

Coffee in Iceland: The Ethics of Java on Android

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Abstract

Google released Android on November 5, 2007 [31] as a platform for mobile phones. Programmers can write applications for Android in Java. These programs are run with Dalvik — a virtual machine that Google created. In 2010, Oracle America Inc. filed a lawsuit against Google [35], claiming that Dalvik infringed on Oracle's intellectual property. This raises the question: is Google's use of the Dalvik virtual machine in Android ethical? Dalvik is ethical because it uses industry standards, follows licensing restrictions, and contributes to the public good, in accordance with the ACM Software Engineering Code of Ethics and Professional Practice [5].

(It should be noted that the author of this paper is employed by Google at time of writing.)

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1 Introduction

Mobile phones are becoming an increasingly important aspect of our lives. When cell phones were first introduced, they could only make calls. Now phones can check email, take pictures, give you directions, and even play videos. This complexity came incrementally, but the turning point was with the introduction of programs written by third-party developers.

User programs are certainly not a new concept. Desktop operating systems like Mac OS X and Windows have been running user programs since their inception. However, cell phones traditionally only ran software written by the phone manufacturer. There was no need for external programs. A phone was only designed to make calls; mobile development was a niche market. Every phone had a slightly different programming environment, and there wasn't an easy way for users to install new applications.

The new trend is toward complex operating systems used on a range of phone models. Apple's iOS platform is the more visible player in the market, but in 2011, Google's Android platform overtook both iOS and Blackberry with 29% of the market share [26]. While iOS is limited to a select number of devices created only by Apple, Android is installed on phones from a variety of manufacturers and carriers. Google manages an online marketplace for users to install applications written by third-party developers.

In order for a developer to write a program for an operating system, a developer must obtain a **software development kit** from the company that made the operating system. A software development kit includes tools for the programmer to create his or her

application and documentation to help the programmer learn how to make programs for that specific environment. There is usually a programming language that the software development kit encourages (or mandates) programmers to use. For example, iOS uses Objective-C and Android uses Java. These tools are essential. Without a software development kit, it is difficult for a third-party developer to create innovative software.

2 Facts

In late 2007, Google (along with a handful of other companies) announced the Open Handset Alliance [31] and Android, the operating system they wished to promote. The Android operating system is built entirely from **open source** projects. Anybody can legally obtain a copy of the original source code from the Android project. Most of the projects Android uses are released under the **Apache License 2.0**, with the exception of the Linux kernel (which is released under the **GNU General Public License**). Google provides a software development kit that allows developers to write applications for Android in the Java programming language. [8]

Java is a programming language created by James Gosling that was originally maintained by Sun Microsystems. In 2006, Sun announced Java's release under the open source GNU General Public License. [37] On August 20, 2009, the U.S. Justice Department approved Oracle's deal to acquire Sun Microsystems and its intellectual property, including Java. [42]

Many programming languages are converted from text directly into instructions

that the CPU understands. Java does not get converted directly to CPU instructions — in order to run Java code, one must use a **virtual machine**. [25, Chapter 1] A virtual machine is a program written for a particular CPU that runs **bytecode instructions** that the CPU doesn't natively understand. A virtual machine guarantees that the same program will run on any CPU without modification. Once a virtual machine has been written for a particular CPU architecture, the CPU can execute programs written for the virtual machine.

The Java compiler produces a documented, well-defined set of standard bytecodes, known as the **JavaVM specification**. [25, Chapter 4] There are many different implementations of the JavaVM specification: HotSpot (Sun/Oracle's de facto implementation) [36], Apache Harmony [10], and Red Hat's IcedTea [22], to name a few.

The developers of Android created a new virtual machine — Dalvik. Dalvik executes bytecodes in a format that is different from JavaVM in order to fulfill the performance requirements on mobile phones. [7] [19] The Android software development kit includes a program, dx, that converts Java bytecodes produced by Oracle's Java compiler into Dalvik bytecodes. [8] In order to provide compatibility with the Java libraries, Dalvik includes portions of the Apache Harmony library. [10] [6] Apache Harmony and Dalvik are released under the Apache License 2.0 [12], which Ryan Paul, a writer for the technology news website, Ars Technica, claims is “preferred by many companies because such licenses make it possible to use open source software code without having to turn proprietary enhancements back over to the open source software community” [39].

On August 12, 2010, Oracle filed a lawsuit against Google, claiming that Dalvik infringed upon their intellectual property. [35, Count VIII]

3 Research Question

Is Google's use of the Dalvik virtual machine in Android ethical?

If Google is unethical, then their partners in the Open Handset Alliance are also unethical. The Android platform is used on a wide variety of phones currently on the market distributed by various companies. This includes Motorola, LG, Samsung, and HTC, among many others; all these companies would be using unethically obtained software. This would be disastrous for many companies and would harm the public. This question also has implications beyond Android. If Google is unethical in using Dalvik, other creators of virtual machines could be just as unethical. This would include Red Hat and the Apache Software Foundation — two high-profile open source organizations.

4 Extant Arguments

4.1 Oracle's Claim

Oracle's claim is that “as a direct and proximate result of Google's direct and indirect willful copyright infringement, Oracle America has suffered, and will continue to suffer, monetary loss to its business, reputation, and goodwill.” [35, p. 9 line 11] Oracle also claims Google infringed on seven of their patents pertaining to the Java programming language.

The first claim being made is that Google is infringing on Oracle’s copyright. This is illegal under United States copyright law, and would therefore be unethical. The second claim is that by infringing, Google is harming the public by causing losses to Oracle’s employees and investors. Either of these actions could be unethical.

Oracle also presented source code files from Android as proof that Google was aware of the infringement. The lawsuit contains a side-by-side comparison of Oracle’s source code to Google’s source code. [34] If any portion of Oracle’s software is copied, it would be unauthorized duplication, which is illegal and unethical.

4.2 Groklaw’s Response

When the lawsuit was announced, Groklaw posted an analysis of the lawsuit. Groklaw is a website run by Pamela Jones, an open source advocate who previously worked as a paralegal. [24] Jones responded to Oracle’s lawsuit, saying: [23]

I expect Google would say Dalvik was an alternative to Java, not a version of it. If indeed none of the Sun employees that ended up at Google worked on this, and it’s built from the ground up without any Sun technology or [Intellectual Property], on what basis can Oracle prevail? Perhaps Oracle figures no room at Google is clean enough. And of course clean room means nothing when it comes to patents.

Jones’s argument is that if Google has not used any of Oracle’s software to build Dalvik, then there’s no violation of intellectual property, and thus no unethical behavior (other than possible patent violations).

4.3 The Copied Code Debate

4.3.1 Florian Mueller’s Discovery

In January 2011, Engadget (a popular technology news website), posted an article indicating that Google may be copying portions of Oracle’s code in the Android source code repository. [38] Florian Mueller, the author of the blog “FOSS Patents”, originally discovered the similarities in the files. [29] These observers claim that Google is unethical because Google directly copied source code from Oracle.

4.3.2 Ars Technica’s Defense

Ars Technica (another technology news website) published an article soon after Engadget’s article, claiming that SONiVOX, another member of the Open Handset Alliance, was responsible for adding the copied files, not Google. [40] The article made the case that because Google was not aware of the code’s presence and they swiftly removed the offending code, they were still acting ethically.

4.3.3 ZDNet’s Defense

Another argument (originally made by Ed Burnette and published on the technology news website ZDNet) is that the files are not shipped with Dalvik — they are only used as part of Dalvik’s unit tests. [16] Because these files are not part of Dalvik itself,

Google is not using illegally obtained code to create Dalvik.

4.4 Summary of Arguments

The main criticism of Dalvik is its use of Java. Because Java is Oracle's product, it infringes on their intellectual property and should not be used. Critics claim that Dalvik copies code from Oracle and is using it unlawfully and unethically. Therefore, Google is harming Oracle and its shareholders by engaging in unfair business practices, effectively using Oracle's products against Oracle.

Supporters of Dalvik claim that Dalvik is an alternative and fulfills the same purpose as Oracle's HotSpot virtual machine, but does not use any of the HotSpot's software. SONiVOX's code duplication was unethical, but Google was not aware of its use and removed it immediately upon discovery. The files used were only unit tests and not shipped as part of Android.

5 Analysis

5.1 Criteria for Analysis

Asking whether Google is ethical is not the same as asking whether Google infringed on Oracle's intellectual property, although it is relevant in answering the former. If Google did infringe, then they would be breaking the law, which is unethical. However, there might be other conditions that Google must meet in order for their use of Dalvik to be ethical.

To determine this criteria and ultimately whether Google is ethical, it is important to provide an objective set of stan-

dards that are well-accepted for the basis of this analysis. At first glance, using Google's Code of Conduct [21] seems like a reasonable choice, and many parts of Google's Code of Conduct are applicable to this issue. However, this analysis will use the ACM Software Engineering Code of Ethics and Professional Practice [5]. The Association for Computing Machinery (or ACM) is "the world's largest educational and scientific computing society" [4]. Their Code of Ethics is not affiliated with a single company, is well accepted, and includes more restrictions than Google's Code of Conduct does.

Google is primarily a software company consisting of software engineers. The ACM Software Engineering Code of Ethics and Professional Practice "prescribes [the Code] as obligations of anyone claiming to be or aspiring to be a software engineer." [5] By this measure, Google would be unethical in using Dalvik if it violates the ACM Software Engineering Code of Ethics and Professional Practice or if there is a higher principle that it conflicts with.

5.2 The Use of Java

The Android software development kit provides a environment for developing Android applications using the Java programming language. [8] In light of the lawsuit, using another company's programming language seems unethical because it violates section 2.02 of the Software Engineering Code of Ethics ("Not knowingly use software that is obtained or retained either illegally or unethically" [5, §2.02]). Furthermore, using Java seems like a particularly unethical move when Google could have easily avoided the

issue by picking another language for the Android software development kit. The licensing issues regarding Java are addressed later in section 5.3 “Licensing”, but first, why did Google pick Java?

Java refers to a few different concepts, so it is important to remember that there are two components that Java encompasses: the compiler and the virtual machine. Oracle created both a compiler and a virtual machine. The compiler takes the source code the programmer writes and converts it into bytecodes, which is then run by the virtual machine. [25, Chapter 1]

The Software Engineering Code of Ethics presents an obligation to “work to follow professional standards, when available, that are most appropriate for the task at hand, departing from these only when ethically or technically justified.” [5, §3.06] Java is a mature programming language and was ranked the most popular programming language in 2006 [2, Long term trends], the year before Android was released. Many introductory university computer science courses (including Cal Poly’s [17, Textbooks]) teach the Java programming language. The Java programming language is a standard because of how widely it is used. Using Java reduces the amount of work for a programmer — an Android programmer does not have to learn a new language. As long as there isn’t an ethical or technical conflict, using Java (the professional standard) would be the appropriate action according to the Software Engineering Code of Ethics.

5.2.1 The dx Program

In an ordinary Java project, a developer uses a compiler to convert his or her Java source

code files into JavaVM bytecodes. Those bytecodes can be run directly by a Java virtual machine. An Android application requires an extra step: running the dx program. dx, a part of the Android software development kit, is a program that converts Java bytecodes to Dalvik bytecodes (the Dalvik executable format, dex). Dalvik doesn’t use JavaVM bytecodes at all; the architecture is fundamentally different. [25] [7] [19]

Because Dalvik uses dex, Java bytecodes are an intermediary, not the final product. Programs could be written that convert other programming languages to the Dalvik executable format (and projects already exist to do this [30]). This means that Dalvik exists completely independently of Java. Dalvik is a generic virtual machine.

Dalvik, then, must be categorized differently than how Oracle is portraying it. Dalvik is not an implementation of Java, it is an alternative, just as Pamela Jones argued. [23] Oracle’s HotSpot and Google’s Dalvik solve the same problem, but they solve it in different ways. Copying someone else’s implementation is certainly intellectual property infringement, but making a different program that accomplishes the same task is ethical. For instance, no one is arguing that Google Docs is violating Oracle’s OpenOffice intellectual property, even though they share many of the same features. A product that solves a problem differently is a different product. Thus, Dalvik does not infringe upon Oracle’s patents. Dalvik can have a purpose that is similar to Oracle’s virtual machine and still be ethical.

5.2.2 Damages to Oracle

Oracle's lawsuit claims that Google is harming the public (specifically Oracle) by breaking intellectual property law to detract from Oracle's profits. [35, Count VIII] Oracle publishes a specification for a similar environment, Java Micro Edition. [33] However, there are no well-known phones that implement Java Micro Edition. Before Android's announcement in 2007, the usage of Java was declining, but 2008 showed a sharp increase in interest. [3] Android may not be directly related to this increase, but with an influx of developers, it would follow that developers will be looking for documentation and resources related to Java. These developers may continue to use Java for other software projects to minimize confusion. At the very least, there is no significant decrease in the use of Java. As of May 2011, Java is still the most widely used programming language. [3]

The Java compiler is already freely distributed under the GNU General Public License. [32] Oracle makes their money in services relating to Java, not Java itself. The lack of phones supporting Java Micro Edition suggests that Oracle is not too heavily invested in the technology. Nicholas Artman, a former employee at Apple and Yahoo, summarized that "Oracle is, in essence, suing Google for actively preventing Oracle from hemorrhaging money on phones." [14]

5.2.3 Summary

Java is now a well-established programming language in the software engineering industry. The Software Engineering Code of Ethics encourages the use of standards whenever possible, so using Java is the proper choice unless there is a conflicting

ethical or technical reason, according to Section 3.06 of the Software Engineering Code of Ethics. [5, §3.06] By separating Dalvik from Oracle's Java implementation, the Android software development kit can use the Java programming language without unethically using Oracle's software. Google's decision to include the Java programming language in the Android software development kit promotes Java. Oracle is not suffering any loss of business due to Google's use of Dalvik. The choice to use Java is ethical.

5.3 Licensing

Section 2.02 of the Software Engineering Code states that software engineers should "not knowingly use software that is obtained or retained either illegally or unethically." [5, §2.02] Oracle claims that Google is doing exactly that: using software that infringes on their intellectual property. To evaluate this claim, we need to examine the licensing terms for both Oracle's Java project and Google's Dalvik project.

Oracle releases their implementation of the Java compiler and virtual machine under the GNU General Public License [32], which means that it can be redistributed or modified as long as the source code is distributed as well. This is a common open source license, but it is referred to as a viral license, because any modifications to a project released under the GNU General Public License have to be made open as well. [20, §5] Companies want to be able to make proprietary modifications to their implementations, but the GNU General Public License does not allow this. One of the requirements of Android is to provide a common platform for a wide variety of phones [31];

the only way to ensure a common platform is to encourage widespread adoption. The Apache License 2.0, another common open source license, allows modification or redistribution of software (even without releasing the source code), as long as the original copyright notice remains intact. [12, §4] Companies prefer the Apache License 2.0 because they want to be able to make proprietary modifications. [39] Thus, to promote adoption, Google needed to release Android (and Dalvik) under the Apache License 2.0 (or another similar license). However, code released under the GNU General Public License cannot legally be released under the Apache License 2.0. [13]

Google does not include any of Oracle’s Java development tools in the Android software development kit [9]; an Android developer must obtain the Java Development Kit directly from Oracle. This means that Google is not redistributing or modifying the Java compiler.

A major part of a Java virtual machine is the runtime **library**, which provides code that is common to many software projects. Oracle does include an extensive standard library in their Java Development Kit, but the Android software development kit specifically disables its use when it compiles an application. Instead, Google uses the Apache Harmony library, an implementation of a subset of Oracle’s standard library, which is released under the Apache License 2.0. [10] [6] In order for this to be ethical, the Software Engineering Code of Ethics dictates that software engineers ought to “credit fully the work of others and refrain from taking undue credit.” [5, §7.03] Google distributes Dalvik under the same Apache License 2.0 and credits Harmony in

the Dalvik README. [6] The principle of giving credit is upheld.

5.3.1 The Unit Test Fiasco

The Oracle lawsuit includes examples of code in Dalvik that matches code inside of the HotSpot virtual machine. [34] As noted in section 4.3.1, “Florian Mueller’s Discovery”, Florian Mueller made the claim that additional files in the Dalvik repository were copied directly from Oracle’s HotSpot virtual machine, beyond the files that Oracle mentioned. [29] If Google knowingly copied code illegally, then Dalvik is unethical.

The duplicated files are not a part of Dalvik, but are in a separate support directory. Dalvik does not use them directly. The developers working on Android used the files to perform unit tests. When Dalvik is built and deployed on a phone, it does not include these files. [16] Therefore, Dalvik itself does not contain any software that is illegally obtained. Google did not know that the code had been copied illegally, and once they discovered it, they deleted the offending files from the repository. Although they used software that was retained illegally, they did not do so knowingly. Therefore, they still acted in accordance with Section 2.02 of the Software Engineering Code of Ethics.

5.3.2 Summary

Google does not redistribute or modify any part of Oracle’s Java Development Kit. Instead, they inform developers to obtain the Java Development Kit from Oracle under the terms of the GNU General Public License. Oracle’s Java implementation is only used in the Android software development kit, but

not in the Android operating system, which is released under the Apache License 2.0.

Google used the Apache Harmony library for Dalvik instead of using Oracle's library. Google created Dalvik and then used Apache Harmony to supplement its functionality, obeying all the terms of the Apache License 2.0. The Apache Software Foundation's copyright notice remained intact, thus giving proper credit to the Apache Software Foundation. All software was either created at Google or obtained legally. Therefore, Google adhered to Section 2.02 of the Software Engineering Code of Ethics.

5.4 Duty to the Public

As part of a software engineer's duty to the public, a software engineer should "approve software only if they have a well-founded belief that it is safe, meets specifications, passes appropriate tests, and does not diminish quality of life, diminish privacy or harm the environment." [5, §1.03] The possibility of its damage is limited because Android operates on consumer-level mobile devices. No claim has been made that Android is not well-tested; Android is derived from the Linux kernel, a well-tested operating system. Therefore, the only relevant concerns here are the conformance to specifications, the effect on quality of life, and the effect on privacy. Dalvik must meet all of these conditions in order to be ethical.

5.4.1 Requirements

The specification of a software product includes the requirements (goals and restrictions) and the details of how to meet those requirements (design documents and user

documentation). If Dalvik does not meet its requirements, then it does not follow its specification, and therefore it is unethical.

When the Open Handset Alliance announced Android, they cited three major design goals for Android. The main requirements are: [31]

- User Experience
- Openness
- Portability

Promoting a good user experience by definition is improving quality of life for the user, so that is an ethical goal. An open operating system is (arguably) neutral from the user's point of view, but it allows companies to share code: Motorola can make bug fixes that assist Samsung, and vice versa, which contributes to the user experience (i.e. less unexpected behavior). Portability means that the same software, which is well-tested and mature, can be used on many phones and still be useful. Software that is portable can improve the quality of life for a greater number of users on a greater number of devices. These requirements are ethical, but are these requirements met?

5.4.2 Why a Virtual Machine?

In considering these requirements, none of these seems to mandate the use of a virtual machine. Indeed, software written for Apple's competing iOS compiles directly to machine code, runs on devices with different ARM processors, and provides a good user experience. The open licensing requirement could be fulfilled with any newly written program. Why was Dalvik chosen as the solution for the requirements?

One of Android’s goals is to provide portability: an application should be able to run on a variety of devices. Each phone may have slightly different hardware; a program which runs well on one phone may run poorly on another phone. The Dalvik virtual machine provides a predictable, consistent execution environment between phones without placing burden on application developers.

Dalvik also has some side benefits that are useful for mobile development. Because a virtual machine has more control over the execution environment, Dalvik can more aggressively collect unused memory. [19] The virtual machine can also track all requests for resources, so Dalvik can enforce that a program only has access to the resources it has permission for (this is discussed in more detail in section 5.4.4, “Privacy and Security”). Dalvik uses these features to make Android secure and memory efficient — important qualities for maintaining user privacy and user experience.

5.4.3 Quality of Life

Section 1.03 of the Software Engineering Code of Ethics states that software should not “diminish the quality of life” [5, §1.03]. This idea of not diminishing quality of life relates to the ethical theory of utilitarianism: that which maximizes utility (or benefit) over a group of people is what is good. [28, pg. 16] It provides a (more or less) objective basis for ethics, and it is a higher principle that also applies outside of software engineering. To be consistent with utilitarianism, Android must provide a net positive (or neutral) effect on the total utility. Taking away utility would be diminishing quality of

life.

The first goal of the Android platform is to provide a good user experience. This promotes utility by making the phone easy to use. Because Android is portable and runs on many phones, users don’t have to learn a new interface every time they get a new phone. Although the primary user is the general public, a large part of Android’s audience are application developers. An application can be written once and deployed on many different phones with radically different hardware specifications, thus reducing development time. When the first Android tablets were introduced, most applications ran correctly on the first day because the virtual machine could handle the better processor and would abstract the hardware. [15] The end-users benefits from this abstraction as well. Applications behave nicely on their phone: resources are managed, programs are secure, and applications are guaranteed to run.

5.4.4 Privacy and Security

The Software Engineering Code of Ethics dictates that software should not adversely affect users’ privacy. [5, §1.03] Dalvik does not directly work with private data, but it runs other programs that do. In this case, Dalvik should promote good practices that aide privacy. This is Dalvik’s security layer.

Mobile phones store personal information such as contacts and browsing history. With a proprietary phone operating system, it is difficult for security experts and privacy enthusiasts to see how their data is being used. Providing an open source platform for mobile phones encourages user privacy by allowing external audits to ensure that the op-

erating system is not transmitting information without consent.

Whenever a user installs a new application from the Android Market, he or she is clearly presented with the list of permissions that the application is requesting. [1, Security Architecture] This is part of Dalvik's runtime environment: applications must declare what resources they want to use when they are created. If Dalvik detects that an application is trying to access a resource it is not authorized to use, Dalvik terminates the application. [1, Using Permissions] Dalvik enforces the user's ability to opt out.

This would be difficult (although not impossible) to do without a virtual machine. Natively compiled code uses the CPU directly, so there would be more burden on the underlying operating system to implement the security features, which are better defined at an application level, instead of an operating system level. The Android Developer Documentation gives the example of a picture attached to an email. [1, URI Permissions] A picture viewing program can't ordinarily access data from the email client, but if the user wants to open an attachment, the email client can temporarily grant access to the corresponding image, and nothing more. By controlling the code executing in user space, Dalvik can enforce much more fine-grained control over security, thus protecting its user's privacy.

5.4.5 Summary

Section 1.03 of the Software Engineering Code of Ethics mandates that software should fulfill its specification, provide utility, and protect privacy. The relevant portion of Android's specification is its require-

ments. Android's requirements are designed to help the public and using Dalvik promotes all of the Android's requirements. Dalvik provides utility by keeping Android phones predictable and portable, even when their hardware is completely different. Dalvik increases security, which keeps users in control of what data each program is allowed to access. Dalvik fulfills Section 1.03 of the Software Engineering Code of Ethics.

6 Conclusion

In order to best meet project requirements, Google needed to use the Java programming language and a virtual machine in Android. Google fulfilled their duty to the public and the Software Engineering Code of Ethics by creating a new virtual machine, Dalvik. Because Dalvik uses a different architecture and doesn't use code from Oracle's Java implementation, it does not infringe upon Oracle's intellectual property and remains ethical. Dalvik meets the requirements of the Android project by promoting user experience, portability, security, and privacy. These requirements could not be met by existing software, so creating Dalvik was the logical choice. Google's use of Dalvik is ethical.

Glossary

Apache License 2.0 An open source license that allows modification and reuse of the source code, even if the user don't redistribute the modified source code [12] . 1, 2, 7, 8

bytecode An instruction understood by a

virtual machine. 2, 5

GNU General Public License An open source license that allows modification and reuse of the source code, as long as users distribute the source code of their modifications [20] . 1, 6, 7

JavaVM The set of bytecodes that is documented by “The Java Virtual Machine Specification” [25] . 2, 5

library A collection of code that is useful in many different programs (e.g. text handling, graphics, etc.) . 7, 8

open source If a software project released as open source, it means that the software’s source code can be obtained and reused legally. There are many licenses that are considered open source, each with different terms . 1–3, 6, 7, 9

software development kit A set of programs and other materials that allows programmers to write programs for a particular environment . 1, 2, 4–7

virtual machine A program that runs instructions that are not natively understood by a CPU . 2, 4–10

References

- [1] “Security and Permissions,” May 2011. [Online]. Available: <http://developer.android.com/guide/topics/security/security.html>

The developer documentation has a detailed discussion of Android’s security system.

- [2] “TIOBE Programming Community Index for May 2011,” May 2011. [Online]. Available: <http://www.tiobe.com/index.php/content/paperinfo/tpci/index.html>

The data shown is a summary of programming popularity by year, maintained by TIOBE.

- [3] “TPCI History for language Java,” May 2011. [Online]. Available: <http://www.tiobe.com/index.php/paperinfo/tpci/Java.html>

The graph shows the usage of Java by year.

- [4] “Welcome — Association for Computing Machinery,” ACM. [Online]. Available: <http://www.acm.org/>

ACM’s website discusses what ACM is and why they are an important organization in software engineering.

- [5] “Software Engineering Code of Ethics and Professional Practice,” <http://www.acm.org/about/se-code>, ACM, April 2011.

The SE Code is a pivotal document in this paper for establishing a baseline of ethics.

- [6] “Dalvik README,” Android Open Source Project. [Online]. Available: <http://android.git.kernel.org/?p=platform/dalvik.git;a=blob;f=README.txt;h=2969180f3dd02b4ae69279d6f1f741812710183f;hb=HEAD>

The README contains all of the credits and licensing information for the Dalvik project

- [7] “Bytecode for the Dalvik VM,” Android Open Source Project, 2007. [Online]. Available: <http://source.android.com/tech/dalvik/dalvik-bytecode.html>

This site provides information about how Dalvik works.

- [8] “Building and Running,” Android Open Source Project, April 2011. [Online]. Available: <http://developer.android.com/guide/developing/building/index.html>

This page from the Android SDK documentation describes in-depth the Android build process. It's from here that I learned about the dx program.

- [9] "Installing the SDK," Android Open Source Project, May 2011. [Online]. Available: <http://developer.android.com/sdk/installing.html>

This page from the Android SDK documentation informs developers that they must install the Java Development Kit separately.

- [10] "Apache Harmony," Apache Software Foundation. [Online]. Available: <http://harmony.apache.org/>

The Apache Foundation's implementation of the Java VM specification.

- [11] "Apache Harmony — Frequently Asked Questions," Apache Software Foundation. [Online]. Available: <http://harmony.apache.org/faq.html>

Has information about Apache Harmony

- [12] "Apache License, Version 2.0," Apache Software Foundation. [Online]. Available: <http://www.apache.org/licenses/LICENSE-2.0.html>

The Apache License 2.0 that Dalvik and Apache Harmony are released under.

- [13] "Apache License v2.0 and GPL Compatibility," Apache Software Foundation, 2011. [Online]. Available: <http://www.apache.org/licenses/GPL-compatibility.html>

The Apache Software Foundation publishes information about how the Apache License 2.0 interacts with the GNU General Public License, specifically, how you cannot put code under the GNU General Public License under the Apache License 2.0.

- [14] N. Artman, "Discussion with Nicholas Artman," May 2011.

I discussed the Oracle lawsuit with Nicholas Artman after a presentation on the subject.

- [15] T. Bray, "Screen Geometry Fun," September 2010. [Online]. Available: <http://android-developers.blogspot.com/2010/09/screen-geometry-fun.html>

In this Android developer blog post, they detail results from running applications on the Samsung Galaxy Tab.

- [16] E. Burnette, "Oops: No copied Java code or weapons of mass destruction found in Android," January 2011. [Online]. Available: <http://www.zdnet.com/blog/burnette/oops-no-copied-java-code-or-weapons-of-mass-destruction-found-in-android/2162>

ZDNet discovered that the copied files were in Android's unit test directory, not in the shipping code for Dalvik.

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The original blog post Engadget used in their news article [38].

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This is the initial press release for Android, stating the goals and requirements of the platform. I used this as the basis for inferring the project's requirements.

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The website for Oracle’s Java Micro Edition, Oracle’s competing standard for mobile devices.

- [34] “Exhibit J,” Oracle America Inc., October 2010. [Online]. Available: <http://docs.justia.com/cases/federal/district-courts/california/candce/3:2010cv03561/231846/36/10.html>

Oracle presented Exhibit J during the lawsuit to show that Google copied code in Dalvik.

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Groklaw posted a mirrored copy of the original Oracle lawsuit. It’s surprisingly readable, and cites a fair number of patents in the case.

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Ars Technica responded to Engadget’s story, saying that SONiVOX accidentally committed the offending files.

- [41] D. K. Taft, “Java Creator Gosling: Oracle’s Android Lawsuit Is No Surprise.” [Online]. Available: <http://www.eweek.com/c/a/Application-Development/Java-Creator-Gosling-Oracles-Android-Lawsuit-is-No-Surprise-272156/>

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