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From the Ground Up: Assessing the Potential of Open Source Hardware

Over the past couple weeks, two of the most significant vulnerabilities in computing history, Meltdown and Spectre, have roiled the chip-making industry. Unlike previous bugs, which generally encompassed only a particular operating system or other software, these bugs are hardware-based, flaws in the fundamental design of the vast majority of computer chips on the market.[1] This means that nearly every digital device with a processor is vulnerable. How did two long-undiscovered exploits manage to cause so much damage? And what lessons can we take away from this crisis? To begin to answer these questions, one must investigate an ideological battle often perceived as solely pertinent to software, but with increasing potential in the field of hardware: the open source debate. Current projects indicate that applying open source principles to hardware, although difficult, could pave the way for more security, customization, and productive competition.

Open source development centers on facilitating complete freedom of availability and ideas; in the case of software, this means enabling free viewing, use, modification, and distribution of the source code of a program.[2] Proponents advocate for this mode of development for both pragmatic and ideological reasons, namely that it reduces the entry barrier for competing software, promoting innovation and exchange of ideas.

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[1] Paul Kocher, "Spectre Attacks: Exploiting Speculative Execution," *Cornell University Library*, accessed January 16, 2018, https://arxiv.org/pdf/1801.01203.pdf.
[2] Ran Levi, "The History of Open Source and Free Software," *Curious Minds*, podcast audio, June 3, 2016, accessed January 16, 2018, https://www.cmpod.net/history_of_open_source_pt1/.

These same ideas have begun to seep into the hardware development market, and in particular the design of computer chips. Currently, three chip makers, Intel, AMD, and ARM dominate the industry; Intel possesses more than 90% of the market share for computer processors and nearly all of the market share for server chips.[3] Competitors are essentially nonexistent, because the process of developing a chip to a scale where it is even feasible to sell takes roughly five years.[4] This has led to a distinct lack of diversity in the market. After all, with these giants possessing such an enormous leg up, and in a market so difficult for small companies to succeed in, there is little incentive for any company to even attempt to make inroads. This may sound fine—these companies devote massive resources toward the singular mission of developing high-quality chips—but Meltdown and Spectre highlighted the extreme risks of such a dominant monopoly.

There are other disadvantages to monopolies, as well. In a chipmaking industry worth a hefty five billion dollars, such a lack of competition has given major companies significant latitude in distributing their designs. They charge not only licensing fees but also exorbitant royalties—up to twenty dollars a chip.[5] Generally, device manufacturers have no choice but to accept those high prices and pass the costs on to the consumer.

Hypothetically, then, the democratization of chips sounds like a fantastic idea: cheaper architecture, fewer bugs, higher quality assurance. And although initial strides toward this goal

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[3] Dina Bass, "Intel's Response to Chip Meltdown Deepens Rift with Microsoft," Bloomberg Technology, last modified January 12, 2018, accessed January 16, 2018, https://www.bloomberg.com/news/articles/2018-01-12/intel-s-response-to-chip-meltdown-deepens-rift-with-microsoft.

[4] John Russell, "For IBM/OpenPOWER: Success in 2017 = (Volume) Sales," HPC Wire, last modified January 11, 2018, accessed January 18, 2018, https://www.hpcwire.com/2017/01/11/ibm-openpower-success-sales/.

[5] Aaron Pressman, "Why Qualcomm's Super Profitable Royalty Business Is Suddenly under Siege," Fortune, last modified January 23, 2017, accessed January 16, 2018, http://fortune.com/2017/01/23/qualcomm-royalty-apple-under-siege/.

sputtered, recent developments show promise. One of the first movements was initiated by Sun Microsystems, when they decided to open-source a chip design called the OpenSPARC T2 under the GNU General Public License in March 2006.[6] Though the chip was functional—it could run operating systems such as Linux successfully—it gained little traction. The widespread consensus was that it served more as a handout than a solid foundation upon which other designers could build. More recently, IBM has proposed a middle ground with its conference, OpenPOWER.[7] The conference brings together designers from across the computer hardware landscape, from chips to storage solutions to networking, to create products and bring them to market. These designs are still licensed, but the summit does upend the traditional model of hardware construction by fostering cooperation between its 149 member groups, which include Google and Nvidia. The chips are on the market and have proven fairly competitive with an Intel chip[8].

Other smaller groups have also successfully completely open-sourced their architectures. The most well-known example may be RISC-V, which originated as an academic project from UC Berkeley and is sponsored by Google, Microsoft, HP and IBM.[9] The chip possesses a modular design, making it highly flexible, and has rapidly gained interest, with the startup SiFive announcing their intentions to use this design to manufacture their chips. Other significant open source computer-related hardware includes the J2 open processor, an open source router called

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[6] Oracle, "About OpenSPARC," Oracle, accessed January 16, 2018, http://www.oracle.com/technetwork/systems/opensparc/opensparc-overview-1562924.html.
[7] Russell, "For IBM/OpenPOWER," HPC Wire.
[8] Rob Enderle, "OpenPOWER Foundation Vs. Intel: The Interesting Contrast of Business Models," ITBusinessEdge, last modified September 30, 2015, accessed January 16, 2018, https://www.itbusinessedge.com/blogs/unfiltered-opinion/openpower-foundation-vs.-intel-the-interesting-contrast-of-business-models.html.
[9] Aaron Tilley, "This New Chip Startup Wants to Bring Open Source to a Stagnant Industry," Forbes, last modified July 11, 2016, accessed January 16, 2018, https://www.forbes.com/sites/aarontilley/2016/07/11/risc-v-sifive-chips/#48a3f62629ec.

Turris, and a fully open source computer design.[10] In essence, designs for nearly every part of a computer have been open sourced, raising the enticing prospect of a computer built entirely from scratch. Even Facebook joined the fray in 2009, announcing a conference called Open Compute Project with the intention of designing an efficient and flexible data center. By 2011, the design was complete and had been shared with the general public.[11] Meanwhile, on the non-computer end, numerous journals such as Engineering for Change offer open source designs for many other, generally simpler products, including medical and mechanical devices.[12]

Of course, there are drawbacks to this approach to hardware design. All open source debates reckon with economic feasibility, and hardware is no exception: not only is designing chips expensive, with smaller companies beginning at a severe disadvantage, but the cost of machinery needed to manufacture the chips makes small-scale production nearly impossible. Open source hardware offers some economic improvements to the average consumer or company, but groups looking to develop their own designs will still face a daunting, and perhaps prohibitively costly, path. Let's start with the cost barrier: developing a highly-advanced system on a chip, or SOC, may cost companies over a billion dollars.[13] Even lower-level chips, such as those used to farm bitcoins, still cost upwards of a million dollars to design.[14] When one takes

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[10] "J2 Open Processor," J-Core, accessed January 16, 2018; http://j-core.org/,CZ.NIC, "Hardware," Project Turris, accessed January 16, 2018, https://project.turris.cz/en/hardware; David Scheltema, "With Linux and Creative Commons, the $9 CHIP Computer Reveals Its Open Source Details," Make, last modified July 22, 2015, accessed January 16, 2018, https://makezine.com/2015/07/22/with-linux-and-creative-commons-the-9-chip-computer-reveals-its-open-source-details/.

[11] Facebook, "About OCP," The Open Compute Project, accessed January 16, 2018, http://www.opencompute.org/about/.

[12] "Buckle up for Fast-Tracked Science Thanks to Open-Source Hardware," Engineering for Change, last modified June 8, 2015, accessed January 16, 2018, https://www.engineeringforchange.org/buckle-up-for-fast-tracked-science-thanks-to-open-source-hardware/.

[13] Andreas Olofsson, "An Introduction to Semiconductor Economics," Adapteva, last modified October 3, 2014, accessed January 16, 2018, http://www.adapteva.com/andreas-blog/semiconductor-economics-101/.

[14] Olofsson, "An Introduction," Adapteva.

into account how a company might hope to recoup such costs in such a suffocating market, it's no wonder few have decided to open source. To even begin to imagine open sourcing such expensive and advanced work may seem ludicrous; however, the broader the range of contributors to a project, the lower the entry barrier for every designer becomes. And as open source chip designs become more sophisticated, contributors can begin to even the playing field against highly-guarded monopolies.

These obstacles aside, the companies who manufacture chips and the consumers who purchase devices using them—that includes just about everyone—stand to derive massive financial benefits from a broader open source movement. Currently, a high-end processor can cost the average consumer as much as $5,000.[15] To be fair, much of these costs are inevitable: every single machine involved in the tooling of these chips costs millions of dollars, to the point where a single manufacturing plant could have a net cost in the billions. This is where the benefits of open hardware mirror the benefits of open source software: the more input a company integrates into their design process, the more potential for cost-effective and innovative solutions, as in the case of Facebook's data centers. In another example of improved cost efficiency, SiFive, the aforementioned open source chip startup, has made it part of their mission to integrate "customer-specific hardware with industry-standard physical interfaces."[16] In doing so, they are creating a standard of flexibility for silicon production that, with luck, will become more widespread. All of these improvements enable manufacturers to produce more advanced, cost-effective, and specialized chips, passing the savings onto the average consumer.

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[15] Jim Handy, "Why Are Computer Chips so Expensive?," Forbes, last modified April 30, 2014, accessed January 16, 2018, https://www.forbes.com/sites/jimhandy/2014/04/30/why-are-chips-so-expensive/#4fd47f1e79c9.

[16] Brian Bailey, "Will Open-Source Work for Chips?," Semiconductor Engineering, last modified June 30, 2016, accessed January 16, 2018, https://semiengineering.com/will-open-source-work-for-chips/.

Another benefit of open source computing is the potential for flexibility and specialization. Currently, developers have little opportunity or incentive to design chips for a specialized purpose. Demand for such products is low, while manufacturing processes are profitable only for massive-scale production.[17] Meanwhile, independent architects have no model to build off of should they seek to manufacture their own devices; as a result, they would have to start from scratch, a nearly impossible prospect. So while opening up chip designs to a broader audience will certainly not completely mitigate high costs, it invites a broader knowledge base so that all parties involved, even the most niche ones, can move closer to autonomous designs.

There exist still more benefits to open sourcing. The current flaws in chips went unnoticed even as they saturated the market. The unchecked nature of these bugs reveals that even the most dominant company may overlook flaws in their designs. However, just as open source software enables anyone to inspect and rigorously test the code for bugs, publicly providing chip designs subjects them to a much broader array of tests; in these cases, the likelihood of such a flaw slipping through is much lower. Meanwhile, more voices in the design process can offer additional insights, bringing in their own opinions and manufacturing knowledge. The cumulative effect of these benefits is that such chips could very well end up more thoughtfully-designed and bug-free than traditional designs.

Given open source's potential, and popularity in other realms, why has the prospect of open source hardware only now become feasible? For one, the increasing presence of powerful computer models and simulations uniquely facilitates these communal designs. These simulations can provide a level of rigor in chip testing that used to only be available through in-

[17] Ed Sperling, "How Much Will That Chip Cost?," Semiconductor Engineering, last modified March 27, 2014, accessed January 16, 2018, http://semiengineering.com/how-much-will-that-chip-cost/.

person, manufactured prototypes.[18] Essentially, what this means is that anyone could design and remotely execute tests of an open source chip design.

Another technology has also opened the door for hardware design, albeit on a smaller scale: 3D printers. Numerous journals, including The Journal of Open Engineering, Elsevier, and Engineering for Change, provide open access to published prototypes for a variety of devices. The ultra-specific products detailed in these journals have immense potential in an environment in which 3D printers are widely available. For instance, one popular article details a design for a printed laboratory shaker and mixer, which costs roughly $20, a 90% savings from proprietary designs and much more customizable.[19] These sorts of designs reveal that the open source movement is not confined to just computers.

The ideological ramifications of all of these developments are immense. The most ideological proponent of open source, the Free Software Foundation, defines “true freedom” as using only fully-accessible software, such as Linux. With the advent of free hardware designs, one can, at least partially, extend this principle to the actual machinery. That should be a goal for any proponent of accessibility to technology: the more easily every person can gain these tools, the greater potential for innovation down the line. The many other benefits of open source will only compound this effect.

[18] Larry Hardesty, "Simulating Tomorrow's Chips," MIT News, last modified April 13, 2012, accessed January 16, 2018, http://news.mit.edu/2012/hardware-testing-multicore-0413.
[19] K. C. Dhankani, "Open Source Laboratory Sample Rotator Mixer and Shaker," *HardwareX* 1, no. 1 (April 2017): doi:10.1016/j.ohx.2016.07.001.