SOFTWARE TRANSPARENCY

Supply Chain Security in an Era of a Software-Driven Society

Chris Hughes and Tony Turner

Foreword by **Allan Friedman, PhD**

Technical Editor, **Steve Springett**

WILEY

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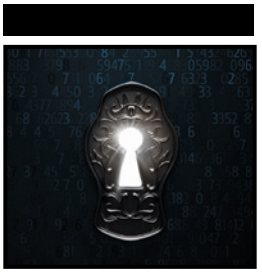

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This is dedicated to my children, Carolina, Calvin, Callie, and Clayton, as well as my wife, Kathleen, for their unwavering love and support which serves as motivation to always strive to be my best. I also would like to dedicate it to my mother Dawn and grandfather Bill, who always taught me the importance of hard work.

— Chris Hughes

This book marks a transition point of so many things in my life, and throughout it all, my wife Becki, and my two sons, Alex and Gavin, have patiently supported me. I'd like to thank them from the bottom of my heart for always being there to remind me of what is most important in life.

— Tony Turner

About the Authors

Chris Hughes currently serves as the co-founder and CISO of Aquia. Chris has nearly 20 years of IT/cybersecurity experience, ranging from active duty time with the U.S. Air Force, as a civil servant with the U.S. Navy and General Services Administration (GSA)/FedRAMP, as well as time as a consultant in the private sector. In addition, he is an adjunct professor for M.S. Cybersecurity programs at Capitol Technology University and University of Maryland Global Campus. Chris also participates in industry working groups such as the Cloud Security Alliances Incident Response and SaaS Security Working Group and serves as the Membership Chair for Cloud Security Alliance D.C. Chris also co-hosts the Resilient Cyber podcast.

Chris holds various industry certifications such as the CISSP/CCSP from $(ISC)^2$, as well as holding both the AWS and Azure security certifications and Cloud Security Alliance's Certificate of Cloud Auditing Knowledge (CCAK). He holds a B.S. in Information Systems, an M.S. in Cybersecurity, and an MBA. He regularly consults with IT and cybersecurity leaders from various industries to assist their organizations with their digital transformation journeys, while keeping security a core component of that transformation. Chris has authored many articles and thought pieces on software supply chain security, as well as presenting on the topic at industry events such as Carnegie Mellon's DevSecOps Days Washington, D.C. among others.

Tony Turner is the founder and CEO of Opswright, a software company focused on security engineering for critical infrastructure. With over 25 years' experience in cybersecurity, Tony has worked as an internal security engineer, developer, network and systems administrator, security consultant, architect, and managed professional services for security vendors. Most recently he functioned as the VP of Research and Development for the Fortress Labs team at Fortress Information Security, where he spearheaded their software transparency and vulnerability management product research and roadmap. Tony also founded and leads the OWASP Orlando chapter since 2011, focused on improving the visibility of application security; is the project leader for WAFEC, a web application firewall documentation project; and co-founded the Security BSides Orlando conference. He sits on multiple trade organizations and industry groups from MITRE, ISA, OWASP, CISA, GlobalPlatform, and others, largely focused on the topics of software transparency, and software and product security within critical infrastructure.

Tony graduated with a B.S. from Hodges University in Naples, Florida, and holds several industry certifications, including the CISSP; CISA; six credentials from SANS/GIAC, OPSE, CSTP, and CSWAE; and multiple vendor certifications from F5, Imperva, and others.

Additionally, Tony has been involved with the certification exam writing process for GIAC and F5 ASM web application firewall certification and is a course author for SANS on Defending Product Supply Chains, to be released in 2023.

Tony lives in Indialantic, Florida, with his wife, Becki; two sons, Alex and Gavin; five cats; three lizards; two guinea pigs; and an army of squirrels in his backyard that demand their morning tribute.

About the Technical Editor

Steven Springett has over 25 years leading product development teams and has spent over 14 years focused on supply chain security. Currently, Steve is the director of secure development at ServiceNow, where he leads application security architecture, threat modeling, security champions, and developer enablement across the organization. Steve is passionate about helping organizations identify and reduce risk from the use of third-party and open source components. He is an open source advocate and leads the OWASP Dependency-Track project, is a coauthor of the OWASP Software Component Verification Standard (SCVS), and is the chair of the OWASP CycloneDX Core Working Group, a bill of materials standard that provides advanced supply chain capabilities for cyber-risk reduction. Steve holds a CSSLP and CCSK, among other industry certifications. Steve lives in Chicago's North Shore with his wife, Vera, and daughter, Aryana.

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We would like to acknowledge the countless industry professionals who we have worked with, for, and learned with over our several decades of combined cybersecurity experience.

This includes industry thought leaders on the topic of software supply chain security, such as Allan Friedman, Joshua Corman, Robert Wood, Virginia Wright, Jason Weiss, and, of course, Steve Springett, who, in addition to serving as an industry leader on the topic of software supply chain security, also served as our technical editor and sounding board. We would also like to thank the countless public and private sector leaders who have participated in working groups and efforts associated with software supply chain security through groups such as OWASP, the Linux Foundation, OpenSSF, Department of Defense, NTIA, CISA, Carnegie Mellon's Software Engineering Institute (SEI), and others. Without the community's collective expertise, knowledge sharing, and collaboration, we would not be able to produce this body of knowledge to give back to the industry. Software is critical to nearly every aspect of our society, and we're in this fight together.

Contents at a Glance

Contents

Foreword

Many of us will remember December 2021 as a time spent hunched over small travel laptops in relatives' guest rooms, dealing with the Log4j crisis. That vulnerability in an open source Java-logging framework developed by The Apache Software Foundation was scored as severe by both official metrics and software experts. It was not the hardest vulnerability to address, either through patches or other inline mitigations. Yet, the real challenge most organizations faced was location: Where is this darn thing? Buried deep in countless modern applications' supply chains, both producers and users of software simply didn't have a usable roadmap of where to focus.

The hard part of security should be in identifying vulnerabilities and discovering attackers sneaking into our supply chains. Instead, we've discovered that understanding what's in the software we make has required a nontrivial amount of work.

The idea of tracking what goes into software isn't new. Academics have been talking about it since the 1990s. Early idea discussions were happening in disparate corners of the software world in the 2000s. Failure to account for the open source licenses got a number of large companies into serious legal trouble. Collecting and leveraging supplier data formed an integral part of the revolution in heavy industry quality that dates back to the late 1940s, with the Deming and the "Toyota revolution" that inspired the DevSecOps and modern software revolution decades later.

Indeed, it's quite remarkable that we don't have better transparency in our software supply chains. I often use the example of a Twinkie (first advanced by Audra Hatch and Josh Corman) to raise the question of why we have a better understanding of what is in a nonbiodegradable snack than what is in the software that runs in our companies, governments, and critical infrastructure.

As we embark on our journey to understand how to implement software bill of materials (SBOMs), it's useful to take a moment to understand why we didn't have this capacity at the beginning, how we're beginning to make progress, and what the value of this transparency is. There are some less-flattering reasons why few organizations wanted to share, including not wanting to be exposed to the previously mentioned open source license compliance risks. Frankly, many organizations did not want to admit to the scale of technical debt or incur the costs of having to set up the basic internal infrastructure and processes to track their dependency data. Moreover, it should be acknowledged that starting this SBOM journey hasn't been easy—it has required bringing together technical expertise, an understanding of the diverse software ecosystem, and an appreciation of incentives. But a massive amount of progress has been made in the last five years.

The first thing we needed was a shared vision of what an SBOM is. Many experts had a general idea; these were debated and refined from 2018 to 2020 in the open, international, "multistakeholder process" that the National Telecommunications and Information Administration (NTIA) convened. The community defined the basics of an SBOM and laid out its core use cases. We then needed a machine-readable means to convey this information across the supply chain. Fortunately, some across the software world were ahead of us, so we were able to align the Linux Foundation's Software Package Data Exchange (SPDX) and Open Worldwide Application Security Project's (OWASP's) CycloneDX to meet these models.

The next step was creating tools to generate and use this machine-readable data. Great progress has been made across the software world in implementing SBOM generally, with new tools emerging across the ecosystem. We're seeing more sector- and technology-specific tools, because the needs of the industrial control systems (ICSs) and operational technology (OT) firmware world are somewhat different from traditional enterprise software, which, in turn, have unique features and integrations compared to the cloud-native world. Generation tools have begun to mature and new tools emerge all the time to help organizations use this data, both operationally and strategically. (It's been one of the perks of my job, first at the NTIA and now at the Cybersecurity and Infrastructure Security Administration [CISA], to meet with start-ups and open source innovators to find ways to meet real needs across the software marketplace.)

Of course, the third leg of the tripod, along with technology and markets, is government. The U.S. government has focused on securing the supply chain in recent years, but there has been strong interest as well as policy innovations by our partners around the world. SBOMs moved to the main stage of cybersecurity policy in May 2021, when the President's Executive Order (EO) on Improving the Nation's Cybersecurity declared, among other things, that suppliers to the U.S. government will provide the purchaser with an SBOM. As this book goes

to press, the final details of those regulations are expected. This goes along with regulations of medical devices in the United States by the Food and Drug Administration (FDA), activity from other U.S. regulators, and proposed regulations emerging around the world.

Because you have this book in your hands or on your screen, you probably don't need to be convinced of the value of transparency across the software supply chain. But you may have to convince others, evangelize across your organization or corner of the software ecosystem, argue for a budget, or convince your suppliers to share data. Despite the usual infosec vendors' hyperbole, the "SB" in SBOM doesn't stand for "silver bullet." SBOM is a data layer. We are still building the tools and processes to the turn that data into intelligence and, ultimately, into action. Just like a Common Vulnerabilities and Exposures (CVE) identifier doesn't actually fix a vulnerability on your network—and CVEs are now an indispensable part of our global vulnerability ecosystem—so, too, will SBOMs become an integral part of the software security and quality world.

Transparency in the software supply chain aids across the life cycle of software. For those of us who build software, SBOMs are a powerful tool to understand our processes and to ensure that we're not building things that are not secure-by-design or shipping with known risks. For those of us who choose or buy software, why would we use a supplier who doesn't understand what they are delivering? Why would we potentially adopt software that was outdated before its use? For those of us who operate software, without an SBOM, how can we respond to newly identified risks or make plans for systems that are built on end-of-life or end-of-support software? Of course, many of us occupy all three roles. It seems inevitable that more uses of this data will be identified and built as SBOMs become more ubiquitous.

There have been a lot of incredible contributions to the software transparency movement, championing the idea of SBOMs, building tools, and debating vital edge cases. Authors Hughes and Turner do a great job of capturing these advances—including some of their own—and explaining the details and nuances as we go from the idea of SBOM to the practice of SBOM. While I expect practitioners around the world to pick up and use this volume to incredible success for their organizations and their customers, it is my paradoxical wish that this book's critical value is actually short-lived. As more of us start to build and manage our software with the types of interoperable automation the authors so helpfully envision and follow the course they lay out, SBOMs will cease to be new and shiny and become a natural, automated part of how all software is made, sold, and used.

It's then we can turn to the next challenge.

Dr. Allan Friedman

Allan Friedman is Senior Advisor and Strategist at the Cybersecurity and Infrastructure Security Agency. He coordinates the global cross-sector community

efforts around software bill of materials (SBOM). He was previously the Director of Cybersecurity Initiatives at NTIA, leading pioneering work on vulnerability disclosure, SBOM, and other security topics. Prior to joining the federal government, Friedman spent over a decade as a noted information security and technology policy scholar at Harvard's Computer Science department, the Brookings Institution, and George Washington University's Engineering School. He is the co-author of the popular text *Cybersecurity and Cyberwar: What Everyone Needs to Know*, has a C.S. degree from Swarthmore College and a PhD from Harvard University.

Introduction

We are living in a time where software touches every aspect of our society. Software is involved in everything from critical infrastructure, digital commerce, and national security. In fact, as of this writing, the World Economic Forum (WEF) predicts that by the end of 2022, 60 percent of global gross domestic product (GDP) will be tied to digital systems (`www3.weforum.org/docs/WEF_Responsible_Digital_Transformation.pdf`). However, that same WEF report found that only 45 percent of people trust the technology that powers our modern economies and society. Part of that lack of trust can be traced to many years of notable digital data breaches and a long-standing issue with transparency when it comes to the software supply chain.

Software supply chain attacks are far from a new phenomenon, and concerns about trusting code have origins dating back to Ken Thompson's famous "Reflections on Trusting Trust" paper in 1984, where Thompson discussed the inability to trust code you did not create yourself. While the idea that code consumed from external sources could be untrustworthy or downright malicious, the manifestations of that statement have only been exacerbated in recent years as software supply chain attacks accelerate. Malicious actors, driven by a variety of motives, have realized that rather than targeting a single entity, they can compromise widely used software (whether proprietary or open source) and have a cascading impact across an entire ecosystem of consumers.

As these incidents have accelerated, organizations have increased their efforts to both understand software supply chain challenges, complexities, and incidents, and have implemented security measures to mitigate their associated risks. The Cloud Native Computing Foundation (CNCF) has compiled a catalog (`http://github.com/cncf/tag-security/tree/main/supply-chain-security/compromises`) of supply chain compromises dating back to 2003. This catalog

captures supply chain compromises from a variety of methods, such as exploited developer tooling, developer negligence, malicious maintainers, or even attack chaining (i.e., several compromises chained together to enable an attack).

Before some of the landmark cases discussed in this text, such as SolarWinds, Log4j, and others, the Office of the Director of National Intelligence (ODNI) published a paper (`http://dni.gov/files/NCSC/documents/supplychain/20190327-Software-Supply-Chain-Attacks02.pdf`) in 2017, calling it a watershed year for software supply chain attacks. The document laid out several significant software supply chain attacks in 2017, which impacted organizations supporting the U.S. government in addition to commercial leaders, several of which originated from nation-state actors. The ODNI paper points out that many software development and distribution channels lack proper security. ODNI also described some malicious actors going upstream due to better cyber hygiene among some organizations. It is often more efficient for malicious actors to go upstream and compromise downstream software consumers at scale, rather than targeting one individual organization. Some software supply chain attacks may be indiscriminate, targeting any consumers, while others may seek out specific upstream software producers knowing who some of their downstream consumers are.

There is no denying that digitally enabled systems have led to unprecedented efficiency, productivity, and innovation. That said, these same digitally connected software-empowered systems have now created levels of systemic risk that are only beginning to be fully understood. It is said that complex interdependencies can heighten systemic risk, and it would be hard to argue that the current state of the software ecosystem and modern digital systems are anything but complex. Malicious actors are realizing the value of targeting the software supply chain as well, with Gartner, an industry leader in technology research, predicting that by 2025, some 45 percent of organizations will experience a software supply chain attack. Some argue that estimate may be low, with organizations such as Sonatype producing a 2022 report (`http://sonatype.com/state-of-the-software-supply-chain/introduction`) showing a 742 percent annual increase in software supply chain attacks over the past three years.

As notable software supply chain attacks have increased, we have now seen ambitious efforts on behalf of governments as well as private sector organizations. In the United States, the White House issued Executive Order 14028, "Improving the Nation's Cybersecurity" (`http://whitehouse.gov/briefing-room/presidential-actions/2021/05/12/executive-order-on-improving-the-nations-cybersecurity`), which has a section dedicated to enhancing software supply chain security. This order includes a section about a common lack of transparency as it relates to software being consumed by organizations, including the federal government.

In this book, we will discuss in more detail relevant software supply chain incidents, industry activities, emerging solutions, as well as the significant challenges that remain when it comes to securing the software supply chain.

Why Is This Critical?

Before we dive into the specifics of software supply chain threats and emerging frameworks and guidance, we should initially discuss why this is such a critical issue that impacts every aspect of modern society. As mentioned previously, digital platforms are quickly on pace to touch over half of the global economic output. Powering those digital platforms and systems is software, much of which is open source software (OSS) components. OSS use is ubiquitous across much of the modern software ecosystem. A recent study (`http://synopsys.com/content/dam/synopsys/sig-assets/reports/rep-ossra-2022.pdf`) found that 97 percent of modern software codebases contain OSS, and not only do they contain OSS, but over half of the codebases are OSS.

OSS is now fundamentally integrated into some of society's most critical infrastructure and systems. Research has shown that over 90 percent of codebases for industries such as transportation, financial services, and manufacturing contain OSS. The same trends exist across industries such as telecommunications and health care as well. In the United States, the Department of Defense (DoD) released a memo titled "Software Development and Open Source Software" (`http://dodcio.defense.gov/Portals/0/Documents/Library/SoftwareDev-OpenSource.pdf`). The memo, which is part of their broader Software Modernization Strategy (`https://dodcio.defense.gov/portals/0/documents/library/softwaredev-opensource.pdf`), calls OSS "the bedrock of the software-defined world and is critical in delivering software faster, resiliently, as is key to their software modernization efforts." The Software Modernization Strategy states that "the ability to securely and rapidly deliver resilient software capability is a competitive advantage that will define future conflicts."

Innovative use of software is not just critical for national security purposes, as emphasized by the DoD, but is pivotal for society at large. In a hearing as part of the U.S. House of Representatives Committee on Science, Space and Technology titled "Securing the Digital Commons: Improving the Health of the Open Source Software Ecosystem" (`www.congress.gov/event/117th-congress/house-event/114727`), several elected officials as well as industry experts testified to the importance of a resilient OSS ecosystem. Congressman Bill Foster called OSS the "hidden workforce of the digital ecosystem." Congresswoman Haley Stevens stated that "a vibrant open-source ecosystem is an engine for U.S. competitiveness and growth." In an Open Source Software Security Summit hosted by the White House in 2022, it was emphasized that most major software packages include OSS, including software that is used by the national security community (`www.whitehouse.gov/briefing-room/statements-releases/2022/01/13/readout-of-white-house-meeting-on-software-security`).

Many are beginning to make the case that OSS is such a vital aspect of society that it should be considered critical infrastructure as well, comparing it to interstate highways, power grids, water treatment, and other fundamental aspects of

our society (http://hbr.org/2021/09/the-digital-economy-runs-on-open-source-heres-how-to-protect-it). The argument also claims that designating OSS critical infrastructure would lead to additional resources, cross-sector coordination, public awareness, and dialogue.

Despite the ubiquity of OSS and its importance to national security, commercial industry, and society, it can be argued that its security concerns have been neglected. In an article titled "Open-Source Security: How Digital Infrastructure Is Built on a House of Cards" (http://lawfareblog.com/open-source-security-how-digital-infrastructure-built-house-cards), researcher Chinmayi Sharma makes the case that OSS and its associated vulnerabilities are pervasive across all critical infrastructure sectors and, due to a lack of resources and incentives, pose a systemic risk to society.

This lack of attention is not lost on malicious actors either, as some studies state we have seen software supply chain attacks experience as much as a 650 percent year-over-year (YoY) increase in 2021. This is not a unique phenomenon, with 2020 seeing an over 400 percent increase. These stark increases are also reflected in sources such as the Cloud Native Computing Foundation's (CNCF) Catalog of Supply Chain Compromises.

This uptick in software supply chain attacks is also supported by research from organizations such as the Atlantic Council, in their "Breaking Trust: Shades of Crisis Across an Insecure Software Supply Chain" white paper (http://atlanticcouncil.org/wp-content/uploads/2020/07/Breaking-trust-Shades-of-crisis-across-an-insecure-software-supply-chain.pdf). Their research shows a sharp increase in software supply chain attacks, with third-party applications among the primary attack vectors, along with OSS. The report documents more than 100 software supply chain attacks over the last decade, through a myriad of vectors such as hijacked updates, malicious dependencies, compromised software development platforms, and account compromises. This demonstrates not just the consistent and increasing use of software supply chain attacks by malicious actors, but also the diversity of attack vectors that malicious actors can use to compromise downstream software consumers due to the complexity of the modern software ecosystem. As demonstrated by the report, not only are these attacks impacting millions of users, but they are also quickly becoming a standardized method of nation-state conflict and engagement in the modern digital society. The attention from malicious nation-state actors was also emphasized by ODNI in its 2017 publication (http://dni.gov/files/NCSC/documents/supplychain/20190327-Software-Supply-Chain-Attacks02.pdf).

It is not just OSS components that are being targeted. Malicious actors are also targeting managed service providers (MSPs), cloud service providers (CSPs), and several other entities, all of which play various roles in the modern software ecosystem.

Malicious actors have realized the fruitfulness of targeting software supply chain components or suppliers and causing a massive downstream impact,