Securing a High-Level Language Virtual Machine Through its ISA: Pharo as a Case Study

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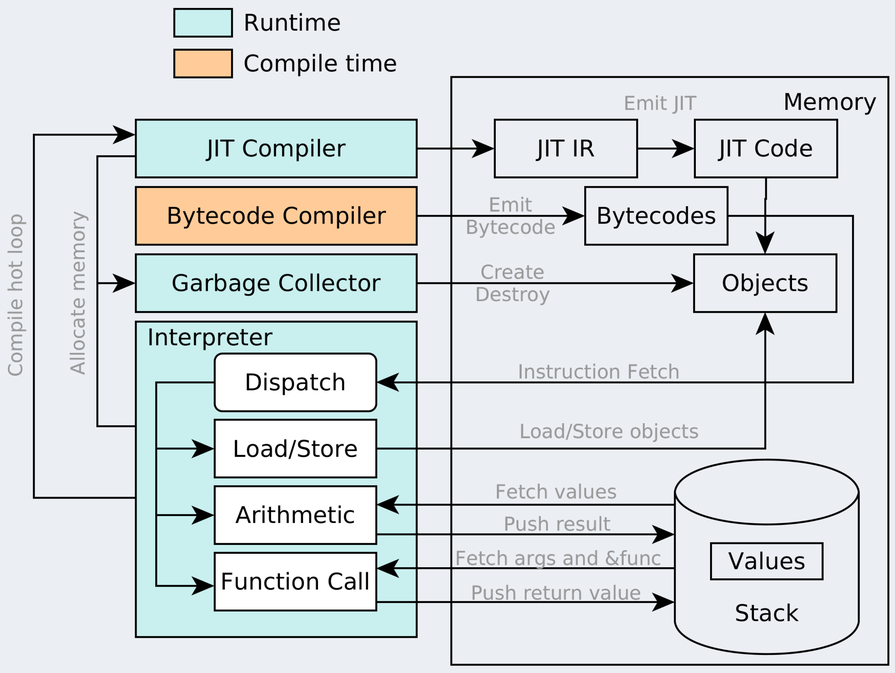
Language Virtual Machines JIT Compilation



- **Bytecode Compiler:** transforms source code in a high-level intermediate representation, **bytecodes**
- **Interpreter:** process the bytecodes and monitor instruction *hotness*
- **JIT compiler:** compiles *hot* methods/blocks/constants into **native code**
- **Garbage Collector:** allocates and deallocates memory

Memory Protection and Process Isolation

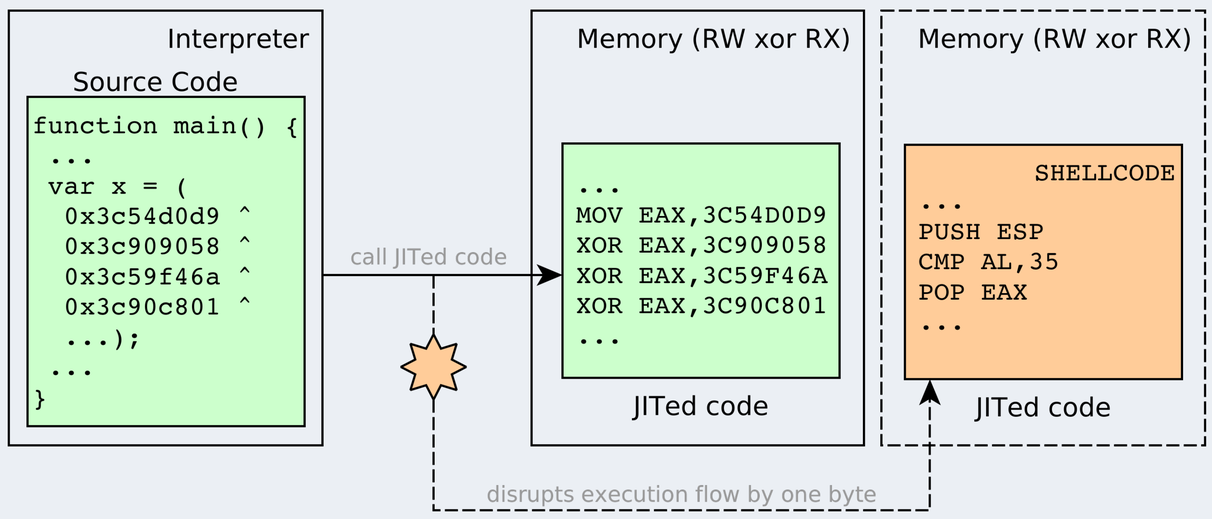
Memory protections are present at different **level** and **granularity**:

- **Memory Page Permissions:** *Read (R), Write (W) or Execute (X)* granted to a given memory page (4kB)
- **Memory Protection Keys:** Userspace hardware mechanism to control page table permissions with key tags.
- **Domain Keys:** Per *process isolation* that can be split through several memory pages.
- **Trusted Execution Environments:** Hardware extension enabling isolated execution environments called *enclaves*.

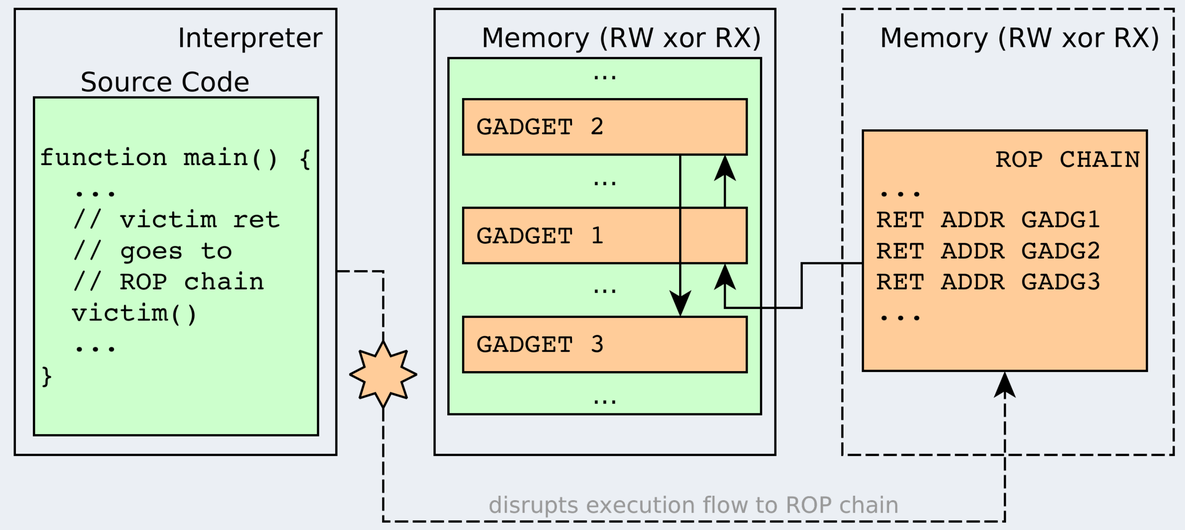
Nanufacturers propose their TEEs such as **ARM Trustzone** or **Intel Software Guard Extension (SGX)** as well as **RISC-V Keystone** [1].

Protections are enforced on JIT engines using $W \oplus X$, **Data Execution Prevention (DEP)**, **Address Space Layout Randomization (ASLR)** or **Control-Flow Integrity (CFI)**. More specific protections have also been developed by integrating **MPK** [2] or **SGX** [3].

Attack on Virtual Machines and their JIT Engines



JIT Spraying [4] forces the JIT compilation of a **XOR chain** to produce a set of constants in JITed memory then disrupts the execution flow by one byte to reveal the hidden shellcode.



JIT-ROP [5] creates the payload from available **gadgets** in memory, either already present or JIT compiled directly by the attacker. The execution flow is disrupted to a return chain to launch the shellcode.

Pharo as a Case Study Virtual Machine for Security

Why choose Pharo?

- **Migration in Process or Completed** to other ISAs (ARM v8).
- **Simpler** than heavily engineered Java or JavaScript Virtual Machines.
- **Complex enough** to be in commercial use and require the security aspect.
- **High-level Language Test Harness** of hundreds of *ISA-agnostic* tests.

A VM implementation for a new ISA runs through three main phases:

1. **Unit-test** a **simulation** of the VM in the development environment itself.
2. **Emulate** the whole system on an **architecture emulator** (QEMU/Unicorn).
3. **Execute** the system on the **real hardware**.

Objectives

- Port the Pharo VM to the RISC-V ISA.
- Replay well-known attacks in a controlled environment.
- Design enclave behaviour on critical components using Keystone.
- Design instructions to handle isolation.
- Test the implementation in hardware (Beagle-V, CVA6).

Open Questions

- Are the attacks replayable on RISC-V?
- What defines a pertinent instruction for JIT engines?

References

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[2] T. Park, K. Dhondt, D. Gens, Y. Na, S. Volckaert, and M. Franz, "Nojitsu: Locking down javascript engines," in *Symposium on Network and Distributed System Security (NDSS)*, 2020.

[3] T. Frassetto, D. Gens, C. Liebchen, and A.-R. Sadeghi, "Jitguard: hardening just-in-time compilers with SGX," in *Proceedings of the 2017 ACM SIGSAC Conference on Computer and Communications Security*, 2017, pp. 2405–2419.

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[5] K. Z. Snow, F. Monrose, L. Davi, A. Dmitrienko, C. Liebchen, and A.-R. Sadeghi, "Just-in-time code reuse: On the effectiveness of fine-grained address space layout randomization," in *2013 IEEE Symposium on Security and Privacy*. IEEE, 2013, pp. 574–588.

At a glance

- **Problem:** JIT engines are powerful but vulnerable pieces of software.
- **Approach:** involving the ISA in a high-level component provides more security guarantees.
- **Implementation:** Pharo VM on RISC-V adding instruction extensions and enclave support.

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