

The Open-Source Advantage: Powering Innovation in the 21st Century

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ABSTRACT

Organizations worldwide are undergoing a fundamental shift in how software is developed, deployed, and sustained. The rapid emergence of new technologies, combined with the accelerating adoption of open-source solutions – has created an ecosystem where innovation thrives alongside increased complexity. As diverse tools, platforms, and communities converge, organizations must balance opportunity with risk.

This presentation examines the benefits, challenges, and emerging opportunities of open-source technologies in the 21st century. Participants will explore how organizations and user communities are addressing critical considerations, including system integration and compatibility, security vulnerabilities, intellectual property concerns, licensing and warranties, and the variability of development and support practices.

Attendees will gain practical insight into the evolving roles of Python, R, SQL, modern database platforms, cloud computing, and open software standards, as well as the collaborative culture that fuels global open-source innovation. Join us for a forward-looking discussion on how open-source software is reshaping technology strategy, collaboration models, and innovation across industries.

INTRODUCTION

Open-source technologies have evolved from niche tools into foundational drivers of innovation, particularly in information technology (IT) and data science (DS). This paper examines the defining features of open-source software (OSS), highlighting its collaborative community, diverse applications, and role across commercial, academic, and private sectors.

OSS offers significant advantages, including transparency, flexibility, rapid vulnerability detection, and reduced licensing and maintenance costs, enabling faster and more resilient development. However, integrating open-source components into proprietary systems introduces challenges such as version control complexity, inconsistent stability, variable documentation, and potential security risks.

By evaluating both the benefits and limitations, this paper underscores the transformative impact of OSS and the importance of strategic integration and ongoing standardization in advancing 21st-century technology.

SOFTWARE TYPES

Software is created using source code which tells a program or application how to function. For this paper, two distinct software types (or categories) will be illustrated: 1) Proprietary (or commercial) software and 2) Open-source software. A major decision confronting a software developer is whether the source code related to the software release will be made publicly available on web hosting services, such as GitHub, for anyone to inspect, modify, enhance, and share – referred to as open-source, versus software where the developer maintains exclusive control over the source code thereby preventing the public availability to inspect, modify, enhance, and share it – referred to as closed source or proprietary software.

So, which type of software is more common? A large majority of apps, games, and other popular software are classified as closed source or proprietary. However, there are a growing number of open-source alternatives for users to choose from. For example, a popular open-source alternative to Microsoft Office is LibreOffice. An open-source alternative to Microsoft Windows is the Linux operating system. Another popular open-source alternative to Google’s or Bing’s web browser software is the Mozilla Firefox web browser.

ECOSYSTEM OF LEADING-EDGE TECHNOLOGIES

A growing number of organizations are launching initiatives to integrate and use leading-edge commercial technologies and open-source software, applications, and tools for the purpose of engineering methodologies and toolkits to meet the needs of organizations worldwide. In an announcement from McKinsey & Company (September 26, 2023), the launch of a technology-driven ecosystem boasts commercial and open-source software, applications, and tools coexisting together - like a biological community of organisms interacting together within a single physical environment. This initiative represents an ecosystem of integrated technologies working together for the purpose of gaining the greatest value from their technology investments.

EXAMPLES OF OPEN-SOURCE SOFTWARE AND TECHNOLOGIES

An alphabetical list of popular examples of open-source software and technologies is presented in table 1.

Open-source Software	Description
Anaconda	Anaconda is a distribution of the Python and R programming languages for scientific computing and data science packages that aim to simplify package deployment and management under Windows, Linux, and macOS operating systems.
Apache Hadoop	Apache Hadoop is a collection of open-source software utilities for data science projects that facilitates the integration of a network of computers to solve problems involving massive amounts of data and computing capacity.
Apache HTTP Server	The Apache HTTP Server is a free and open-source cross-platform web server software, released under the terms of Apache License 2.0. Apache HTTP Server allows users to deploy their websites on the Internet.
Apache Mahout	Apache Mahout is an environment for building scalable machine learning algorithms.
Data Version Control	Data Version Control (DVC) is a popular open-source tool used to version data, annotate it with metadata, track changes to data, and collaborate with others on data science projects.
Firefox	Mozilla Firefox is free and open-source software, released under the terms of the Mozilla Public License which means you may use, copy, and distribute Firefox to others.
GDAL	The Geospatial Data Abstraction Library is an open-source, cross-platform spatial data management program. Capable of importing, accessing, manipulating, and exporting geospatial data in several raster file and vector file formats, GDAL is widely accessible through APIs for Python, R, PHP, and Java.
GIMP	GNU Image Manipulation Program (GIMP) is freely distributed software for image composition, image retouching, and image restoration.
jQuery	jQuery is free, open-source software using the permissive MIT license consisting of a JavaScript library that simplifies the creation and navigation of web applications.
Knime	Knime is a free, open-source data analytics, reporting, integration, and machine learning platform for data scientists.
LibreOffice	LibreOffice is powerful and free open-source office software suite for word processing, spreadsheets, presentations, graphics, flowcharts, databases, and formula editing.

Open-source Software	Description
Linux	Linux is released under an open-source license which lets anyone use, run, modify, and redistribute the source code and sell copies of their modified source code if they do so under the same license. The source code for Linux is under copyright by its many individual authors and licensed under the General Public License Version 2 (GPLv2) license.
Matplotlib	Matplotlib is an open-source software graph plotting library for the Python programming language.
NumPy	NumPy is a library for the Python programming language and used for scientific computing tasks.
Orange	Orange is an open-source data science toolkit for developing, visualizing, and testing data mining workflows.
PostgreSQL	PostgreSQL is an open-source object-relational database management system, supporting both relational (SQL) and non-relational (JSON) and offering advanced SQL functions, including foreign keys, subqueries, and triggers. PostgreSQL is commonly used as the main data warehouse to support internet-scale web, mobile, and geospatial applications. Importantly, PostgreSQL runs on most machines and operating systems.
Project Jupyter	Project Jupyter provides an environment to develop open-source software applications and tools to perform data cleaning, statistical computation, data visualization, and create predictive machine learning models.
Python	Python is a powerful open-source programming language that is available under a free software license. It supports object-oriented and structured programming along with other programming paradigms. Developed by Guido van Rossum in the late 1980s, Python is designed to be an “easy to read language” with numerous third-party modules to interact with other languages; extensive support libraries such as web service tools; text processing; string operations; internet protocols; a powerful scripting language; an extensive user community; and many other features.
Quarto	Quarto is an open-source scientific and technical publishing system, frequently referred to as “the next generation of R markdown.” Quarto allows users to author using both Jupyter notebooks or with plain text markdown in their editor of choice, with dynamic content in Python, R, Julia, and Observable. The Quarto system allows for reproducible, production-quality articles, presentations, dashboards, websites, blogs, and books in a wide range of formats (ex: HTML, PDF, and more).
QGIS	QGIS is an open-source spatiotemporal software suite capable of viewing, modifying, manipulating, and exporting geospatial data through a graphical user interface. It is the open-source equivalent to the proprietary ArcGIS geospatial software suite. QGIS supports tiling systems; merging and mosaicking raster files; importing and exporting vector shapefiles; delivering customizable data visualizations; interactive mapmaking; spatiotemporal summary statistics; and other GIS features.
R	R is a powerful open-source programming language and is used for statistical computing, graphics, and data analysis. Available under a free software license, R runs on all important platforms and is used by statisticians, data miners and thousands of major corporations and institutions worldwide. Developed by Ross Ihaka and Robert Gentleman at the University of Auckland, New Zealand, their initial version of R was released in 1995 with a stable beta version in 2000. R boasts an extensive array of packages including data wrangling; data analysis; plotting; graphing; reporting; statistics; an extensive user community; and many other features.
Shiny	Shiny is an open-source R package and Python library that provides an elegant and powerful web framework for building web applications, including interactive data exploration tools, dashboards, and full-blown applications. Shiny helps you turn your analyses into interactive web applications without requiring HTML, CSS, or JavaScript knowledge.

Open-source Software	Description
SQL	Structured Query Language (SQL) is a relational database language that is used in managing and programming relational database management systems (RDBMS). SQL is specifically useful in handling structured data and comprises many types of statements including a data query language (DQL), a data definition language (DDL), a data control language (DCL), and a data manipulation language (DML). MySQL and Microsoft SQL Server Express are open-source database applications with a codebase that is free to view, download, modify, distribute, and reuse.
tidyverse	The tidyverse is a collection of R packages that allow for data reading, cleaning, wrangling, and graphing using a standardized syntax on top of the core R programming language. The tidyverse is among the most frequently utilized packages in the R ecosystem, particularly for data analysts and data scientists. The “tidy” syntax introduced by these packages serves as a key design principle for many other R packages, including packages like tidymodels.
VLC Media Player	VideoLAN Client (VLC) Media Player is a free open-source multi-platform media player for desktop operating systems and mobile platforms such as Android, iOS, and iPadOS that plays multimedia files including DVDs, Audio CDs, and many video formats and streaming content.
VNC	Virtual Network Computing (VNC) is an open-source application that provides screen sharing services. VNC is secure over the Internet with all end-to-end connections encrypted and remote computers are protected by a password or by a system login credentials.

Table 1. Open-source Software Descriptions, continued

EXAMPLE OF OPEN-SOURCE INTEGRATION – A SYMBIOTIC SYSTEM

The open-source applications and tools described above are not typically used in isolated environments, but instead in symbiotic relationships with each other, working together toward a common goal. An example of OSS integration for data science is provided in Figure 1 below.

The Open Source Workflow of a Data Scientist

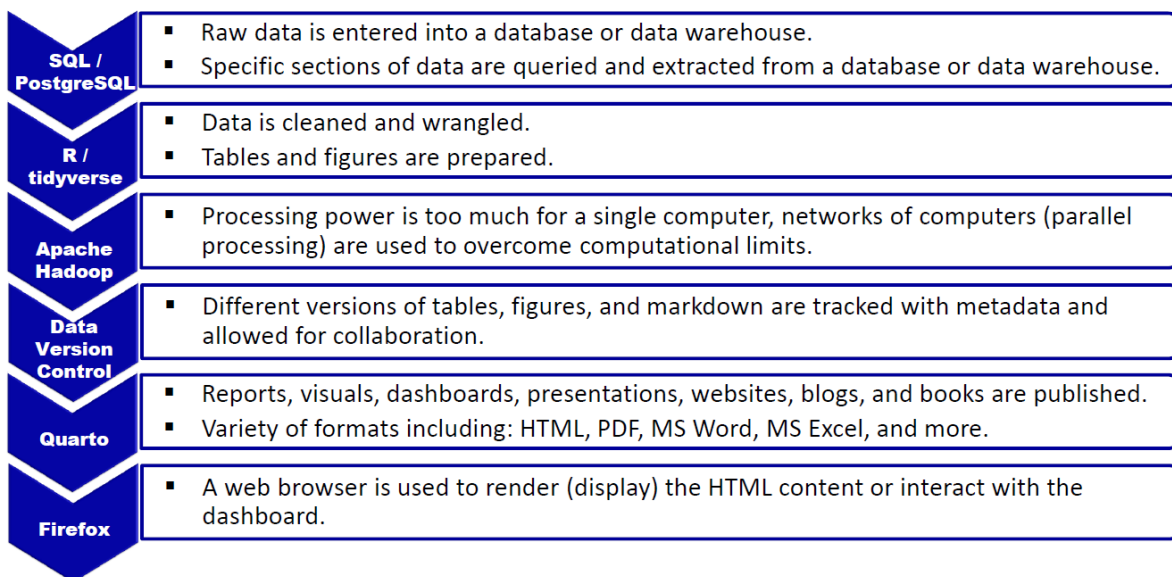


Figure 1. The Open-Source workflow of a data scientist.

OPEN-SOURCE INTEGRATION – BENEFITS, CHALLENGES, AND OPPORTUNITIES

Open-source integration promotes free access to inspect, modify, enhance, and share source code. The redistribution of software is not only permitted but encouraged to sustain innovation. According to a recent study by Gartner, open-source tools provide flexibility and cost-effectiveness for data integration tasks and projects such as connectivity, data routing, and transformation.

IS OPEN-SOURCE BUG-FREE?

The short answer to this question is no. But no matter the type of software, commercial or open-source, bugs (or code flaws that affect quality, performance, and security) are inevitable. The primary difference between both types of software is who is ultimately responsible for fixing the bugs. For commercial software, vendors and their professional developers are responsible for fixing bugs; while for open-source software, the legions of users, like you and me, are responsible for fixing bugs.

OPEN-SOURCE STANDARDIZATION EFFORTS

There are many efforts across the open-source landscape that are focused on standardization, specifically regarding version control and quality assurance. Within the R ecosystem, the pharmaverse is a network of companies aimed at curating open-source R packages that are standardized for clinical reporting in the pharmaceutical industry. Other groups that are working toward standardization in R include PHUSE Working Groups, R Consortium Working Groups, R Validation Hub, and TransCelerate. Importantly, on September 27th, 2023, the R Submissions Working Group successfully completed the first publicly available submission package to the U.S. Food & Drug Administration (FDA) that included a Shiny component.

In the Python ecosystem, one can observe similar endeavors to those in the R ecosystem, like the creation of centralized repositories and working groups dedicated to enhancing the utility and reliability of Python packages. Projects such as PyPA (Python Packaging Authority) work to improve the packaging landscape and develop standards for Python package distribution. The Python Software Foundation also promotes and protects Python through community-driven efforts.

In the realm of data science and machine learning, groups such as NumFOCUS support and organize standards around popular Python packages like NumPy, pandas, and scikit-learn, ensuring they meet the high standards required for academic and industrial research. Additionally, industry collaborations, like the Consortium for Python Data API Standards, aim to create a uniform API for array/tensor-like data structures across various libraries, improving interoperability and user experience.

These efforts aim to directly address many of the challenges associated with open-source technologies.

CONCLUSION

Open-source software (OSS) has become a central driver of innovation in information technology (IT) and data science (DS). This paper has outlined its core characteristics, diverse applications, and the role of its collaborative community, while also examining the benefits, challenges, and ongoing standardization efforts associated with its adoption.

Key advantages of OSS include transparency, flexibility, rapid vulnerability detection and resolution, and reduced licensing and maintenance costs. Despite challenges such as version control complexity and inconsistent documentation, open-source solutions remain highly adaptable and cost-effective.

Spanning applications from programming languages to data platforms and geospatial systems, OSS continues to enable scalable, customizable, and accessible solutions. Its growing adoption underscores its lasting impact on modern technological development.

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ACKNOWLEDGMENTS

The authors thank the PharmaSUG 2026 Conference Committee, particularly the Conference Chairs for organizing and supporting a great “in-person” conference event; and SAS Institute Inc. for providing SAS users with wonderful software!

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The Open-Source Advantage: Powering Innovation in the 21st Century, continued

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Comments and suggestions are always welcome and can be sent to:

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