation in "CS 2110 Introduction to Software Development" were essential to quickly getting up to speed on this project.

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Advisor

Joshua Earle, Department of Engineering and Society

Reducing the Environmental Impact of Data Centers

How do interest groups, including environmentalists, policymakers, and technology companies, strive to reduce the environmental impact of data centers?

Background

Why the Data Center?

Data centers are the backbone of the worlds computing infrastructure, supporting everything from the business sector to government and academic operations. As the economy has become increasingly dependent on the digital medium, data centers have become critical in turn. Data centers are large scale computing infrastructures containing equipment for data storage, processing, and communication, collectively known as “Information Technology” (IT) equipment, as well as supporting power generation, cooling, and environmental control equipment.

There is great variety in the structure of data centers. There exist both large scale data centers located in specialized buildings and small-scale data centers within general purpose commercial buildings. While some institutions manage their own data centers, others rely on consolidated data centers managed by outside companies that cater to multiple institutions. Some larger companies can manage upwards of hundreds of data centers, whether for themselves or to partition out to others. (Shehabi et al., 2016)

Introduction

Increasing Computing Workloads

Computing workloads going through data centers have become more intensive within the last two decades due to a flood of data from new technologies. Online platforms, social media, “smart” infrastructure, artificial intelligence, amongst other existing and budding technologies demand the processing, storage, and communication of data. Computing workloads increased by an estimated 550% between 2010 and 2018, with data center traffic having an annual growth rate of 23 percent. Increases in computing workload has naturally caused the average power density, or power required per rack, to increase in tandem. (Siddik et al., 2021) This landscape continues to shift in the 2020s. As of the 2021 State of the Data Center Report, 58% of survey respondents saw a shift of computing workload from the cloud onto on-site or colocation data centers (centers that can be rented out to individual enterprises), while 62% of respondents reported a continued increase in rack density to account for computation intensive workloads. (Kleyman et al., 2021)

Resource Consumption of Data Centers

Maintaining this data is similarly intensive, not only in energy consumption, but in greenhouse gas emissions and water use. Data centers account for 0.3 percent of global carbon emissions and about 2 percent of global electricity consumption, with demand increasing at an annual rate of about 5 percent. (Dayarathna et al., 2016; Jones, 2018). A benchmarking study by Andrae et al. (2015) predicted the IT ecosystem could use up to 20 percent of global electricity use by 2030, with data centers accounting for a third.

Water is used in data centers to dissipate heat produced by IT equipment in operation. A typical data center uses about as much water as a city with a population of about 30,000 to 40,000 people. Electricity is also used indirectly in wastewater plants supplying these centers to treat water for use, and to clean it after use. (Calma, 2021) Cooling infrastructure is particularly energy intensive, with high potential for waste. (Jones, 2018). The power grid, another large polluter and the second heaviest water consumer, supplies most of this electricity. (Siddik et al., 2021) A comprehensive view of these systems reveals the potential for environmental impact.

Electricity use was essentially steady in data centers from 2016 – 2018 despite the after mentioned increase in workloads. In this time, data center electricity consumption only rose 6% in this time even given the high annual growth rate of traffic, implying the centers were able to keep up with increased demand. This trend usually attributed to industry-wide improvements in energy efficiency and storage-drive density. The movement towards modernized hyperscale data centers and colocation data centers which are almost 6 times more water efficient over internal data centers has also heavily contributed. (Jones, 2018; Siddik et al., 2021) However, once workload is moved to more efficient hyperscale data centers further optimization is limited. “The trend is good right now, but it’s questionable what it’s going to look like in 5–10 years,” says Dale Sartor, who oversees the Federal Energy Management Program’s Center of Expertise for Data Centers. (Jones, 2018; LBNL, n.d.a). Thus, we must look beyond only technological developments to maintain this trend.

Methods

A review of existing technology initiatives, policy, and activism as follows will highlight techniques that allowed for improvements in efficiency in the past decade on both the local and global level. This review focuses primarily on the sociotechnical systems rather than technological developments as those systems shape the progress of large-scale sustainability measures in data centers. The primary participants in the system surrounding data centers are the technology companies responsible for the centers, the governmental agencies regulating them, and the communities who live around them. Primary sources were used to explore the perspectives of these participants. This included press releases regarding sustainability practices, policy documents and summaries, and first-hand accounts from activists. Secondary news reports, analysis, and academic journal articles were used to provide context to and supplement these perspectives as well as explore the effectiveness of various approaches.

Technology Companies

Complex Sustainability Plans

The technology companies that build and maintain data centers play a key role in sustainability. Many "tech giants" outline self-imposed sustainability plans to modernize technology and source green energy. (Joppa & Walsh, 2021) These plans are usually multipronged, having to tackle the issue at multiple levels due to the scale of operations, and implementation is often capital intensive. (Calma, 2021; Walsh, 2022) Taking Microsoft as a case study, it plans to build 50 to 100 new data centers per year to keep up with their cloud demand. They have also pledged to cut water usage in their data centers by up to 95% by 2024 and become "carbon negative" (store more carbon than they generate) by the same deadline - in the long term they similarly aim to become "water positive" (replace more water than they use). (Calma, 2021) This involves a lot of varied and intensive research and development - whether it be for less carbon-intensive building materials, carbon tracking tools, new cooling methodology, or simply researching how servers perform under higher temperatures. (Walsh, 2022)

Special attention must be given to data centers in hot and dry climates - the same techniques provide less benefits. "You can become water positive as a company, but it's not useful if you save all the water in one location, as an extreme case, and you create bigger deficits elsewhere." remarked Venkatesh Uddameri, the director of the Water Resources Center at Texas Tech University. Managing these data centers on a local level must happen on a case-to-case basis, and centers in hot climates should be prioritized due to the relative scarcity of water. (Calma, 2021) For example, Companies such as Microsoft have promoted recent efforts to build “sustainable data centers”, the center built cooling technologies that are stated to reduce impact on water supplies by working with locals near their Arizona plant (Walsh, 2021)

The potential positives of these changes are great, but the undertaking of changing these supply chains and designs is itself a challenge. (Calma, 2021) However, these initiatives can be waylaid even despite the economic incentive of lowered energy use. In the big picture, Mills et. Al. (2007) found that most smaller companies prioritize capital use for short-term gain despite long term profits from improved energy efficiency in high tech facilities such as data centers

Open Source Information

Promoting data center modernization must be a group effort on the corporate scale. Modernization is supported by open data access to originally propriety designs and research which allows efficient designs to become ubiquitous and be iterated on. This idea is espoused by key technology companies such as Microsoft (Walsh, 2022) and Facebook. (Facebook, n.d.) Microsoft’s Vice President of Cloud Ops and Innovation Noelle Walsh has stated, “to get there, we need to share our learnings and progress, and create new tools and solutions to benchmark where we are today, measure our progress and make them widely available” in relation to the release of the Microsoft Cloud for Sustainability tools which help track and manage carbon emissions. (Walsh, 2022)

Modernization is also buoyed by organizations such as Open Compute by Facebook that promote free access, redesigned hardware, and research into making computing more energy efficient. This project aims to make important information more available by publishing standards for green data centers and encouraging “major technology innovators” to make their work public. This allows for more hands to take an attempt at boosting data center efficiency and enables these more efficient designs to become more ubiquitous. (Facebook, n.d.) Both

Facebook and Google have openly published server design advancements under this framework. Sales of hardware based on Open Compute Project designs reached $1.2 billion in 2017. (Sayer, 2018)

Effective Policy

Research and Outreach

Policymakers have historically also promoted data center energy efficiency. The U.S. Department of Energy spearheads promotion efforts by establishing publicly accessible data center design guidelines, publishing case studies, and funding research for energy efficient technologies. All such research and guidelines are publicly accessible. (Office, n.d.). In particular, the Department of Energy partnered with the Environmental Protection Agency to create the National Data Center Energy Efficiency Information Program in 2011. This program was notably voluntary, rather than a requirement or law. It standardized efficiency metrics, developed tools to assist data center managers, and provided labeling and recognition for well preforming server technology and data centers. (DOE & EPA, 2008) These programs aimed to ease the path towards greener data centers by making the information easier to acquire and interpret.

Initiatives also partnered with data center efficiency laboratories which provide training directly to private stakeholders, closing the gap between federal guidelines and the private enterprise that run data centers. These specialized laboratories also provide technical support, advising, and training programs directly to private stakeholders regarding good data center practice. Some of these laboratories were also established via government initiative, such as Center of Expertise for Energy Efficiency in Data Centers which was established by the Federal Energy Management Program (LBNL, n.d.b). Government backed research initiatives also allows for development and demonstration of new technology outside of commercialization, which is vital in areas where incentive for privately funded research is low. In particular, public funding over private funding may be especially necessary as chip performance limits approach, lowering the incentive for privately funded research. (Koronen et al. 2019)

Incentives and Requirements in Policy

States offer tailored economic incentives for data centers as they are a significant taxable investment that provide many employment opportunities. Incentives include credits, tax exemptions, and lowered electricity rates. Michael F. Kaestner (2014) discusses how these incentives are often incongruous with energy policies in the same states. Data centers take up a disproportionate amount of electricity, often subsidized by the locals, for a service that isn't always buoying the local stores. Policymakers could be more mindful of energy availability and environmental impact of data centers by limiting incentives to facilities that have proven to be committed to sustainability and conservation efforts. (Kaestner, 2014) General reviews of the technological challenges, environmental impact, and ethical concerns of large-scale data usage have also drawn similar comparisons between environmental and economic policy (Song et al., 2019; Lucivero, 2019)

Policy promoting the use of sustainable technology in private companies can take the form of requirements codified into law, sustainability programs that have voluntary participation, or a mix of both – to varying results. For example, the European Code of Conduct for Data Centre Energy Efficiency initiative (CoC) was a successful non-regulatory/voluntary policy that aimed account for the diversity in data center facilities - from age of IT equipment to style of core infrastructure. It provided a platform for stakeholders to agree on acceptable actions towards greener data centers and requested both an actionable plan and regular audits to track efficiency over time. All participating sites implemented at least the minimum expected best practices guidelines outlined within the program, and the number of applications for the next round of the program increased. This was one of the most successful data center policies in the EU, and shows a data backed non-regulatory/voluntary policy. As such Avgerinou et al. (2017) concluded voluntary agreements were favored over mandatory regulations when dealing with the private companies as they account for diversity in design, goals, and ownership.

In contrast, the "Ecodesign Directive" established in 2009 sets minimum efficiency requirements for servers and storage devices often used in data centers as of 2020. They also set reporting standards for manufacturers selling this equipment. While Ecodesign could at least prevent the least energy efficient servers coming into circulation, this area is difficult to regulate compared to domestic appliances due to the rapid pace of development and the complexity of technology, The resulting standards are both harder to define well and harder to measure the effectiveness of over that of more comprehensive, but voluntary, programs such as the CoC. (Koronen et al. 2019)

Local Level

Tensions over Water

Traditional wisdom states that communitys welcome data centers due to the lack of visible environmental detriments and the internet sector's "sleek" reputation. (Avgerinou et al., 2017). Even so, tensions have risen in certain local communities regarding high water and energy usage. An example is the previously referenced Microsoft data centers in Arizona where Microsoft promoted efforts to build more sustainable centers working with locals. (Walsh, 2021) However, Vice Mayor Jenn Duff of the Mesa City Council, Arizona echoed local concerns and voted against a new data center development - citing an “an irresponsible use of our water” in the “driest 12 months in 126 years”.

This is not an out of the norm case. Data centers tend to be located close to infrastructure and customers, and where the cost of land, local tax incentives, and electricity prices are low. As such, they are often drawn to arid, water-starved areas in the west such as Arizona where solar and wind energy is plentiful, but usual energy saving techniques are less effective. Virginia Tech researchers estimated that one-fifth of data centers draw water from moderately or highly stressed watersheds in 2021. (Solon, 2021) Managing the impact of data centers must be a local effort from a technological perspective. (Calma, 2021; Walsh, 2022)

There is a trend in such cases were environmental concerns butt heads with economic benefit. In 2017, Google requested a permit to draw 1.5 million gallons of water per day from an aquifer in Berkeley County, South Georgia to cool its local data center as it expanded. Both residents and local conservation groups were concerned about this increased water usage in an already depleted aquifer, where groundwater supplies were running low. Google maintained that it had met with local stakeholders and experts that their water use was in fact sustainable in the area. This two-year push and pull with the South Carolina Coastal Conservation League culminated with an agreement for limited use of local groundwater, with google using alternative water sources instead. (Solon, 2021) A review from Gilmore & Troutman (2021) demonstrates how communities can respond to concerns and how concerns gaining traction, in this case framing the news as a contest between the potential threat to public health and the economic input of Google, with Google presenting themselves as also being a member of the community. The usage of natural resources generally draws public attention to the environmental impact of data centers and embroils companies in local politics. (Gilmore & Troutman, 2021)

Grassroots and The Power Plant

These issues don't receive as much press in less populated areas, with the tax revenue providing incentive to maintain the data centers, despite negative effects on the local populace. (Glanz, 2012) A case study is of Microsoft's data centers in Quincy, Washington, attracted by incentivized electricity rates and state level economic incentives in the farming town. However, soon after its 2007 completion, it was a target of a local citizen's group protesting the use of over 40 diesel generators used for consistent backup power. Microsoft was able to use its status and economic leverage to avoid fines and accelerate construction as local officials attempted to address the issue. In contrast, Microsoft came under scrutiny for its use of diesel generators in 2008 and 2009. Their Bay Area data center was considered one of the largest diesel polluters and the increased emissions prompted review from the State of California.

Local concerns about carbon emissions and power usage can still be drivers of change especially regarding power generation structures. "Data centers don't usually freak people out. But power plants do." (Miller, 2014). "Not in My Backyard" (NIMBY) regional grassroot organizations who organize local community and environmental groups can build momentum. An example was the collapse of a planned data center in Newark, Deleware, due to its innovation of an onsite power plant. NIMBY organizations organized community leaders, consistently communicated with their base, gained support from both local authorities and environmental groups, and eventually built enough momentum to file a lawsuit against the project. Miller (2014) called out the need for clear communication of future energy consumption and clarity in power operations to avoid such issues in the future.

Similar cases of grassroot organization have been recorded for other gas-powered high energy computing endeavors, such as Bitcoin mining by Greenridge Generation being opposed by citizens of the town of Torrey on Seneca lake. (Jordan, 2021) Another similar phenomenon occurred in Plattsburgh, New York where the cheap electricity drew bitcoin miners who regularly overran the city's quota of cheap power, causing electricity prices for locals to increase by almost 50%. Attention drawn by these organizations can spur local lawmakers to enact policy to mitigate heat output, noise, and energy drain from local data farms and even prevent future operations. (D'Ambrosio, 2019).

This is not to say that these controversies are entirely local - a similar push and pull can be observed at the country level. In Ireland, new data center construction was blocked for several months due to potential blackouts as the data centers eat up a great portion of electricity in the area. This was compounded by environmental concerns that the constructions of new data centers would impact carbon neutrality goals. (Fox, 2022) In response, a business lobby group was created by tech giants such as Google, Apple, and Amazon opposing those country-wide data center construction limits. (Beesley, 2021).

Conclusion

On the policy level, it is shown repeatedly that effective communication with private stakeholders is key in meeting efficiency goals. This should mostly take the form of voluntary programs such as the CoC and the laboratory partnerships as they create demonstratable increases in data center efficiency not only in these larger companies. These must be paired with research and outreach programs to create solutions in a way that is publicly available and independent from economic incentive. (Koronen et al. 2019) The free sharing of information is tantamount to the success of green data centers. (Facebook, n.d.).

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At the local level, data centers benefit from the reputation of the internet and the lack of visible environmental effect. (Avgerinou et al., 2017) However, there are many cases where use of natural resources affects communities surrounding these data centers. While big technology companies have created effective, comprehensive plans to bolster both their cadre of data centers and their surrounding power generation structures, special attention must be given to the local community circumstances where data centers are built. Community pushback can draw attention to these issues to promote change, while clarity and better communication from companies would help assess data center impact beyond its economic incentives. (D'Ambrosio, 2019; Glanz, 2012; Miller, 2014) The environmental security of local areas must involve advocacy on the local level, both from residents and the companies wishing to station there.

A multidisciplinary approach will be required to manage their energy requirements as data centers only become more essential to computing infrastructure. Keeping the environmental footprint of data centers in check will require a mix of policy implementation, local efforts, and a large knowledge base as efficiency gains from chip optimization and data relocation cap out.

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Expanding on Multiple Cryptocurrency and Wallet Software

(Technical Paper)

Reducing the Environmental Impact of Data Centers

(STS Paper)

A Thesis Prospectus Submitted to the

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In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

Nikita Saxena

Fall, 2021

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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General Research Problem

How can computationally intensive technologies better integrate into society?

Moore's Law is a prediction made in 1965 stating that the number of transistors per silicon chip, and thus computing power, will double every year. Moore's Law has held in the 65 years since enabling powerful new consumer technologies in the "Digital Age" (Moore, 1965). Greater access to complex technologies have led to a society built on digital technology and the movement of information (IGI Global, n.d.). It is critical to assess the impact of the computation heavy technology that shapes society, innovation, and the environment (UNEP, n.d.). Increased software complexity and greater dependance on communication technologies brings challenges in large scale software architecture, storing data, developing accessible software designs, promoting digital literacy, and in powering this new array of technologies.

Expanding on Multiple Cryptocurrency and Wallet Software

How can abstraction simplify interaction with multiple cryptocurrencies within the same software for developers and users?

Cryptocurrencies and software wallets lack uniformity in implementation and features creating scaling issues for software intending to interact with multiple types. This project aimed to generalize the interaction process into stages, streamlining the developer experience and minimizing domain knowledge required by a user. A framework was designed by a technical lead to simplify interaction with multiple currencies via abstraction and encapsulation. I contributed to this team project in a previous internship by understanding the established codebase, fixing bugs, and researching tools to implement the cryptocurrency Monero within the framework. Professor Daniel Graham of the Computer Science department will sign off as the technical advisor for this independent project.

Multi-wallet software is directly related to this project. Software such as “FreeWallet”, “Exodus”, and “Coinomi” provide custom individual wallets for each cryptocurrency they are able to work with (Coinomi Ltd., n.d; Exodus n.d.; Wallet Services Ltd., n.d.). In contrast, this multi-wallet framework works with external wallets allowing for flexibility for the user. An alternate design for working with multiple currencies is multi-asset wallets like “ViaWallet” which provides a single wallet that stores multiple cryptocurrencies. ViaWallet also exposes some of its blockchain functionality in an API for public use, demonstrating similar developer-oriented design goals (ViaWallet, n.d.). Previous research has explored new methodology for multi-asset system design. Tian et al. (2021) investigated an alternative transaction scheme for cross-cryptocurrency transaction using smart contracts, while Xu et al. (2020) designed a system to maintain privacy and security when managing multi-asset cryptocurrency transactions.

A prototype software was built to implement and test project features before deployment. I was directed to use test driven development since functionality for each currency was predefined by the framework. Test Networks were used along with replica currency to test functionality without the risk of using real currency. Project features were split across developers by currencies and/or wallet as each implementation is independent. Planning and general development was handled with a loose agile development style with weekly sprints.

The framework abstracts away the minutiae of a cryptocurrency transaction by splitting the process into two portions - connecting to a daemon and interacting with the software wallet. The developer implements a standardized set of functionalities for each new wallet and cryptocurrency while the user must only know their own currency and wallet. I was initially tasked with exploring and understanding this system such that I could fix bugs and assist in implementing new cryptocurrencies. I then researched whether the publicly available resources for the coin Monero would allow implementation within the multi-wallet framework as is. Monero is a privacy focused coin as opposed to a transaction-oriented coin like the other implemented currencies (Bitcoin, Ethereum, and Litecoin) causing it to have unique quirks in its management of its public and private keys.

Bug fixes and research into additional currencies expanded the array of currencies the framework, and thus the end user, could interact with. The potential implementation of Monero also demonstrates strength in framework design and implies potential in handling similar currencies.

Reducing the Environmental Impact of Data Centers

How do interest groups, including environmentalists, policymakers, and technology companies, strive to reduce the environmental impact of data centers?

Data centers are large scale computing infrastructures that are critical to the backend of the internet, cloud, and data-intensive applications. Global electricity consumption of data centers is about 2 percent and these demands have an annual growth rate of about 5 percent. (Dayarathna et al., 2016). Data centers also account for 0.3 percent of global carbon emissions due to energy use in IT equipment. Cooling infrastructures are particularly energy intensive, with high potential for waste. (Jones, 2018). A benchmarking study by Andrae et al. (2015) predicted the information and communications technology (ICT) ecosystem could use up to 20 percent of global electricity use by 2030, with data centers accounting for a third. Despite data center traffic having an annual growth rate of 23 percent, as of 2018 the electricity use was steady in data centers due to increased efficiency in computing. “The trend is good right now, but it’s questionable what it’s going to look like in 5–10 years,” says Dale Sartor, who oversees the Federal Energy Management Program’s Center of Expertise for Data Centers. (Jones, 2018;

LBNL, n.d.a). As demand for data only increases, what techniques have been used to reduce the environmental impact of data centers?

Participants include “tech giants” such as Google, Microsoft, and Facebook who outline self-imposed sustainability plans (Joppa & Walsh, 2021) and establish groups such as the Open Compute Project (Facebook, n.d.) to promote redesigned hardware to make computing more energy efficient. These efforts manifest in “sustainable data centers” with innovative cooling technologies that are stated to reduce impact on water supplies by working with locals (Walsh, 2021). Participants also include regional policymakers such as the Office of Energy Efficiency that establish data center design guidelines and fund research for energy efficient technologies. (Office, n.d.). Data center efficiency organizations such as the Center of Expertise for Energy Efficiency in Data Centers established by the Federal Energy Management Program also provide technical support, advising, and training programs to private stakeholders (LBNL, n.d.b).

Local participants include “Not in My Backyard” regional grassroot organizations that oppose pollution from generators and high resource use of local data centers. (Glanz, 2012) Environmentalist groups often organize against gas-powered data centers threatening large carbon emissions. (Jordan, 2021; Miller 2014) This has spurred local lawmakers to enact policy mitigating heat, noise, and energy drain from local data farms. (D'Ambrosio, 2019) Participants also include lobby groups created by tech giants such as Google, Apple, and Amazon opposing country-wide data center construction limits established to avoid impacting carbon neutrality goals (Beesley, 2021). Finally, participants include unorganized and organized groups of environmentalists seeking to raise awareness on the energy consumption and carbon emissions of data centers (Kolbert, 2021).

Researchers have investigated policy effectiveness and incentives for reducing energy consumption. Avgerinou et al. (2017) concluded voluntary agreements were favored over mandatory regulations when dealing with the private companies who own data centers such as Europe’s Data Centre Code of Conduct. Koronen et al. (2019) highlighted “Ecodesign” requirements in Europe setting minimum efficiency and reporting standards for data center technologies. Kaestner (2014) contrasted incentives for data centers and energy policies within the same U.S. states and discussed how they could better align. General reviews of the technological challenges, environmental impact, and ethical concerns of large-scale data usage have also drawn comparisons between environmental and economic policy (Song et al., 2019; Lucivero, 2019).

Researchers have also investigated company and local participant perspectives. Gilmore & Troutman (2021) performed a review of the local conflicts about water use surrounding Google’s South Carolina data center through local news, concluding that despite the potential economic incentives, the core issue is the use of natural resources which embroils Google in local politics. Mills et. Al. (2007) found that improved energy efficiency in high tech facilities such as data centers would lead to increased profits, but companies often prioritize capital use for short over long-term gain.

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