19 June 2025

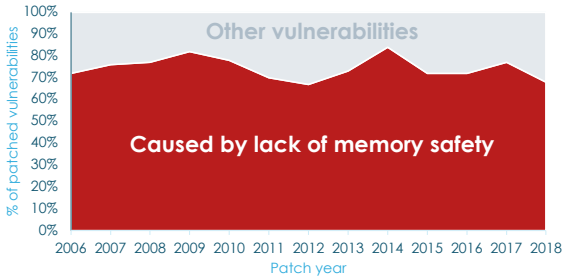
CHERI technology overview

A quick introduction

Executive Summary

Solving the worst cybersecurity issue

- Cyberattacks cause more than $10 trillion of damage / year
- Most attacks due to a lack of **Memory safety**
- Unsolvable problem with traditional software solutions (new languages, practices, tools…)
- **CHERI** technology solves the memory safety problem



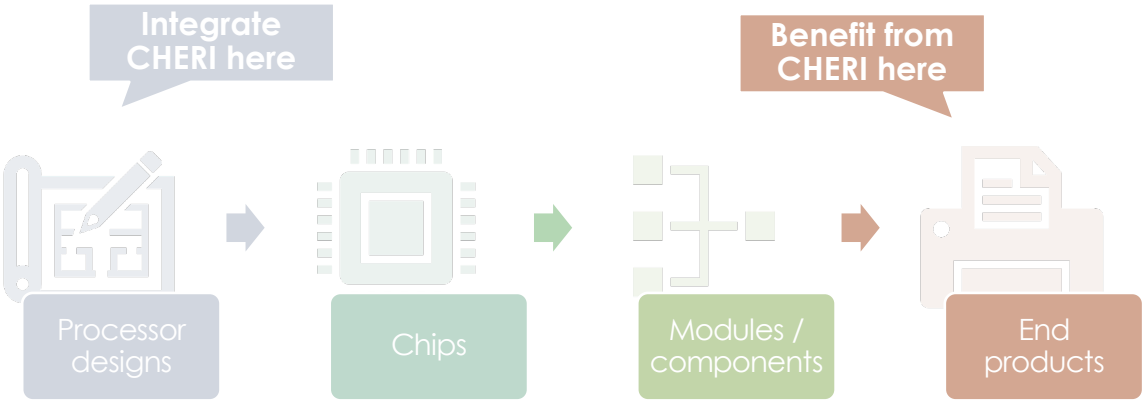
Source: Trends, challenge, and shifts in software vulnerability mitigation - Microsoft 2019

CHERI

Hardware-based solution to a software problem

- CHERI
  - Open technology
  - Hardware protection at processor-level
  - Brings strong security to **existing code**
- Now out of the lab
  - 15 years of development by University of Cambridge (UK) / SRI (USA)
  - Formally proven
  - Demo and prototypes available – now getting into products
  - Ready for industry to adopt

CHERI requires new hardware



CHERI backed by strong supporters

~ $300 million investment in the development of CHERI

(by governments and industry)

CHERI benefits

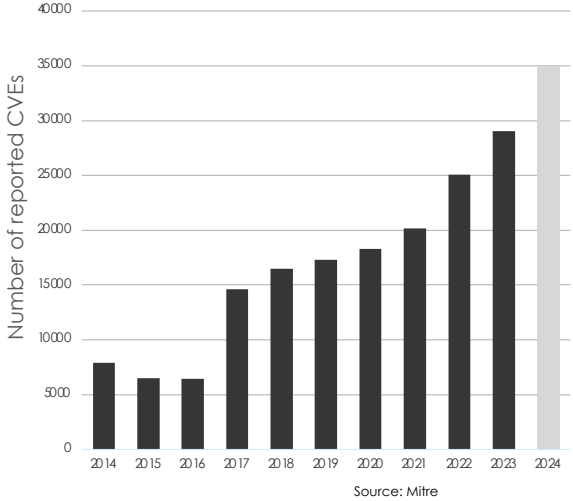
- Brings security even to existing code
  - No need to rewrite — mostly recompile & optimize
  - Built-in compartmentalization — secrets remain secret
  - Fast learning curve — no need to change language, habits…
- Low impact
  - Area & Power — < 5% more at CPU level
  - Performance — ~3-5% less (work in progress – still improving)
- Possible to increase performance with optimization
  - Use native capabilities instead of inefficient security software
  - Some case studies show up to 800% improvement!

The memory safety problem

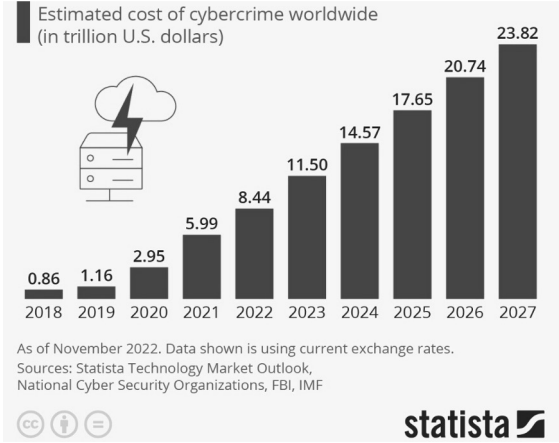
Data breaches are very costly

>$500M	6X	~$10T
Cost of addressing Heartbleed buffer overflow vulnerability	Increase in firmware attacks reported by NIST between 2017 and 2024	Worldwide cost estimate of cyberattacks per year (and growing fast)

Software vulnerabilities are causing increasing risk

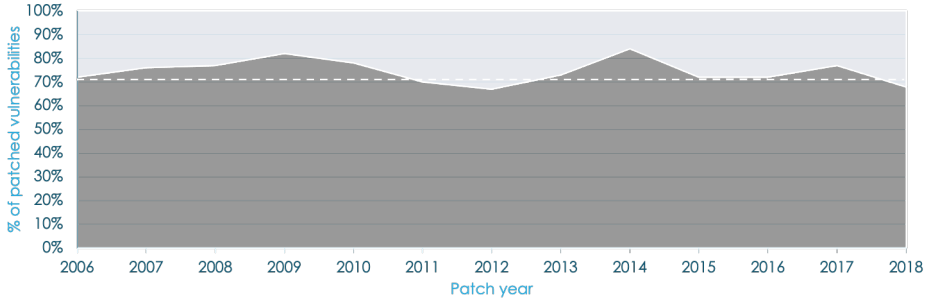


Source: Mitre



Memory safety is necessary

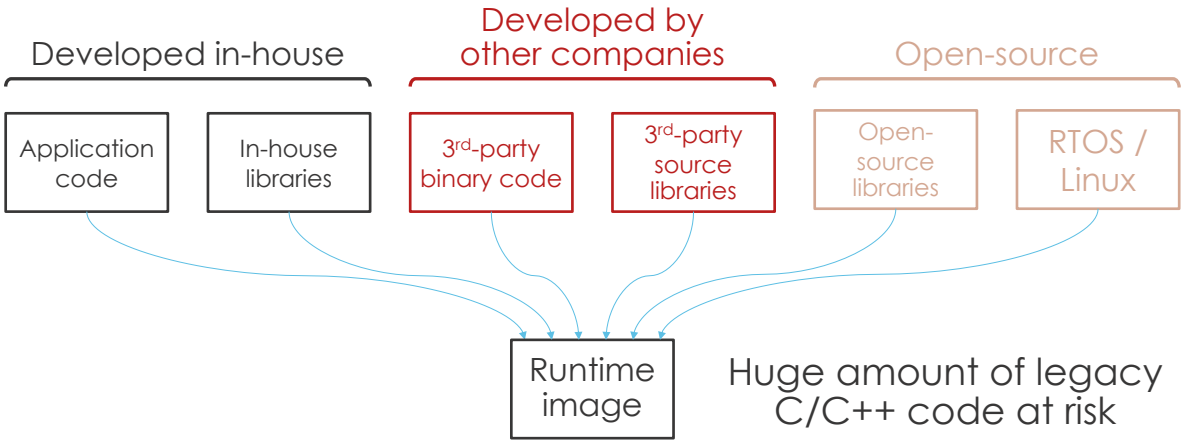
- Memory abuse (e.g. buffer overflows) is the main attack vector
- Constant ratio of over the past 20 years
  - … even with all the work done on software to avoid this!



CHERI solves this!

Source: Trends, challenge, and shifts in software vulnerability mitigation - Microsoft 2019

Impossible to re-write software to fix the problem



Possible solutions for memory safety

✗ Use “memory safe” languages like Rust or .Net

- Requires rewriting trillions of lines of C/C++ code
- Possible for new code, but no compartmentalisation

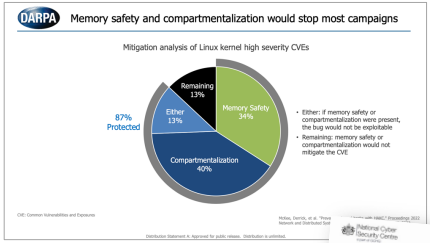
✗ Use “coarse-grained” techniques like stack “canaries” to detect issues

- Helpful, but they statistically leave too many holes
- Hacking techniques already developed

✓ Use “fine-grained” techniques like CHERI

- Best option, but needs new hardware

Memory safety becomes a key topic




FEBRUARY 26, 2024

Press Release: Future Software Should Be Memory Safe

ONCD › BRIEFING ROOM › PRESS RELEASE

Leaders in Industry Support White House Call to Address Root Cause of Many of the Worst Cyber Attacks

Highlight CHERI as a solution

Article: https://bidenwhitehouse.archives.gov/oncd/briefing-room/2024/02/26/press-release-technical-report/
Report: https://bidenwhitehouse.archives.gov/wp-content/uploads/2024/02/Final-ONCD-Technical-Report.pdf
(CHERI mentioned on p9)

https://www.ncsc.gov.uk/collection/ncsc-annual-review-2024


America's Cyber Defense Agency
NATIONAL COORDINATOR FOR CRITICAL INFRASTRUCTURE SECURITY AND RESILIENCE

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The Urgent Need for Memory Safety in Software Products

Released: September 20, 2023
Revised: December 06, 2023

Bob Lord, Senior Technical Advisor

RELATED TOPICS: CYBERSECURITY BEST PRACTICES, ORGANIZATIONS AND CYBER SAFETY

https://www.cisa.gov/news-events/news/urgent-need-memory-safety-software-products

CHERI technology

Capability
Hardware
Enhanced
RISC
Instructions

About CHERI

- Initiated by a project from

- Originally developed by

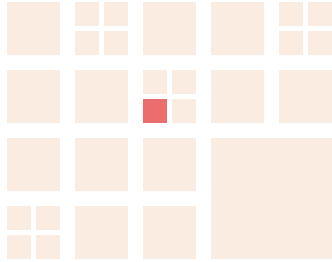
- Matured for 15 years
- Supported by

~ $300 million investment in the development of CHERI

(by governments and industry)

CHERI

- A new **hardware-based approach** to memory safety
- Strong, fine-grained **memory protection**
  - Hardware enforced
  - Deterministic
- **Compartmentalization**
  - Principle of least privilege



Compartmentalization prevents contagion

Main memory issues with C/C++

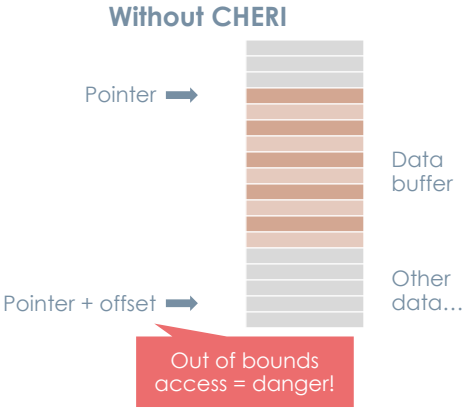
- Possible to access memory out of expected buffers
  - Access confidential data
  - Modify / delete critical data or code
  - Inject malware code
  - Spy on communications
  - Erase traces of attack
- Functions cannot protect their data from each other
  - Only works when the software can be trusted
  - Enable privilege escalation

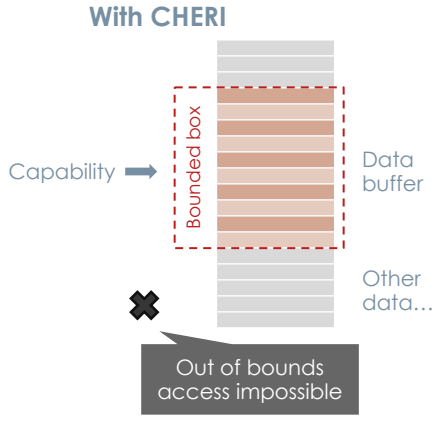
Need memory safety

Need compartmentalization

CHERI brings memory safety

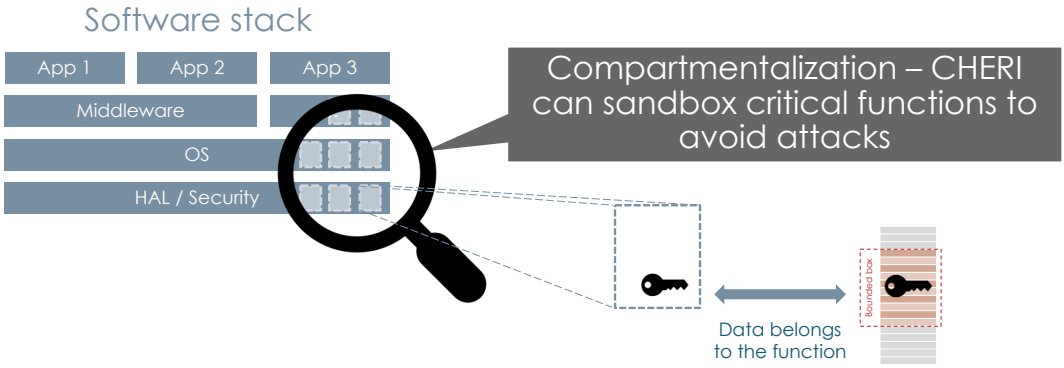
- Replacing pointers by capabilities – with hardware control





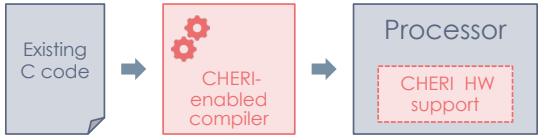
CHERI brings compartmentalization

- Capabilities belong to an identified function / execution context



CHERI relies on hardware protection

- CHERI requires adapted processor
  - Can be applied to any type of core
- Hardware-enforced security
  - Impossible to bypass by software
  - Formally proven
- Reuse existing code
  - Just recompile application
  - Choose which part to protect
- Benefit from CHERI
  - Rejects dangerous code
  - Create CHERI compartments for critical code



CHERI adoption
(costs, benefits)

CHERI has a positive impact

Limited costs

- Area impact
  - Processor only 4% larger*
  - Similar power consumption
  - Similar performance**
- Memory impact
  - Small area for tag storage
  - Double size for pointers (mostly impacts stack)
  - No change on data storage requirements
- Software development
  - Need adapted tools (open-source available)
  - Less than 0.5% application code*** to adapt
  - Need recompilation
  - OS / low-level drivers need work (done once)

Huge gains

- Memory safety!
  - Save in patching costs
  - Compiler detects mistakes in existing code
- Performance gains****
  - Remove or simplify software-based mechanisms (TEE, compartmentalization, security modes, …)
  - Eliminate context switching in hypervisor
  - Reduce code, improve execution speed
- Fast, low-risk integration of unsafe code
- Save security experts' time
  - Not wasting it on bug hunting…

CHERI Alliance will help by stimulating the ecosystem to adapt OS / software / tools

* Real data from Codasip – Comparing the same commercial processor with/without CHERI
** Slight degradation for chips with low-bandwidth internal bus (i.e. less than 128bit)
*** Real data from application porting
**** Requires OS / security mechanisms adaptation (done once, usually by the ecosystem)

What makes CHERI different?

	Previous solutions	Problem	CHERI
Security control	Statistical • "likely" to detect a problem	Targeted attacks bypass protection Some problems detected too late	Systematic • 100% coverage
Enforcement	Some complex, disparate hardware features, no coherency across architectures Rely on "trusted" software and/or explicit checks	Additional complexity Software can be hacked (and has been…)	Hardware-enforced • Simple, holistic protection • No way to bypass by software (unforgeable tags)
Software impact	High impact on software • A lot of additional code needed to protect and isolate • Need best security experts to review all software stack • Often need to rewrite code	Difficult to catch all issues Reduce performance and increase code size Experts are scarce	Extremely low software impact • Need recompilation • Adapt some very low-level code • Fix previously undetected problems
Type of solution	Reactive • Fix problem if vulnerability discovered Proactive solution possible (but uneconomical)	Huge exploitable attack surface, susceptible to 0-day attacks Most systems are not upgraded immediately / regularly	Preventive • Protects against existing and to-be-designed attacks on memory

Easy software migration

- CHERI-enabled processors can run legacy code *
  - "Hybrid mode" – run CHERI and non-CHERI code simultaneously
- Recompile / adapt / optimize code progressively
- Major OS are being ported to CHERI
  - Driven / coordinated by the CHERI Alliance
  - FreeRTOS, Zephyr, Linux, FreeBSD, Linux, seL4, …

* Except for CHERI processors that only accept full-capabilities mode

Easy software migration – Typical paths

Typical bare-metal / RTOS development

Typical rich-OS development

* e.g. user-facing arrays – skip this stage for an RTOS as many low-level functions are abstracted
** Optional: may require some re-architecting of code

Benefits of CHERI for functional safety

- Reduce development and certification costs
  - Detect programming mistakes faster
  - Simplify the analysis of source code
  - Demonstrate absence of memory vulnerabilities
- Allow modern development
  - No need for strict MISRA-C or SAFE-C constraints
  - Use all features of the C language
  - Enable innovation and new features
- Enable consolidation of multiple functions on a chip
  - Watertight isolation
  - Reduces cost and complexity

CHERI backed by strong supporters

CHERI projects / products

- Prototypes / proof of concept
  - Proof of concept
    arm Morello Program
  - Open-source / prototype
    UNIVERSITY OF CAMBRIDGE Microsoft
- Commercial use
  - Already available from
    Codasip lowRISC SCI Semiconductor
  - CHERI RISC-V standard ratified soon
    RISC-V
- OS ported to CHERI (Free RTOS, Zephyr, Linux, FreeBSD, seL4…)

Now collaborating as part of the
CHERI Alliance

- Support HW/SW ecosystem
- Solve common problems
- Joint promotion

The CHERI architecture's support for fine-grain memory protection and scalable compartmentalization promises to revolutionise our ability to protect personal data and provide strong defences against malware on mobile devices and in the cloud

Ben Laurie, Director of Security,
Google Research

As noted by the White House in a recent report on a path toward secure and measurable software, hardware support is critical to robust and efficient memory safety. Compiling software to run on CHERI enhanced processors guarantees very strong memory safety that an attacker cannot bypass

Professor Simon Moore,
University of Cambridge

CHERI

THANK YOU

Contact contact@cheri-alliance.org

Web www.cheri-alliance.org