The Proof Must Go On

Formal Methods in the Theater of Secure Software Development of the Future

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Trust in Software
(the concept, not an imperative)

What is trust?

- Confidence software behaves as intended
- Reliability, security, correctness
- Trust varies by user and context
- Often invisible until broken

Who needs to trust software?

- Users of critical systems (finance, healthcare)
- Governments and regulators
- Developers building on existing code
- Society at large relies on infrastructure

What are formal methods?

- Mathematical verification of program correctness
- Proofs, model checking, type systems
- Mostly academic until recently
- Reduce bugs and security vulnerabilities

Pioneering

The Early Days

1920s-50s:

- Hilbert's Program spurs research into fundamental questions
- What is it possible to know? And under what conditions?
- Leads to invention/discovery of foundations of formal programming languages

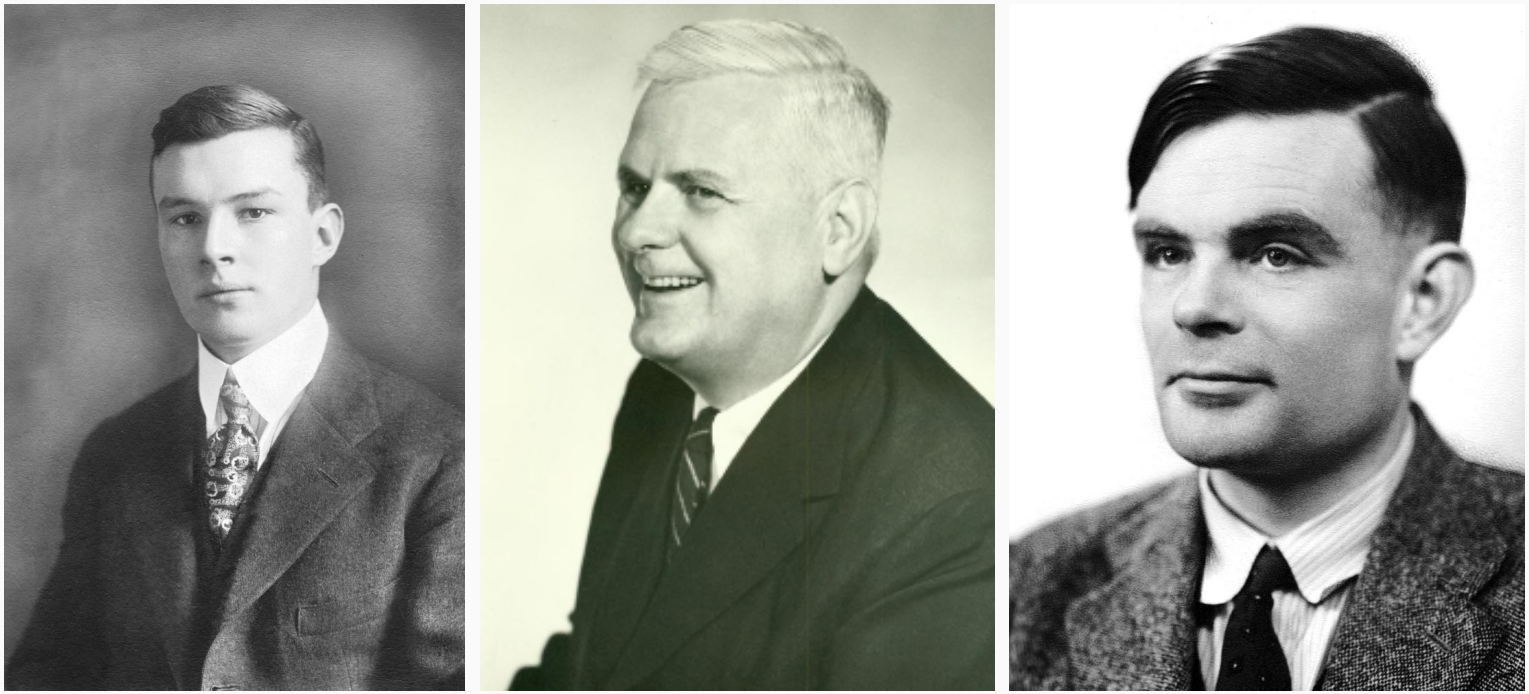


Figure 1: Curry, Church, Turing

The Early Days

- First electronic computers are developed for military purposes (so expensive!)
- Scientific/Business computers created post-WW2

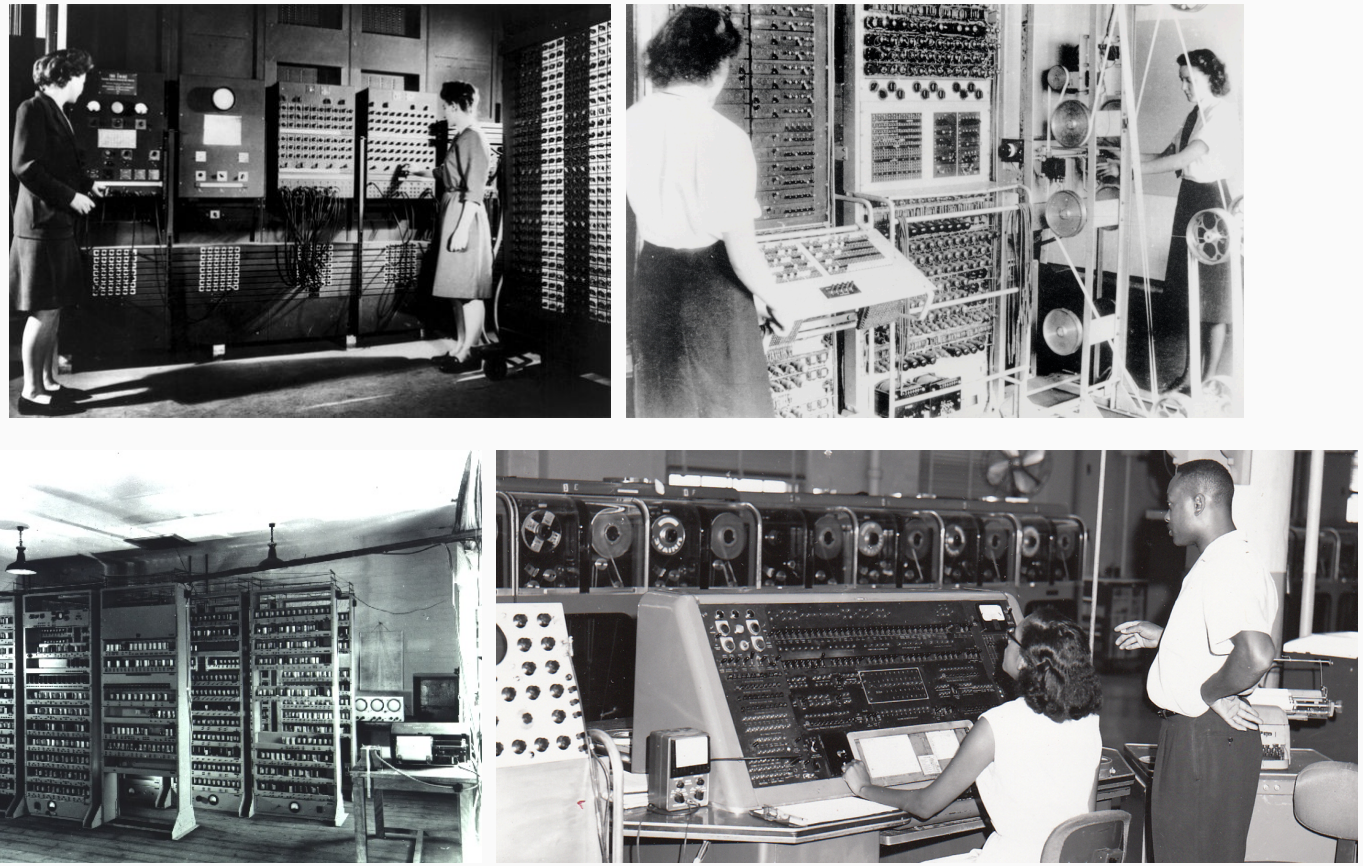


Figure 2: ENIAC, Colossus, EDSAC, UNIVAC 1

The Software Crisis

- 1960s: Hardware costs drop, but software costs soar
- **Problem**: how do we stop developers from writing lots of low-quality, unmaintainable code?
- **Solution**: robust reasoning tools for program analysis

The Software Crisis

- **Goal**: build reasoning tools in order to develop better software
- Denotational semantics introduced
- Hoare Logic, weakest precondition inference, “Assigning Meaning to Programs”

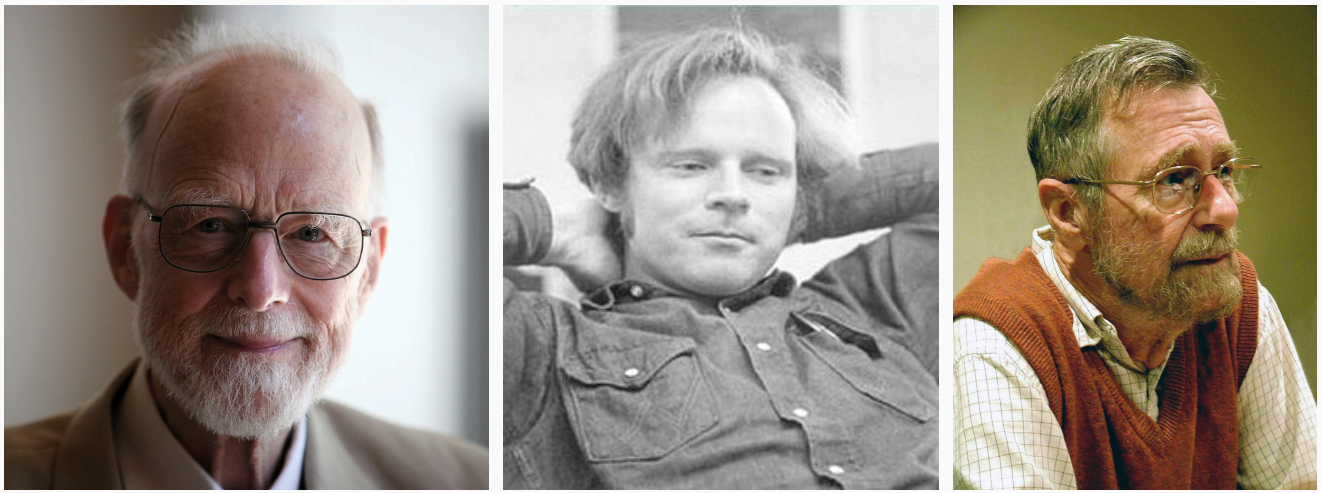
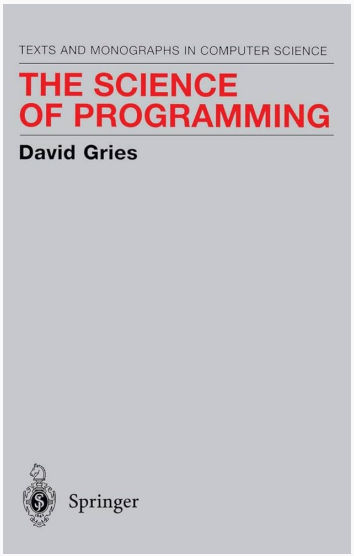
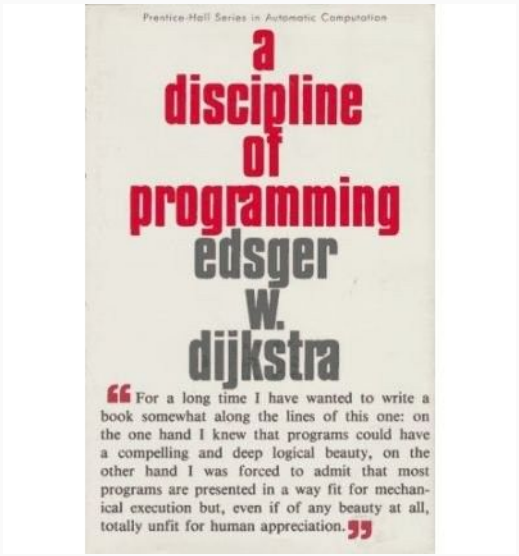


Figure 3: Sir Tony Hoare, Robert Floyd, Edsger Dijkstra

Hitting the Books

- By 1970s/80s, FM is common in standard university curricula
- Students required to develop program analysis skills
- Generations educated on prior 20 years of research





Giving it to The Man

- Programming practices influenced by defense needs
- Government programs: Cold War funding, Ada
- Type systems, model checking, process calculi developed

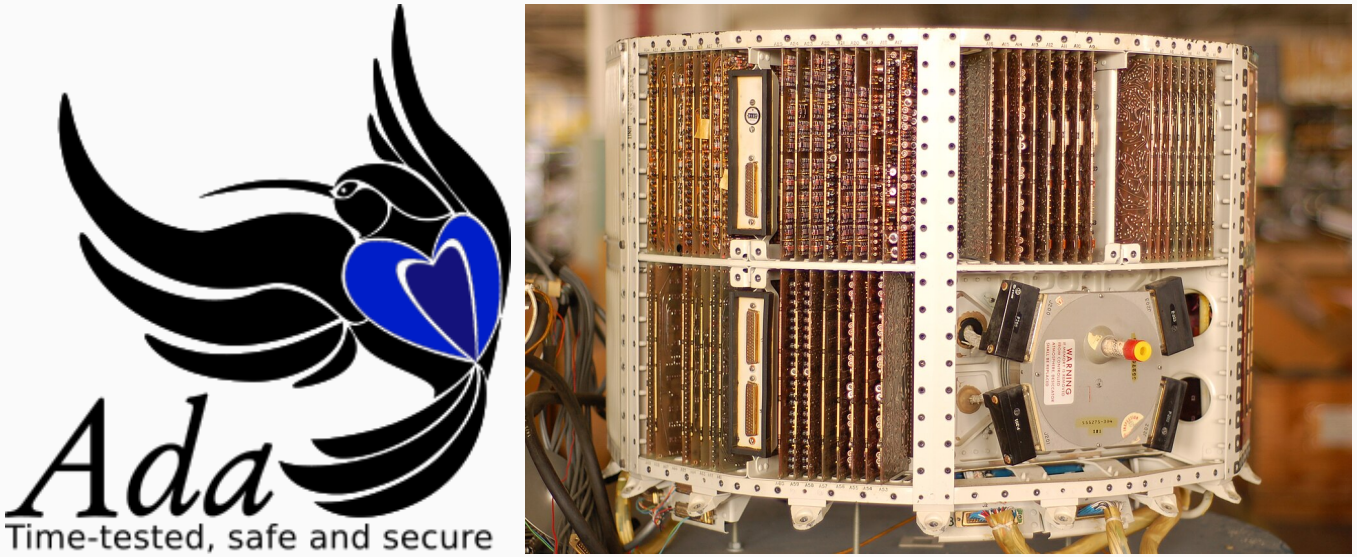


Figure 4: Ada, D-17B Missile Guidance System

The New Century

The Divergence

- Two (rough) camps of program analysis: formal methods and programming techniques
- Programming methods and techniques becoming widely adopted: unit testing frameworks, smarter IDEs, software model checking
- FM progresses in the background: separation logic, certified compilers, SMT-COMP

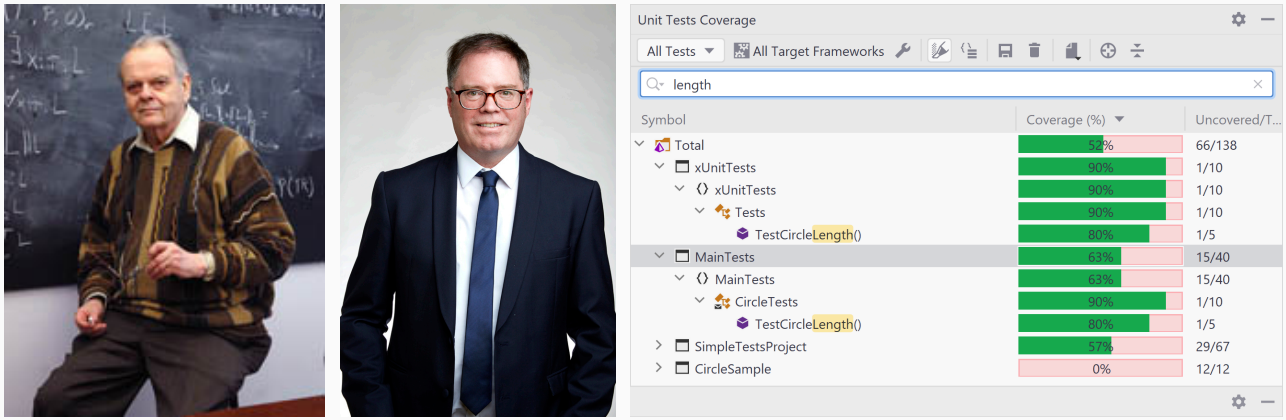


Figure 5: Reynolds, O'Hearn, unit test coverage tool

Adoption

- Governments, military, aviation, supply chains adopt many forms of FM in greater quantities
- Cloud and HFT companies adopt verification
- Verified components enter production gradually
- Early industrial successes build confidence

Back to the Present

Where are we now?

- Wealth of tools for all purposes at our disposal
- Uneven adoption due to high costs of training developers, rewriting software
- Adoption being driven by pressure from cybercrime
- FM courses slowly return to undergrad programs as electives

The Pattern

Academia

- Most FM discoveries come from universities
- Motivated by solving current problems of the day
- Hilbert's Program, code quality, code security
- Research often years ahead of industrial use

Government

- Funds large-scale research and applies it to critical systems
- Takes academic ideas and sponsors iteration and application
- WW2 cipher-breaking, Cold War systems, drones, computer infrastructure
- Often the only source of funding large enough to take risks on unproven research

Industry

- Adopts proven techniques from government and academia
- Adoption motivated by profitability or infrastructure needs
- Typically waits for validated, large-scale results
- Exception: massive companies can fund some research themselves

Education

- Students given opportunities to study cutting-edge research, but not required
- Curriculum focuses on marketable skills first
- Writing correct software, OOP, modern programming practices
- Prepares next generation to adopt new methods when they reach industry

Summary

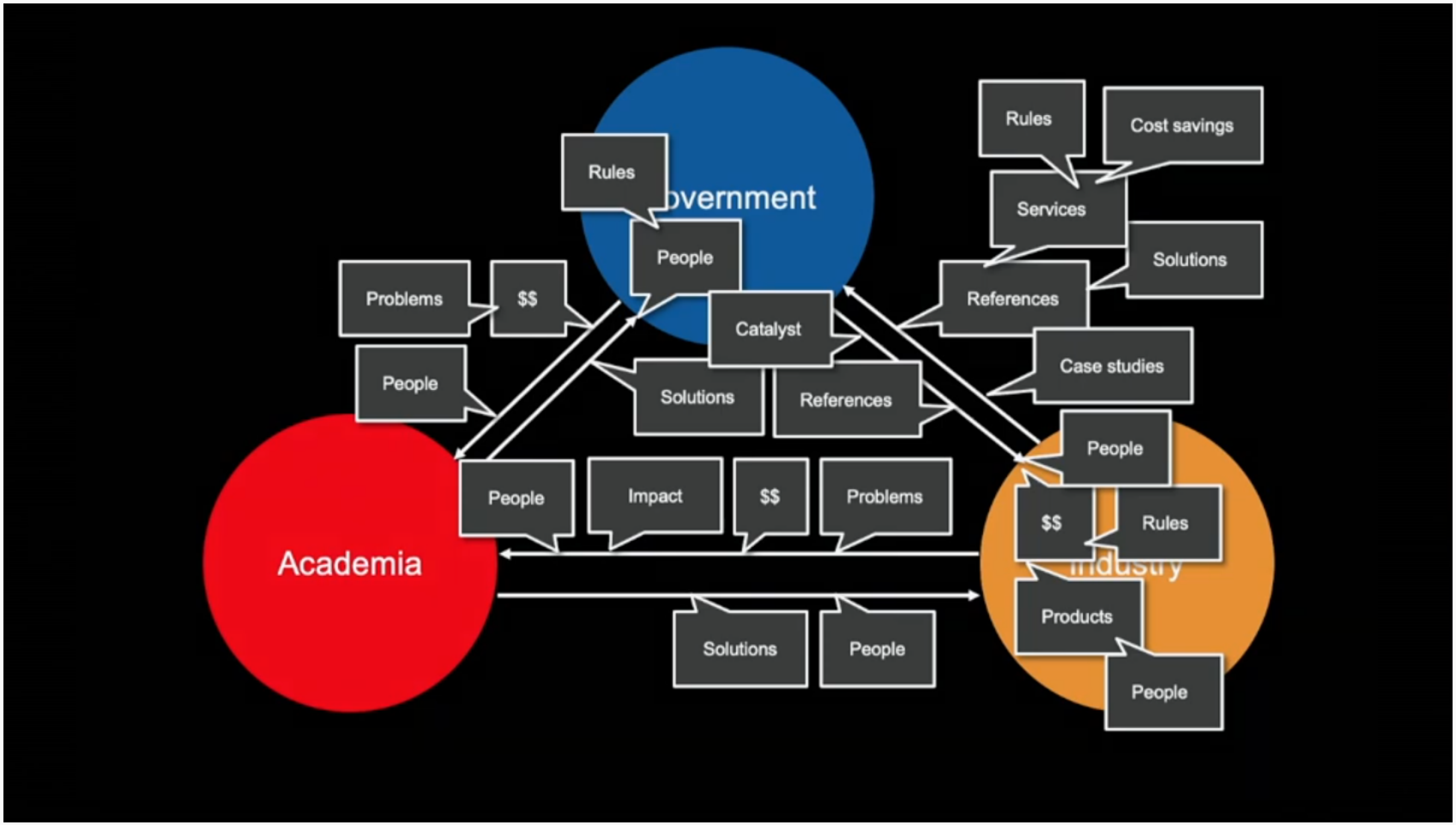


Figure 6: From “Thoughts on the interplay between corporate, government, and university R&D” - Byron Cook [1]

The Secure Software of Tomorrow

Timeline

- Hybrid top-down/bottom-up verification
- MVCs, verified libraries, language support
- Dealing with hardware
- Educational reforms driven by cybersecurity needs
- Deus ex Machina

Meeting in the Middle

- Combine high-level semantics and low-level effects
- Full-stack proof frontends emerge
- Reason about correctness, processor, timing, cache
- Enables more complete software verification

Minimal Verified Components

- Small, verified building blocks to replace critical low-level code
- DARPA-funded development
- Rapidly proliferate across libraries
- Parsers, encoders, cryptography

Veritas

- First verified C standard library
- Uses MVCs extensively
- Compilers allow substitution in standard libraries
- Adoption spreads to embedded and open-source code

The Unverifiable Core

- AI and I/O partially unverifiable
- Hybrid trust strategies required
- Hardware specs formalized by GIANT Labs
- Cybercrime acceleration slows, but still grows

The Catalyst

- Education increasingly re-adopts FM
- Governments mandate FM for critical software
- Rowan Carter: automated loop verification
- Breakthrough reduces manual reasoning burden

The End

- CI pipelines verify complex control flow automatically
- Critical industries reach near-universal coverage
- Cybercrime mitigated by verified software
- FM becomes invisible infrastructure

Contact

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Cook, B.
[PLMW@PLDI24] Thoughts on the interplay between corporate, government, and university R&D, Jul 2024.