Undergraduate Thesis Prospectus

Verifying the Soundness of Compiler Optimizations

(technical research project in Computer Science)

Nonmedical Vaccination Exemptions: A Balance of Rights

(sociotechnical research project)

by

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.
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General research problem

How can local measures improve the safety and security of a larger system?

Though comprehensive management of sociotechnical systems may be infeasible, multiple local components of such systems may be improved to the benefit of the whole system.

In 2019, measles cases reached their highest levels since the disease was eliminated in the U.S. in 2000 (CDC, 2019). To control infectious diseases, health agencies must vaccinate every community in the nation. In the U.S., states issue and enforce most public health mandates. In authorizing exemptions, states must balance individuals' rights and health requirements against public health necessities.

Managing computer security is a similar optimization problem. According to the Council of Economic Advisors, in 2016 malicious cyber activity cost the U.S. economy $57-109 billion (CEA, 2018). In a secure computer system, both the components and the connections between them are secure. Securing entire computer systems is often infeasible, but administrators can protect systems by ensuring the security of their foundational software, even without directly securing other components.

Verifying the soundness of compiler optimizations

How can the correctness of optimizations performed by a compiler be verified in an automatic and flexible way?

The technical research will take place in the Computer Science department, with Prof. serving as the technical advisor. The research will serve as a capstone project, and will have no other collaborators.

Modern software is produced by compilers – programs which transform code into a format which can be executed. As part of the compilation process, compilers generally apply a series of optimizing transformations to the code to create a more efficient final program. These optimizations are critical to creating performant software, but if they are not sound, they may introduce logical errors, reliability issues, and security vulnerabilities (Ashraf et al., n.d; Hohnka et al., 2019). In recent years it has become increasingly clear that security issues in software can have devastating, wide reaching effects on society. Ensuring the correctness of code that produces most of the software today is therefore a local measure that can help to secure the foundation of large numbers of software and their surrounding systems.

The goal of the project is to design a piece of software to aid verification of optimizations by proving that a particular transformation retains the semantics of the original code. The project is constrained by theory in that no algorithm can verify correctness of all code, so any result will be imperfect. The complexity of the problem is also large, so the scope of the project must be fairly limited in order to be practical. This likely means focusing on one specific compiler and its optimizations instead of attempting to create a general solution.

The most pertinent work lies in research by Lopes et al. (2015), which focuses on verifying optimizations in the LLVM compiler architecture. The project has been largely successful and represents the most novel solution in this problem space. In an earlier work, Lerner et al. (2003) used a similar approach but focused on a compiler of their own making, and their solution required more manual intervention to work. This existing work still leaves room to focus on other, unexplored compilers, as well as improve the usability of the resulting tools.

The methodology for this project will likely be adapted from the existing work in this area, such as the research described earlier. The project will involve using a technique called

symbolic execution, as described by Khurshid et al., which reasons about code's behavior given arbitrary inputs (Khurshid et al., 2003). It will also require using an automated theorem prover, such as the tool produced by de Moura et al. (2008), to test whether certain logical constructs hold. The research will take the form of creating a prototype program to test for effectiveness.

By the end of the research, I hope to have a prototype that can verify certain compiler optimizations are correct. This will provide more tooling to help secure the foundation of software used throughout society.

Nonmedical vaccination exemptions: a balance of rights

How do advocates and critics of nonmedical vaccination exemptions advance their agendas?

In the U.S., all states authorize some medical exemptions to vaccination mandates; 45 states authorize religious exemptions, and 15 authorize philosophical exemptions (NCSL, n.d.). Recently some states, responding to rising disease incidence, have restricted or eliminated nonmedical exemptions. These initiatives have been controversial (Pew, 2019). How do the critics and the defenders of nonmedical exemptions advance their respective agendas?

Researchers have investigated the movements for and against nonmedical vaccine exemptions and their impacts. Lillvis et al. (2014) found that groups that support philosophical exemptions often frame them to legislators in moral or ethical terms. Olive et al. (2018) found that in states that allow nonmedical exemptions, exemptions tend to proliferate. Many demand exemptions on grounds of vaccine safety rather than on religious or philosophical grounds. According to Pierik (2017), nonmedical exemptions for measles vaccinations can compromise herd immunity. Finding that personal belief exemptions cluster in areas of high socioeconomic

homogeneity, Estep and Greenberg (2020) concluded that vaccine-hesitant parents often are attracted to others with similar views.

The American Medical Association opposes nonmedical vaccination exemptions on public safety grounds, arguing that "when individuals are not immunized as a matter of personal preference … they put themselves and others at risk" (AMA, 2019). Pharmaceutical companies have a material interest in mandates requiring the vaccines they manufacture. Merck & Co., Inc has engaged in lobbying to promote mandates requiring its HPV vaccine, though Merck itself characterizes such efforts as public health promotion (Reuters, 2007). Advocates for nonmedical exemptions include parent-run, grassroots advocacies such as the National Vaccine Information Center (NVIC, n.d.), which argues that it is a "human right to exercise voluntary informed consent to vaccination" and that this right warrants personal belief exemptions. Some groups defend exemptions on religious grounds. Agudath Israel of America (2019), which represents Haredi Orthodox Jews, argues that "governmental aversion toward impinging on the free exercise of religion" is a "constitutional principle"; restrictions of religious exemptions are an "erosion" of this principle that set "a dangerous precedent."

References

Agudath Israel of America (2019, June 14). NYS Eliminates Religious Exemption for Vaccinations: Agudath Israel Statement. Agudath Israel of America. https://agudah.org/nys-eliminates-religious-exemption-for-vaccinations-agudath-israel-statement/

AMA (2019, June 13). American Medical Association. AMA policy advocates to eliminate non-medical vaccine exemptions. American Medical Association. https://www.ama-assn.org/press-center/press-releases/ama-policy-advocates-eliminate-non-medical-vaccine-exemptions

Ashraf, R. A., Gioiosa, R., Kestor, G., & DeMara, R. F. (2017). Exploring the Effect of Compiler Optimizations on the Reliability of HPC Applications. *2017 IEEE International Parallel and Distributed Processing Symposium Workshops*.

CDC (2019, April 26). U.S. Centers for Disease Control and Prevention. CDC Media Statement: Measles cases in the U.S. are highest since measles was eliminated in 2000. https://www.cdc.gov/media/releases/2019/s0424-highest-measles-cases-since-elimination.html

CEA. (2018, February 16). Council of Economic Advisors. CEA Report: The Cost of Malicious Cyber Activity to the U.S. Economy. The White House. https://www.whitehouse.gov/articles/cea-report-cost-malicious-cyber-activity-u-s-economy/

de Moura, L., & Bjørner, N. (2008). Z3: An Efficient SMT Solver. *Tools and Algorithms for the Construction and Analysis of Systems*, 337–340.

Estep, K., & Greenberg, P. (2020). Opting Out: Individualism and Vaccine Refusal in Pockets of Socioeconomic Homogeneity. *American Sociological Review*, 000312242096069.

Hohnka, M. J., Miller, J. A., Dacumos, K. M., Fritton, T. J., Erdley, J. D., & Long, L. N. (2019). Evaluation of Compiler-Induced Vulnerabilities. *Journal of Aerospace Information Systems*, *16*(10), 409–426.

Khurshid, S., Pasareanu, C. S., & Visser, W. (2003). Generalized Symbolic Execution for Model Checking and Testing. *Tools and Algorithms for the Construction and Analysis of Systems*, 553–568.

Lerner, S., Millstein, T., & Chambers, C. (2003). Automatically proving the correctness of compiler optimizations. *Proceedings of the ACM SIGPLAN 2003 Conference on Programming Language Design and Implementation - PLDI '03*.

Lillvis, D. F., Kirkland, A., & Frick, A. (2014). Power and Persuasion in the Vaccine Debates: An Analysis of Political Efforts and Outcomes in the United States, 1998-2012. *Milbank Quarterly*, *3*, 475–508.

Lopes, N. P., Menendez, D., Nagarakatte, S., & Regehr, J. (2015). Provably correct peephole optimizations with alive. *ACM SIGPLAN Notices*, *50*(6), 22–32.

NCSL (2020). National Conference of State Legislatures. (2020, June 26). States With Religious and Philosophical Exemptions From School Immunization Requirements. https://www.ncsl.org/research/health/school-immunization-exemption-state-laws.aspx

NVIC (n.d.). National Vaccine Information Center. Protecting & expanding state exemptions FAQs - NVIC. https://www.nvic.org/faqs/protecting-expanding-state-vaccine-exemptions.aspx

Olive, J. K., Hotez, P. J., Damania, A., & Nolan, M. S. (2018). The state of the antivaccine movement in the United States: A focused examination of nonmedical exemptions in states and counties. *PLOS Medicine*, *6*, e1002578.

Pew (2019, June 28). Pew Research Center. Most states allow religious exemptions for vaccinations. https://www.pewresearch.org/fact-tank/2019/06/28/nearly-all-states-allow-religious-exemptions-for-vaccinations/

Pierik, R. (2017). On religious and secular exemptions: A case study of childhood vaccination waivers. *Ethnicities*, *2*, 220–241.

Reuters (2007, Feb. 20). Reuters Staff. Merck ending lobbying for mandatory Gardasil vaccine. https://www.reuters.com/article/us-merck-gardasil/merck-ending-lobbying-for-mandatory-gardasil-vaccine-idUSN2022501520070221