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Digital Security by Verification: Fuzz Testing on CHERI

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Outline

- What is Digital Security by Design (DSbD) and Digital Security by Verification?
- What is CHERI?
- What is Fuzz Testing?
- Fuzz Testing on CHERI
- Conclusion

Digital Security by Design

- 'Security by Design' is a proactive approach to introduce security measures into systems from the very start, rather than as an add-on
- Secure by Design Problem Book, DSTL, UK MOD, April 2025 - "'Secure by Design' is becoming mandated across UK government for securing crown data and services."
- Cyber Resilience Act, European Union, 2024 - "EU regulation that introduces mandatory cybersecurity requirements for hardware and software products"
- Cybersecurity and Infrastructure Security Agency (CISA), United States federal agency within the Department of Homeland Security (DHS) - "Secure by Design principles prioritize the security of customers as a core business requirement."

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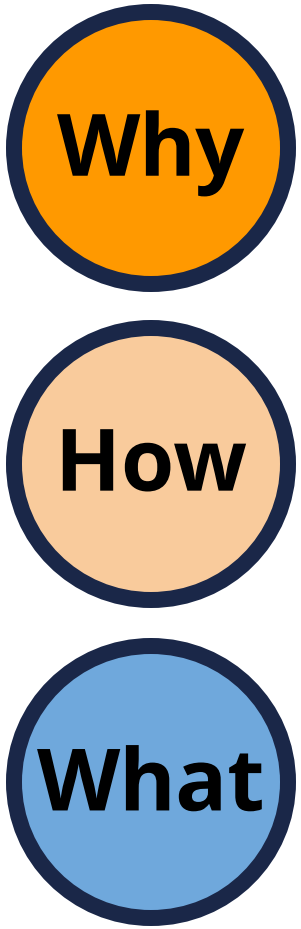
Digital Security by Design

Airworthiness Security Process Specification – ED-202A / DO-326A
Airworthiness Security Methods and Considerations – ED-203A / DO-356A

CHERI – Capability Hardware Enhanced RISC Instructions

- Joint research project of SRI International and the University of Cambridge
- CHERI extends conventional hardware Instruction-Set Architectures with new architectural features to enable fine-grained memory protection and highly scalable software compartmentalization.
- CHERI Alliance – industry initiative spearheading the global adoption of the CHERI security technology across the computing industry

CHERI – Capability Hardware Enhanced RISC Instructions

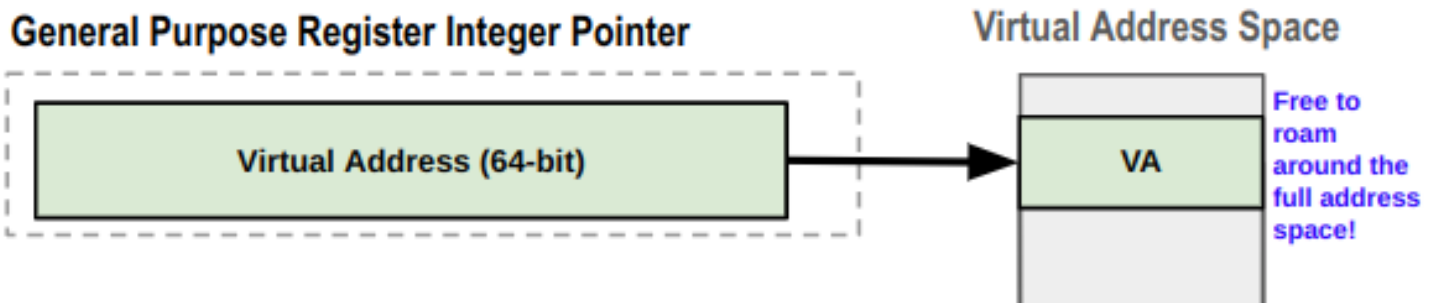


- The current strategy for "handling" cybersecurity is unsustainable (monitor, patch, fix, repeat…).
- Recognition that to be safe, the digital world must secure by default (memory safety is paramount).

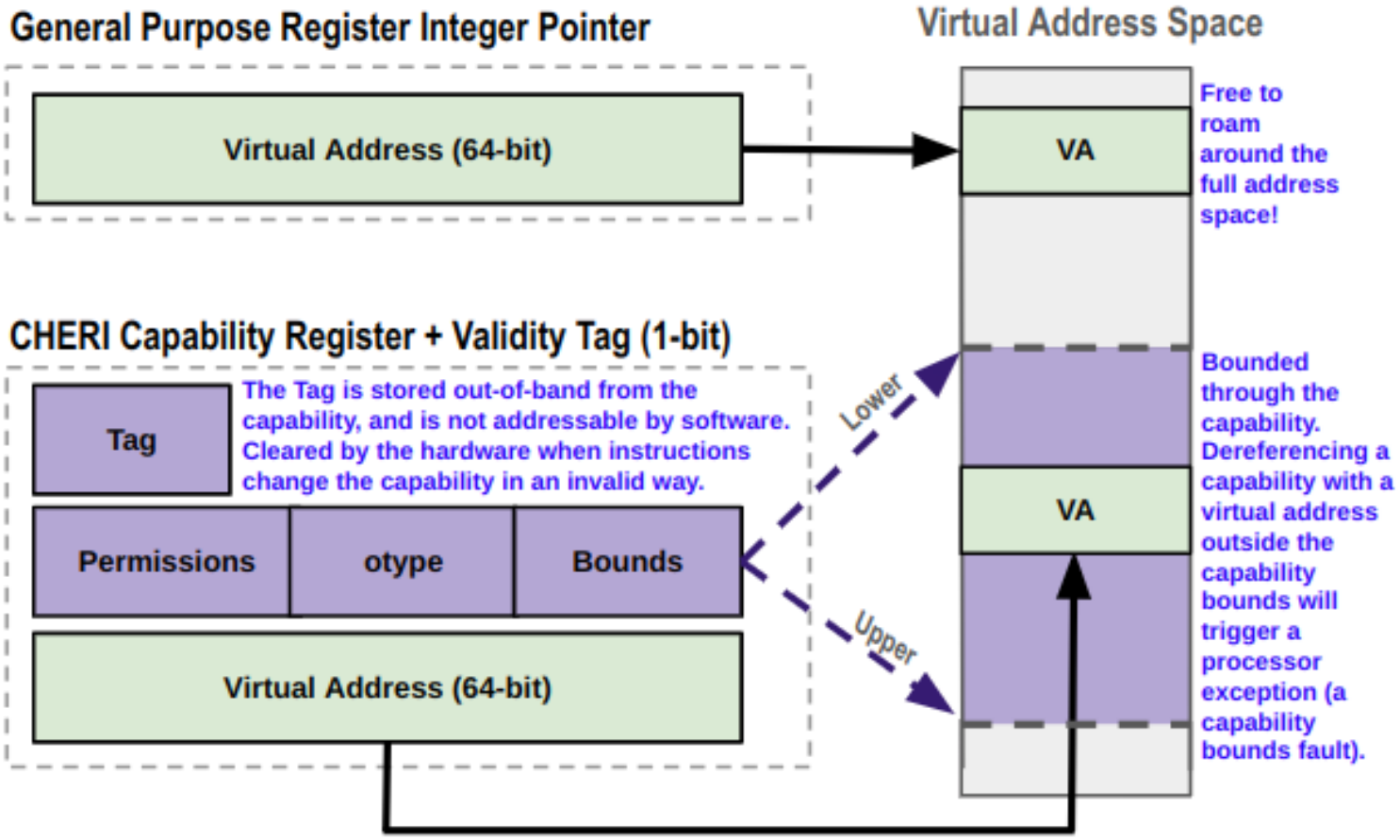
- Adopt a preemptive approach of designing in guards against violation of security properties.

- New CPU architectures guards against violation of security properties (unsafe memory instructions, for example, buffer overflows); upon detection, hardware exceptions are raised.

CHERI – Conventional Pointers



CHERI – Capabilities



Full GNAT Pro Ada Pure Capability runtime for CheriBSD

- Under the Secure Avionics by Design project, funded by the UK RAF Rapid Capabilities Office and overseen by DSTL
- Various Ada Runtimes for the Arm Morello CHERI evaluation board
- CHERI pure capability memory allocators - all memory addresses are CHERI capabilities
- Propagation of CHERI hardware traps into Ada software exception handlers
- Works with both GCC and LLVM

Memory Safe Programming Languages

- Ada
- SPARK
- Rust

Memory Safe Programming Languages

- **Ada** – Unchecked programming
- **SPARK** – Assumptions
- **Rust** – Unsafe programming

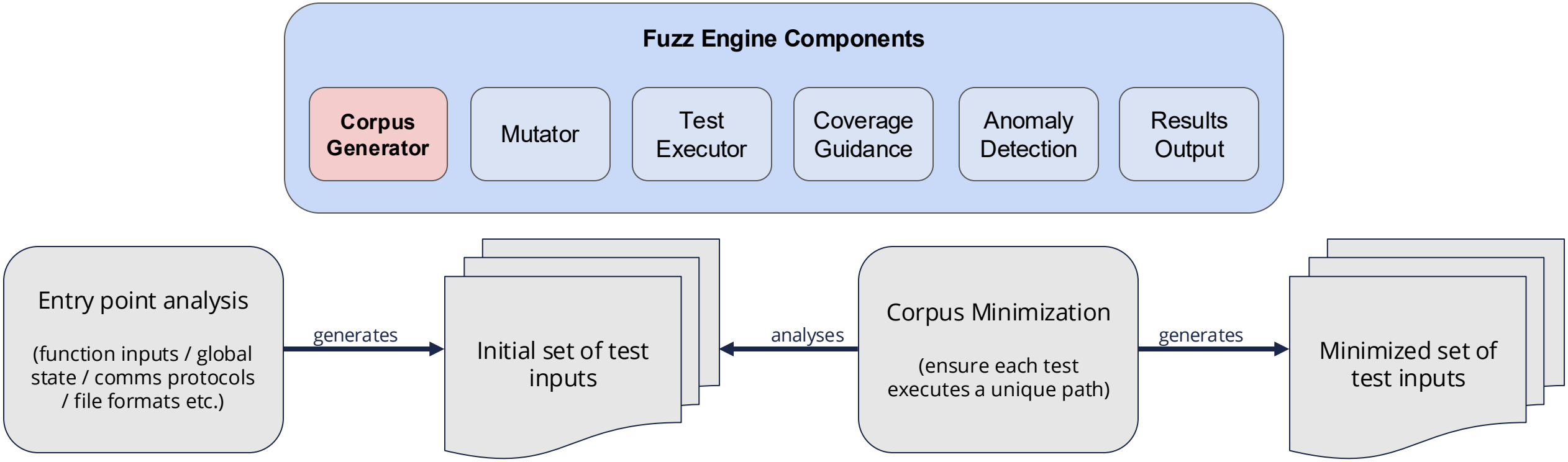
Fuzz Testing

- Automated software testing technique
- Involves the mutation of a corpus of test inputs to create new inputs
- Intermediate tooling includes coverage guidance feedback
- Advanced tooling includes branch solving algorithms (Symbolic execution, redqueen / CMPLOG)

"Program testing can be a very effective way to show the presence of bugs, but it is hopelessly inadequate for showing their absence."

The Humble Programmer, Edsger W. Dijkstra, 1972

Fuzz Testing



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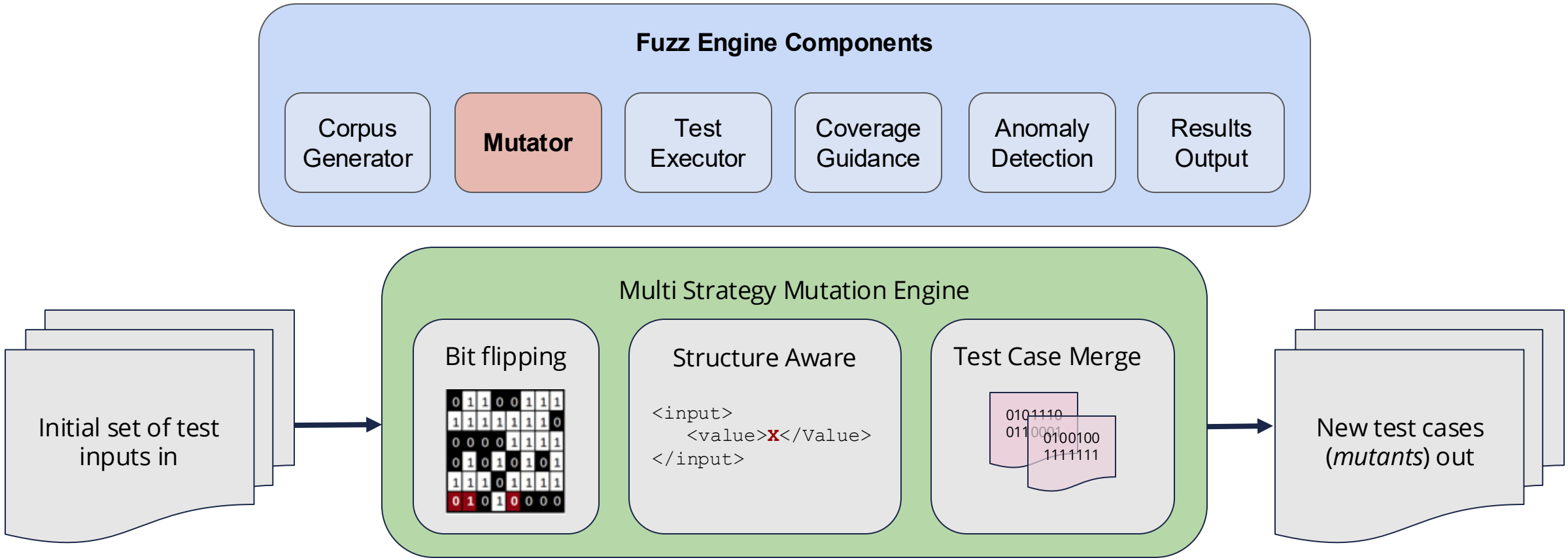

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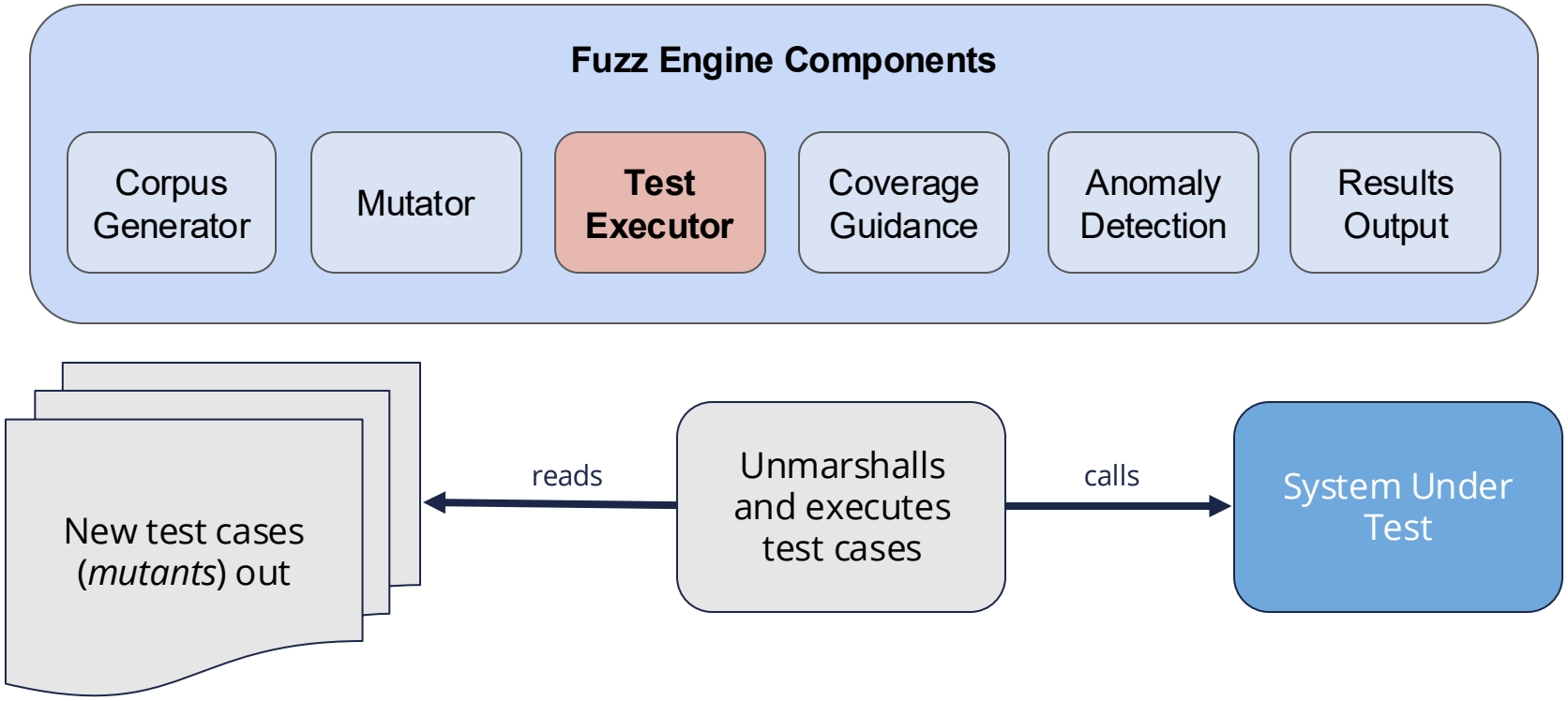

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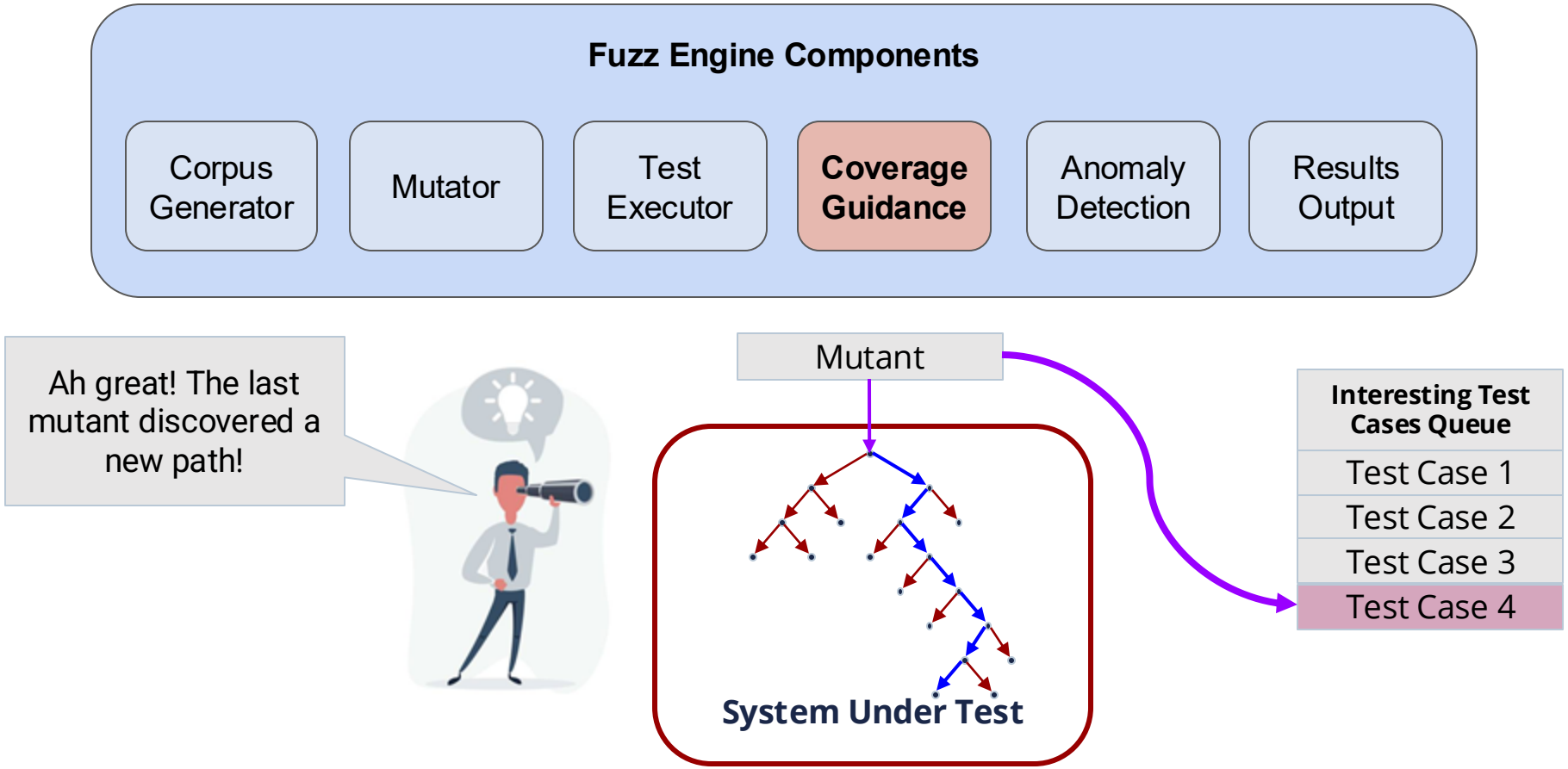

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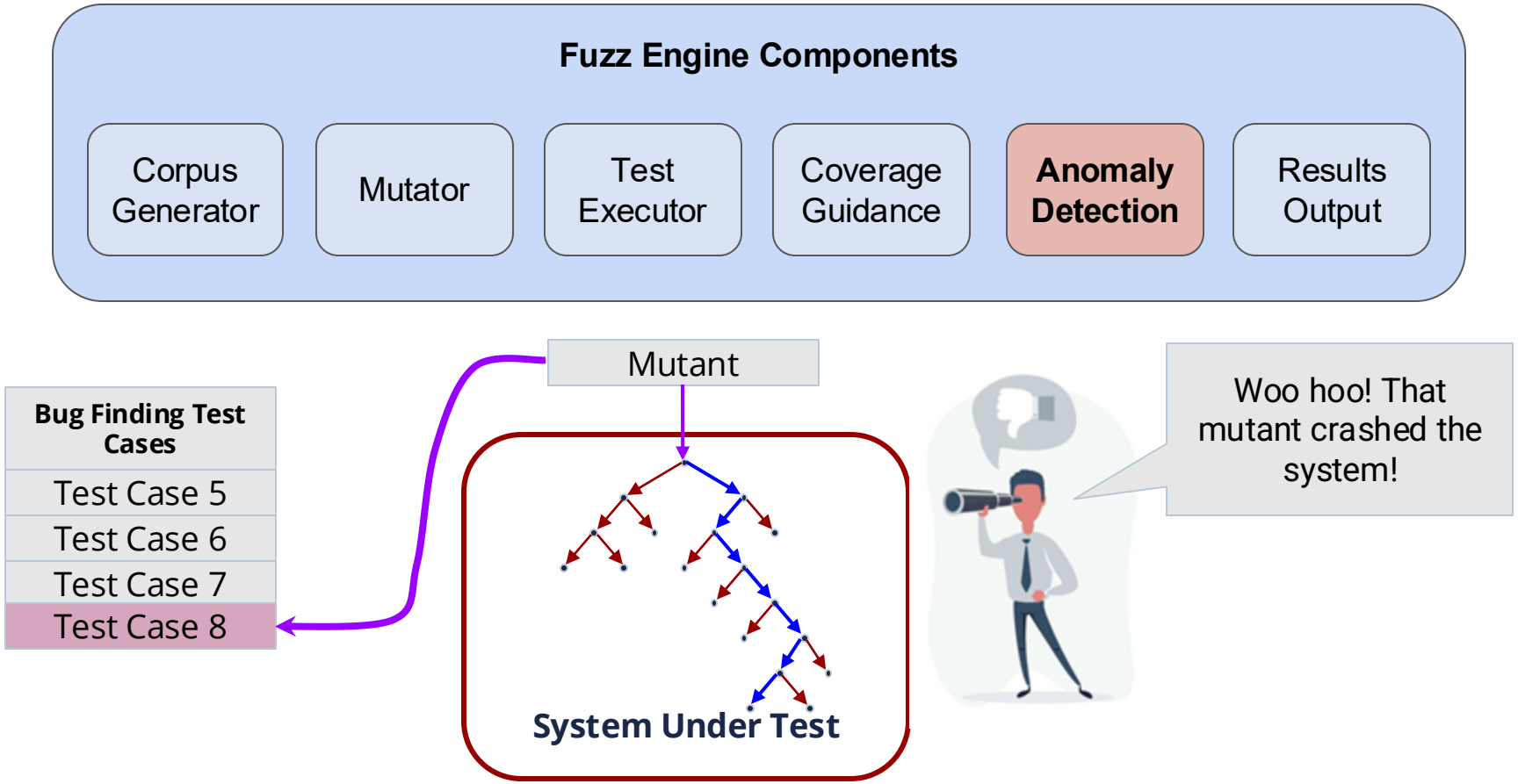

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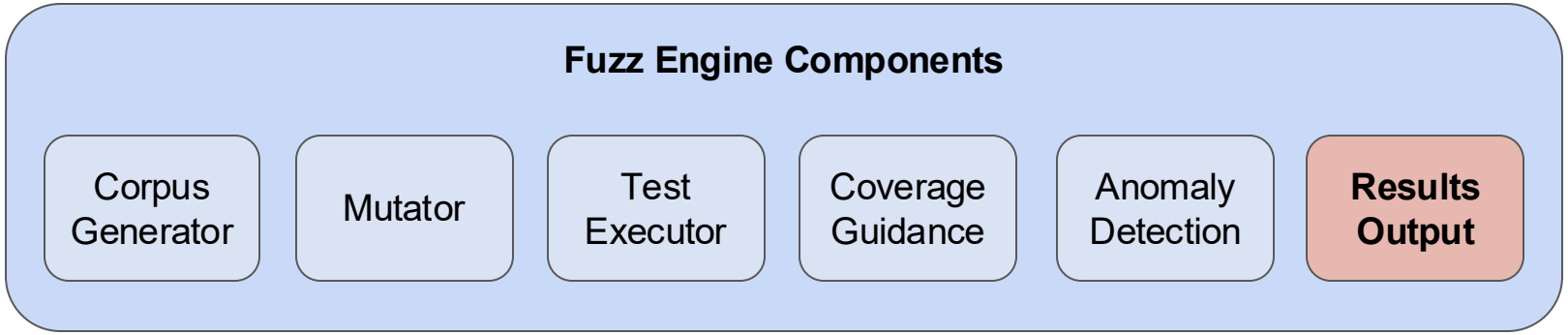

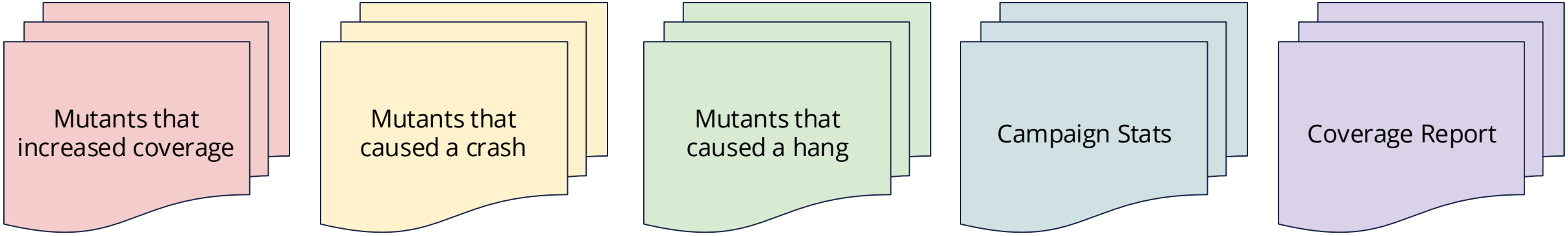

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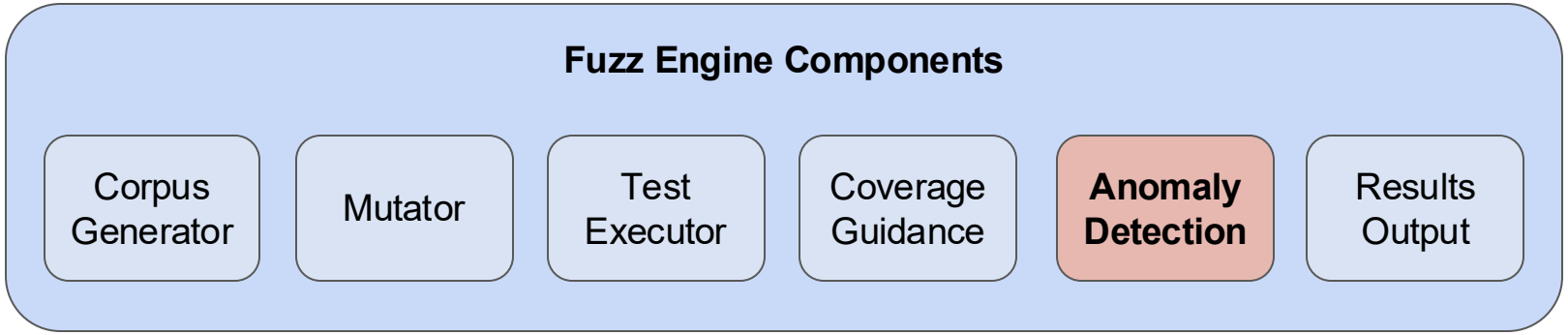
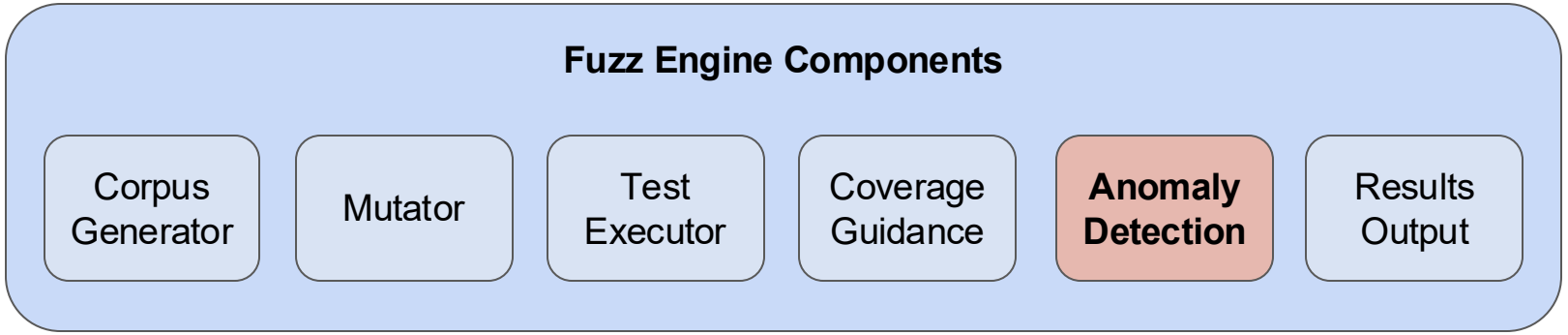


AFL++   LibFuzzer

- Segmentation faults detected through core dump files
- AddressSanitizer or LeakSanitizer

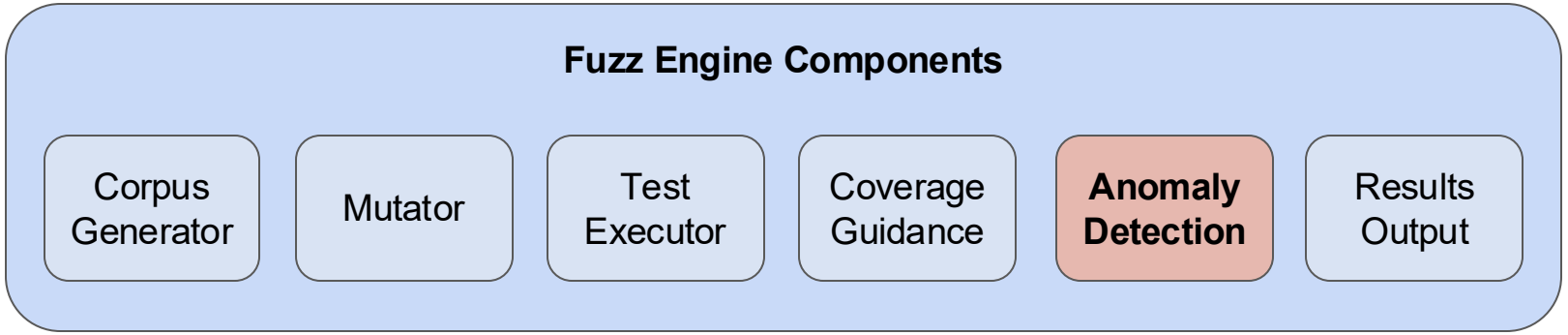
Fuzz Testing



Ada
Run Time Constraint Checks

- Access check / discriminant check / division check / index check / length check / overflow check / range check / tag check / accessibility check / allocation check / elaboration check / storage check

Fuzz Testing on CHERI



Can CHERI help further with anomaly detection?

CHERI Hardware Capability Faults

Fuzz Testing on CHERI

- CHERI is a Dynamic Analysis solution
- Stopping vulnerabilities before they happen is important, but what about high assurance systems where we also want to argue our system is absent of runtime errors before deployment?
- Verification testing on a CHERI architecture is only ever going to be as good as the range of inputs you provide it with (**i.e. not seeing a fault does not mean the fault is not there**)

Fuzz Testing on CHERI – Adaptive Engine

- AdaCore "Adaptive" fuzzing engine
  - Explore the benefits of on-target fuzzing
  - Target CHERI architectures and pure-capability compliant CHERI OS ports
  - Typical smart grey box fuzzer features
    - Corpus generation
    - Mutation engine
    - Coverage-guided feedback via enhancements to GNATcoverage MC/DC coverage
  - Relies on the Full GNAT Pro Ada Pure Capability runtime for CheriBSD
    - Support for bare metal (GNAT Pro Embedded Ada runtime) is a feasible future enhancement

Fuzz Testing on CHERI – Adaptive Engine

- Strengths
  - Portable – only depends on the Ada standard library
  - Catches errors even with unchecked operations
  - It supports every target that GNATfuzz supports
  - Supports fuzzing of C code through bindings from Ada

Fuzz Testing on CHERI – Adaptive Engine

- Current limitations
  - Emulators are too slow to do effective fuzzing
  - No recovery from a timeout
  - It's in-process fuzzing, so if there's memory corruption at some point, the fuzzer could malfunction - CHERI detects these cases

Fuzz Testing on CHERI

	Project sources	Architecture	Duration	Level of Assurance
Continuous Integration	Changes only	Host	X Minutes	Some
Nightly	All	Host	Y Hours	More
Weekly	All	CHERI	Z Days	Lots

Conclusions

- Government entities are increasingly prioritizing 'Secure by Design' principles (and in some regions are already mandated)
- CHERI's enhanced security properties make it an excellent candidate for a memory safe verification environment
- Fuzz testing on a CHERI architecture provides elevated anomaly detection above and beyond the limits of memory-safe programming language runtimes and other dynamic analysis sanitizers

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Thank you

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