Open-Source: Benefits and Paths Forward

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***Abstract*—Nearly all software and hardware produced for consumer and hobbyist use by major technology corporations today is proprietary and listed for a price, meaning that not only are users denied the right to know what their software contains and what it may be running behind its facade, but they must also pay for this software as well. Thankfully, free and open source software and hardware does exist, and brings with it many benefits. With the goal of increasing knowledge about and market penetration of free and open source products, this report discusses multiple reasons why free and open source software and hardware is beneficial, compares and contrasts various distributions from the Linux family of class-leading open-source operating systems, and details possible specifications for an open-source Linux-based microcontroller that Rice University could build to competitively enter the market.**

***Index Terms*—Linux, RISC-V, FOSS, open-source**

I. Introduction

There are many downsides to the widespread use of proprietary technology, from sustainability to privacy to cost to customizability. The following sections of the report will address these major issues, discuss the best alternative software solutions for different use cases, and present the team's chosen specifications for a competitive open-source microcontroller design.

II. Open-Source Benefits

A. Sustainability

One major drawback of proprietary (and almost always paid) software is that it is created primarily with the broader goal of profit, rather than user experience, in mind. As such, companies will often end support for certain versions of their operating systems to encourage users to upgrade, but then artificially limit the number of upgrades a user can perform on their hardware to force them to buy new systems that will ultimately return to their company's bottom line. In fact, the two largest consumer operating system vendors, Microsoft and Apple, use this technique with their operating systems, Windows and macOS, respectively [1] [2]. For example, Microsoft currently does not allow computers without a Trusted Platform Module 2 (TPM2) chip update to Windows 11—essentially preventing any computer from pre-2017 from running the operating system, no matter how capable it may be. Given that its technical demands are quite similar to Windows 10's (and as shown by the fact that the quite artifical TPM2 requirement can be easy circumvented), it is easily known that Windows 11 *could* run on much older computers than it does [3]. The even more disheartening news is that Microsoft is ending Windows 10 support on October 14, 2025. And given the previous discussion regarding Windows 11 requirements, this will cause millions of devices to become e-waste—that is, if their users do not install another operating system. In addition, Apple also typically only supports their Mac computers for 7–8 years, which is around the same length of time that the newest devices that cannot run Windows 11 will have had support for [4].

The great benefit of free and open-source software in this regard is that the purpose of the software is that it is built to provide the best experience possible, *not* to take as much money as it can from users. There is no incentive to force users to upgrade their computers—as such, many modern Linux distributions can run on 15 or 20 year old computers quite well. And, with the wide variety of open-source operating systems available, if one does end support, users can easily switch to another that supports their hardware. Open-source operating systems can help keep older technology not just usable, but thriving, in the modern day, something that would be a near-impossibility with proprietary operating systems.

B. Privacy

When users purchase proprietary software, it is nearly impossible for them to see everything the software is accomplishing without significant reverse-engineering (which still will likely not uncover everything). This is to the benefit of the companies creating the software—they can now embed telemetry and data-capturing systems without showing users how and where their data is being used. While some of this can often be turned off, some of it cannot, as exemplified in Windows 11 and Windows 10 [5]. However, with open-source software, users have access to the software's code itself—hence, with open-source operating systems, users can know exactly what they are running and what data they are sharing.

C. Cost

Most open-source software and operating systems are free, given that they are primarily community-driven. And while a few are paid (such as the Linux distribution Zorin OS Pro or Red Hat Linux), the cost of said paid open-source software is typically less than that of a closed-source product. As such, if a user wanted to install a new operating system on their computer, they could save over $100 by choosing a free and open-source operating system (Windows 11 costs $139) [6].

D. Customizability

As the companies who own closed-source products ultimately have near complete control over the look, feel, and operation of their software, users are bound by their lines. However, as previously mentioned, users have access to the source code for open-source software and operating systems, meaning that they can implement any changes they like to the operating system themselves, or easily suggest them to others. Due to this, there are hundreds of (open-source) Linux distributions available for download, some of which cater to broader categories of people, and many of which cater to more specific niches! As such, open-source software can generally provide users with a more tailored experience as well.

E. Effects on Educational Materials

The benefit of free and open-source hardware and software in educational settings cannot be understated. Such FOSS platforms enable expanded access to learning, quick circulation of material, ease of scalable distribution, and can enhance regular course content by easily presenting an alternative description of the same material [7]. Many hobbyists looking to gain experience with complicated, expensive, and often proprietary RF hardware and wireless communications software, in addition to academic researchers in labs like the Smart Antenna Research Laboratory at Georgia Tech, have also benefited greatly from free and open source platforms like GNURadio, SDR#, SDR++, SatDump, Gpredict, GQRX, and RTL-SDR forums to build, configure, and write software for low-cost software-defined radio devices and antennas that are capable of communicating with Low-Earth Orbit (LEO) and Geostationary (GEO) satellites [8] [9]. As a result, the general public gains an appreciation and a motivation to pursue the advancement of these technologies while academic researchers gain tools to appreciably accelerate their investigations into novel wireless and satellite communications techniques.

III. Comparison of Operating Systems

A. Comparison of Linux Operating Systems

Given the numerous benefits of open-source software and operating systems discussed in the previous section, the following section will compare and contrast several of the most popular and widely-used Linux distributions available today. Linux has carved its niche in the world of operating systems. It offers a powerful, versatile, and open-source alternative to proprietary giants like Windows and macOS. This comparison will address the distributions' target audiences, ease of use, performance, customizability, and community support, with the ultimate goal of recommending the best distributions for various use cases and hardware configurations. By examining these key aspects, users can gain valuable insights into the diverse landscape of Linux distributions and make informed decisions about which one best suits their individual needs and preferences. Specifically, this section will explore the top 5 Linux distributions of 2024, comparing their strengths and weaknesses across various factors, and ultimately recommending the best choices for old PCs, modern computers, and microcontrollers.

Before diving into the specifics of each distribution, it is important to understand how the top 5 were selected. The selection criteria were based on a combination of factors. The first is data usage. Data from various sources, including web server surveys and online community statistics, were analyzed to identify the most widely used distributions. The trends in on-line forums, social media discussions, and download statistics were then examined to gauge the popularity of different distributions among users. Finally, the size and activity of online communities, the availability of documentation, and the responsiveness of support channels were assessed to determine the level of community support for each distribution.

By considering these factors, the following distributions emerged as the top contenders: Ubuntu, Debian, Fedora, Arch Linux, and Linux Mint. These distributions have consistently demonstrated their relevance and strong support ecosystems [10]. To provide a comprehensive comparison, each distribution is analyzed across several key aspects, categorized for clarity.

Each distribution has its own set of strengths and weaknesses. When making a decision for which Linux distribution to use for a given situation, it is critical to understand the following trade-offs:

- Ubuntu is known for its user-friendliness and extensive software availability, but can be resource-intensive and may have stability issues.
- Debian is highly stable and secure with a vast software repository, but can have a steep learning curve and limited proprietary software support.

TABLE I
USER EXPERIENCE

Feature	Ubuntu	Debian	Fedora	Arch	Mint
Target audience	Beginners, home users, developers	Experienced users, system administrators	Developers, enthusiasts, advanced users	Advanced users, tinkerers	Beginners, Windows users
Ease of use	Very user-friendly, easy to install and configure	Can be challenging for beginners, requires some technical knowledge	Relatively user-friendly, but some features may require technical expertise	Not beginner-friendly, requires significant command-line knowledge	Very user-friendly, designed for ease of use and a familiar interface
Community support	Excellent, with active forums, comprehensive documentation, and local communities	Very good, with active forums, mailing lists, and IRC channels	Excellent, with active forums, mailing lists, and a dedicated community website	Very good, with active forums, a comprehensive wiki, and IRC channels	Excellent, with forums, chat rooms, and local communities

TABLE II
TECHNICAL ASPECTS (1)

Feature	Ubuntu	Debian	Fedora	Arch	Mint
Hardware requirements	Moderate, suitable for modern hardware	Minimal, ideal for older hardware	Moderate, suitable for modern hardware	Minimal, suitable for both old and new hardware	Minimal, ideal for older hardware

- Fedora offers cutting-edge software and a strong community, but may experience occasional instability and has a shorter support lifespan.
- Arch Linux provides unparalleled customization and a rolling release model, but can be difficult for beginners and potentially unstable.
- Linux Mint is user-friendly and familiar with excellent multimedia support, but has limited desktop environment choices and relies on proprietary software for certain drivers.

Based on the analysis of the most popular Linux distributions, Debian is the ideal choice for older PCs due to its minimal hardware requirements and exceptional stability. It can breathe new life into aging hardware while providing a secure and reliable operating system. Fedora is the most optimal choice for modern computers, offering cutting-edge software, a strong community, and excellent performance. Its focus on innovation and the latest technologies makes it ideal for users who want to stay at the forefront of Linux development. Lastly, Arch Linux ARM stands out for its extensive support for embedded devices and microcontrollers. Its minimalist approach and focus on customization make it ideal for developers who need a highly adaptable and efficient operating system for their projects.

TABLE III
TECHNICAL ASPECTS (2)

Feature	Ubuntu	Debian	Fedora	Arch	Mint
Performance on modern hardware	Good, but can be resource-intensive	Excellent, very efficient	Excellent, optimized for performance	Excellent, highly customizable for performance	Very good, lightweight and efficient
Microcontroller support	Limited, primarily through Ubuntu Core for IoT and embedded devices	Good, with support for various architectures and tools for interacting with microcontrollers	Good, with packages for embedded development and support for Microchip PIC and Atmel AVR microcontrollers	Excellent, with Arch Linux ARM for embedded devices and a wide range of supported architectures	Limited, with some support for PIC microcontrollers through tools like Piklab
Release cycle	Regular releases with Long Term Support (LTS) versions every two years, balancing stability and new features	Offers stable, testing, and unstable branches with a conservative focus on stability	Short release cycle, approximately every six months, providing access to the latest software	Rolling release model, providing continuous updates and the latest software	Long Term Support (LTS) releases every two years, with a focus on stability and reliability
Package manager	APT (Advanced Package Tool) for managing software packages	APT (Advanced Package Tool) for managing software packages	DNF (Dandified YUM) for managing software packages	Pacman, a fast and efficient package manager	APT (Advanced Package Tool) for managing software packages

TABLE IV
DISTINCTIVE FEATURES (1)

Feature	Ubuntu	Debian	Fedora	Arch	Mint
Security features	Includes AppArmor for enhanced application security	Strong focus on security through rigorous testing and a stable release cycle	Employs SELinux for enhanced security and system protection	Security is primarily achieved through user vigilance and keeping the system updated	Includes a variety of security tools and features, with a focus on user-friendliness
Customization options	Offers moderate customization through various desktop environments and configuration tools	Highly customizable, allowing users to tailor the system to their specific needs	Provides extensive customization options, including support for different desktop environments and configuration tools	Extremely customizable, allowing users to build a system from scratch and tailor every aspect	Offers moderate customization through various desktop environments and configuration tools [14]

TABLE V
DISTINCTIVE FEATURES (2)

Feature	Ubuntu	Debian	Fedora	Arch	Mint
Commercial support	Commercial support available from Canonical for enterprise users	Primarily relies on community support, with options for hiring consultants	Limited commercial support available through Red Hat, primarily for Fedora Server	Relies entirely on community support	Primarily relies on community support, with options for donations and sponsorships

B. Comparison with Most Heavily-Used Operating Systems

To help further contextualize the compared Linux distributions, this section will compare the benefits and drawbacks associated with Linux against those of Windows and macOS, the two most commonly used operating systems.

As of November 2024, Windows has historically and currently dominates the OS market in terms of user base, with around 73% of all computers operating under the Microsoft's flagship product [11]. macOS captures around 15% of the market, leaving Linux accounting for just 4% of user desktop operating systems [11].

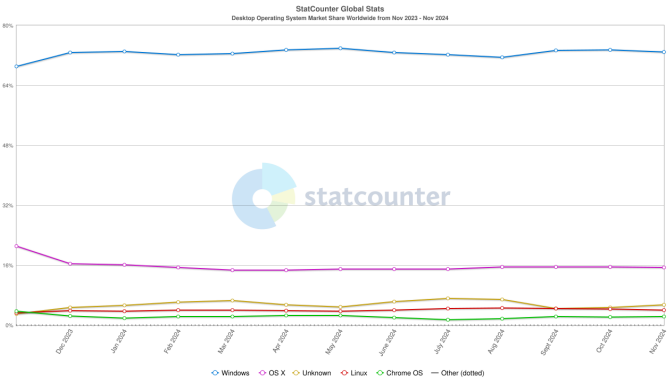

Fig. 1. statcounter.com desktop OS worldwide market share graph [11]

However, there are very good reasons behind these figures. Over the course of the last three decades, Windows has dominated the OS market in terms of desktop market share on the back of its strengths in usability and comparability. Similarly to Linux, Windows can run effectively on almost any hardware. However, while many Linux distributions require a bit of a learning curve to effectively operate, Windows is designed to be very user-friendly, even for those who are not technically inclined. On top of having a very intuitive UI, software and hardware alike are essentially plug-and-play with Windows, making it a jack of all trades in the OS space. There are however, a number of drawbacks that come with this size. Being the most widely used OS, Windows is also the largest target for hackers and viruses. Furthermore, it is often heavily bloated by auxiliary programs and data-monitoring software, which can severely compromise hardware performance, especially on lesser systems. Windows comes pre-installed on most non-Apple machines, with physical and digital copies also purchasable in a "freemium" model

Turning to look at macOS, it shares with Windows many of the characteristics which make it both intuitive and user-friendly. However, the key difference with both Windows and Linux lies in its comparability, or lack thereof. Despite being a Unix-based OS, macOS is limited to running only on Apple hardware, severely limiting the scope of its deployment. Furthermore some software developed for Windows are not yet compatible with macOS, requiring users to either emulate or dual-boot Windows on Apple hardware. However, for users who exclusively use Apple devices, macOS more than makes up for these deficiencies with an abundance of built-in support and features spanning across the famed Apple Ecosystem. Thanks to its lower user base and hardware exclusivity, macOS is also comparatively more secure than Windows. macOS comes pre-installed on all Apple desktop and laptop devices.

When compared with Windows and macOS, Linux operating systems stand out in one key area: freedom. Being open-source, the OS is built for the user rather than for profit, meaning the OS can be adapted to suit a user's needs and desires. However, it is important to note this freedom can come with a steep learning curve, and, as detailed in the previous section, can vary with the distribution. Compatibility with software and hardware, while greatly improved in recent years, is still not nearly on the level of Windows or even the macOS ecosystem. Intuitiveness of use and the ability to plug and play can require lengthy environment configuration, something the common computer user may not want or be capable of doing. However, with very few built-in background process and zero bloatware, it is also important to note that Linux allows its users to maximize the hardware potential of their devices. Furthermore, it is by far and beyond the safest and most stable OS, as there is no unified network or system through which malicious activity can take place.

Linux operating systems have significant benefits over the consumer market share leaders as described above. However, the benefits of open-source technology extend beyond software to hardware as well. Below, we detail the Athena, an open-source microcontroller designed by Rice University.

IV. RICE ATHENA 2024

The Rice Athena Board is a RISC-V based microcontroller development board. This board primarily seeks to support embedded system prototyping, and is being designed to be utilized in undergraduate computer engineering courses. The RISC-V architecture allows for open-source design and provides an easy-to-learn instruction set while still providing many of the benefits of higher, more complex computation.

	Linux	Windows	macOS
Hardware Quality	Versatile, can run on low-spec PCs	Very versatile	Proprietary hardware, very high-end
Cost	Mostly free, some distros have paid versions	Freemium, accessing all features costs approximately $150	Free but comes on an expensive hardware
Software Compatibility	Open-source substitutes for proprietary software	Unparalleled	Has its own app ecosystem
Ease of Installation	Requires some computing knowledge	Easy	Very easy
Security and Stability	The safest and most stable OS	Generally great, requires plenty of frequent updates	Very good, requires only a few periodic updates
Ease of Use	Ease of use determined by the distro	Simple to use	Very easy to use

Fig. 2. Chart comparing key features of Windows, macOS, and Linux [12]

A. Athena Features

The Athena Board effectively utilizes many of the built-in features found on the SiFive FE310 microprocessor [12]. This microprocessor has substantial computational power and contains many features that allow for flexibility and multifaceted use of the Athena Board.
Among these features are:

1) Processing
   The onboard FE310 on the Athena Board features processing clock speeds at 16 MHz
2) Memory
   The onboard FE310 on the Athena board features:
   - 8 kB One Time Programmable Memory
   - 8 kB Mask ROM
   - 16 kB Data SRAM
3) Cache
   The onboard FE310 on the Athena Board features a 16 kB instruction cache
4) Communication Protocols
   The Athena Board, utilizing the FE310, features the following Communication Protocols:
   - UART
   - SPI
   - I2C
   - JTAG
5) Other Features
   - PWM
   - Hardware Multiply and Divide

B. Feature Comparison

The Athena Board is comparable with many general purpose microcontroller boards currently used in similar capacities. The table below shows the comparison of the similar boards. 3 other boards will be considered, those being:

- Arduino Uno [13]
- TI MSP430F2553 [14]
- TI Tiva TM4C123G [15]

This comparison can be shown on the table below.

TABLE VI
MICROCONTROLLER FEATURE COMPARISON

Feature	Athena	Arduino Uno	TI MSP430F2553	TI TM4C123G
Instruction Set Architecture	RISC-V	Atmel AVR	TI Proprietary RISC Architecture	ARM
Processisng	16 MHz	16 MHz	16 MHz	16 MHz
Memory (SRAM)	16 kB	2 kB	16 kB	32 kB
Cache	16kB Instruction Cache	N/a	N/a	N/a
Communication Protocols	UART, SPI, I2C, JTAG	UART, SPI, I2C	UART, SPI, I2C	UART, I2C, JTAG

C. Feature Comparison Analysis

1) Arduino Uno: The Arduino Uno is a microcontroller board that is commonly used by electronics hobbyists and enthusiasts. One of the primary benefits of the Ardudino Uno is the community support and open-source software. This microcontroller is comparable to the Athena Board in terms of most of its specifications, but falls short in some aspects.
One of the primary issues facing the Arduino Uno is the low availability of SRAM Memory. The Uno only has 2 kB of SRAM memory, which prevents users from programming larger, more complex programs onto the board. Compared to the Athena Board, the Uno only has an eighth of the available SRAM Memory.
Another primary drawback of the Arduino Uno is the lack of a cache memory hierarchy. In most cases, this reduces the throughput of the Arduino Uno compared to that of the cached Athena microcontroller. This gives the Uno a weak point compared to the Athena Board as the Uno has to wait longer periods of time for instructions than the Athena Board.

2) TI MSP430F2553: The TI MSP430F2553 is a general purpose microcontroller, and it is currently being utilized in undergraduate instruction at Rice University for higher level digital design classes. The TI MSP430F2553 is a proprietary device, but can be developed using an open source compiler. While the TI MSP430F2553 does not suffer from low SRAM memory compared to the Athena Board, it still experiences a diminished throughput compared to the Athena Board for a lack of a cache hierarchy. This, like the Arduino Uno, limits the flexibility and increases the computational time necessary for complex problems.

3) TI Tiva TM4C123G: Like the TI MSP430F2553, the TI Tiva TM4C123G is a general purpose microcontroller and was once used in undergraduate instruction at Rice University for an intro-level Computer Engineering course. The design

is also proprietary, but uses an open source compiler for development.

One advantage the TI Tiva TM4C123G has over the Athena board is the amount of SRAM Memory, which is 32 kB compared to the 16 kB found on the Athena Board. This can allow for greater program size and flexibility when utilizing the TI Tiva TM4C123G.

Despite this, the TI Tiva TM4C123G still suffers from the lack of a cache hierarchy like the Arduino Uno and the TI MSP430F2553. This, as previously mentioned, can ultimately reduce the available throughput of the microcontroller.

Conclusion

Just some of the many benefits of open-source hardware and software have been described in this paper. Despite open source technology's generally lesser market share in the consumer market when compared to closed-source technology, we believe that when it is a possibility to move from a closed-source solution to an open-source solution, this change will benefit all. Hence, we encourage you, the reader, to analyze which pieces of technology you use today that could be replaced with open-source alternatives. Once you have analyzed these items, evaluate the possibility of switching—because the switch you make will be for good.

Acknowledgment

Athena Board

The Athena Board is a development board created by the RISC-V at Rice Research Lab [16]. The RVR lab principal investigator is Ray Simar.

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