

Secure Calling Convention with Uninitialized Capabilities

Sander Huyghebaert

Promotor: Prof. Dr. Dominique Devriese

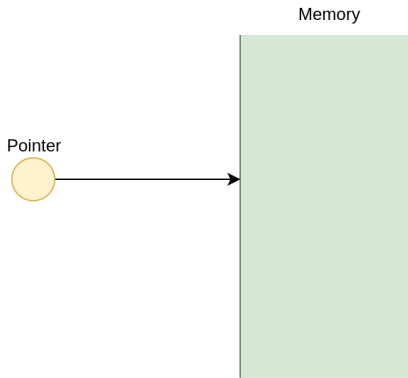
Supervisor: Thomas Van Strydonck

Supervisor: Dr. Steven Keuchel

OUTLINE

1. Introduction
2. Uninitialized Capabilities
3. Secure Calling Convention
4. Evaluation
5. Future Work
6. Conclusions

POINTERS



- ▶ No Bounds
- ▶ No Permissions

CALLING CONVENTION WITH POINTERS

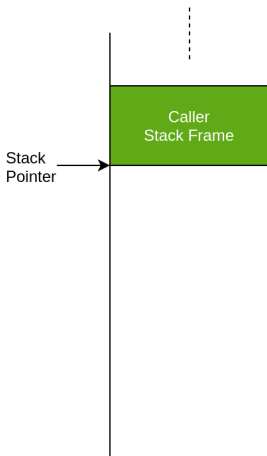


Figure: Stack at some point of a program

CALLING CONVENTION WITH POINTERS

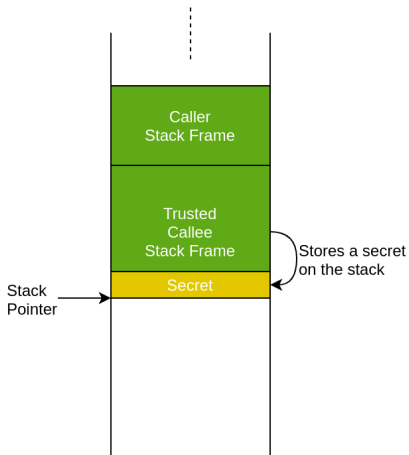


Figure: Stack after calling a function

CALLING CONVENTION WITH POINTERS

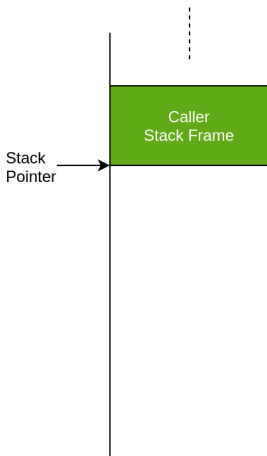


Figure: Callee returns

CALLING CONVENTION WITH POINTERS

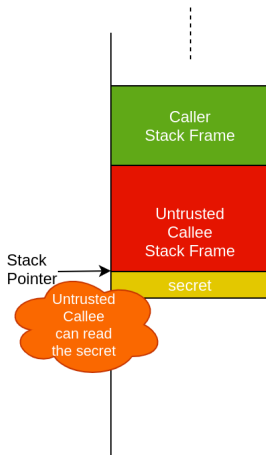


Figure: Caller invokes untrusted function

CAPABILITY MACHINES

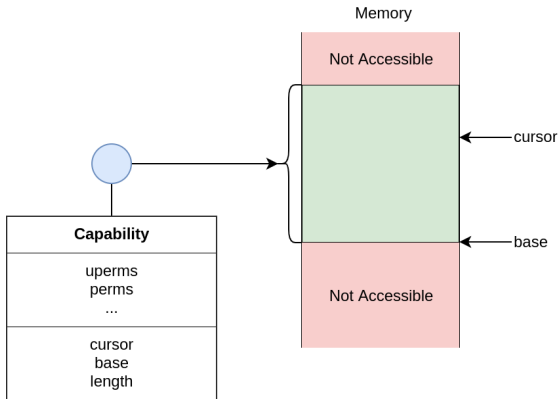


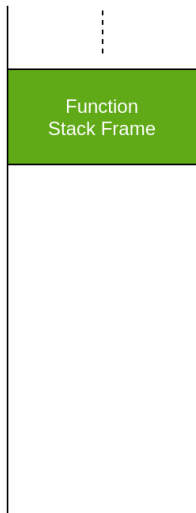
Figure: Capability for a region of memory

- Bounds
- Permissions

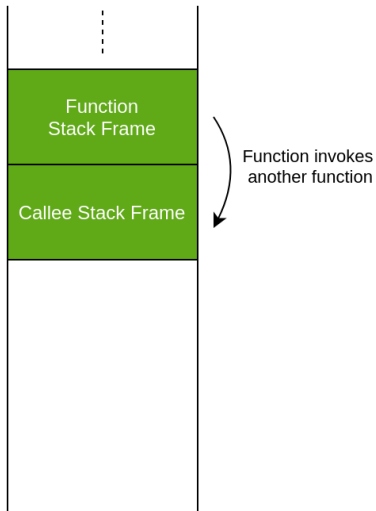
- ▶ Capability extension to Instruction Set Architectures
- ▶ Hardware implementation for CHERI-MIPS
- ▶ Backwards compatibility
- ▶ Software stack
 - ▶ CLang/LLVM, CHERI BSD, QEMU Emulator

- ▶ Secure Calling Convention with Local Capabilities
 - ▶ Skorstengaard et al. (2018)
 - ▶ Enforces Well-Bracketed Control Flow (WBCF) and Local State Encapsulation (LSE)
 - ▶ Clearing Requirement
- ▶ Secure Calling Convention With Linear Capabilities
 - ▶ Skorstengaard et al. (2019)
 - ▶ Enforces WBCF and LSE
 - ▶ Difficult to implement in hardware

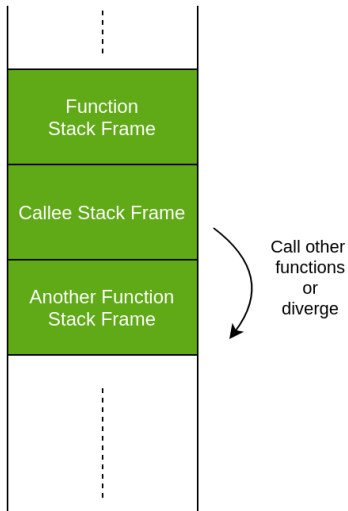
WELL-BRACKETED CONTROL FLOW



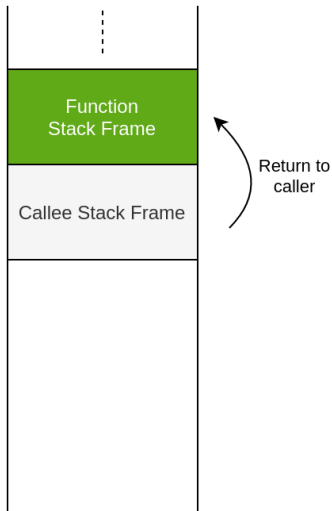
WELL-BRACKETED CONTROL FLOW



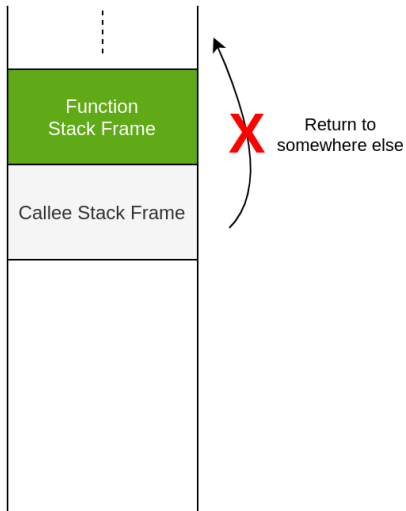
WELL-BRACKETED CONTROL FLOW



WELL-BRACKETED CONTROL FLOW



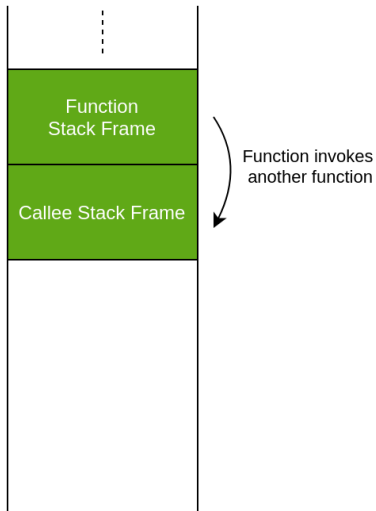
WELL-BRACKETED CONTROL FLOW



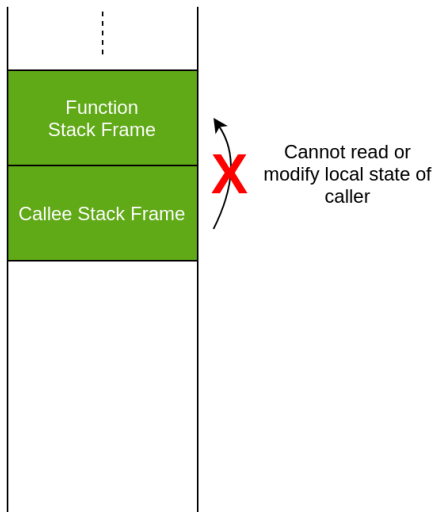
LOCAL STATE ENCAPSULATION



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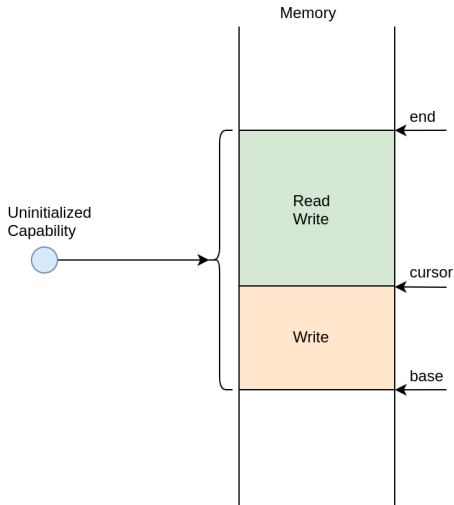
- ▶ "Efficient and Provable Local Capability Revocation using Uninitialized Capabilities"
- ▶ Collaboration between VUB and Aarhus University (Denmark)
- ▶ Thesis Results Part of Paper

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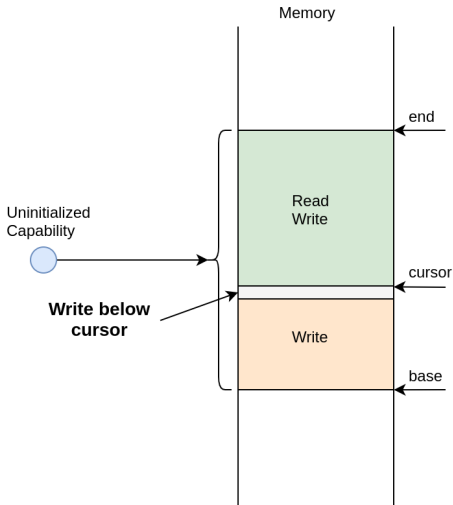
UNINITIALIZED CAPABILITIES

CONCEPT



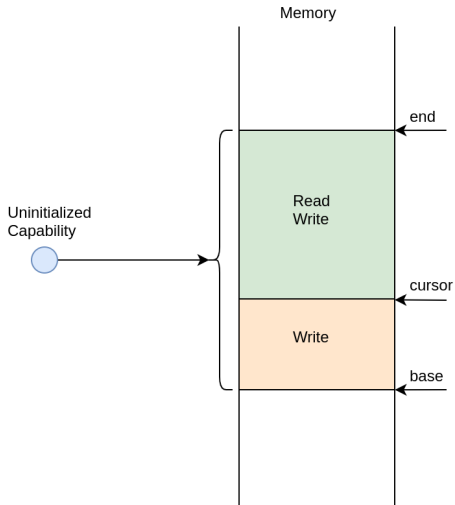
UNINITIALIZED CAPABILITIES

CONCEPT



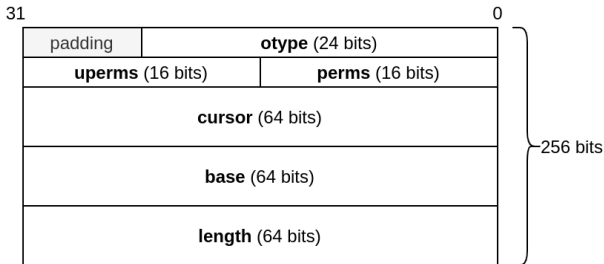
UNINITIALIZED CAPABILITIES

CONCEPT



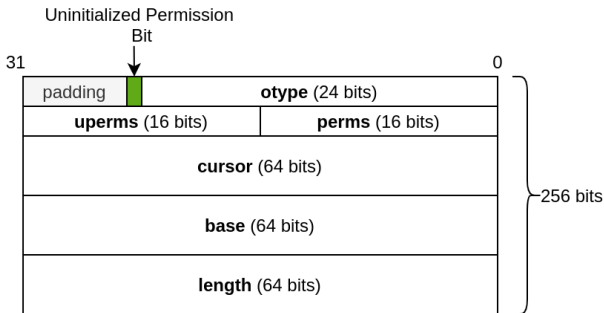
UNINITIALIZED CAPABILITIES

IMPLEMENTATION OVERVIEW: PERMISSION BIT



UNINITIALIZED CAPABILITIES

IMPLEMENTATION OVERVIEW: PERMISSION BIT



UNINITIALIZED CAPABILITIES

IMPLEMENTATION OVERVIEW: INSTRUCTION MODIFICATIONS

- ▶ Load Instructions
 - ▶ Uninitialized capabilities cannot load if *address* < *cursor*
 - ▶ CL[BHWD][U], CLC
- ▶ Instructions that modify the cursor
 - ▶ Only store right below cursor can lower the cursor of an uninitialized capability
 - ▶ CSetOffset, CIncOffset, CSetAddr, CAndAddr

UNINITIALIZED CAPABILITIES

IMPLEMENTATION OVERVIEW: NEW INSTRUCTIONS

- ▶ Uninitialized Permission Bit
 - ▶ Get, Set and Drop
- ▶ Uninitialized Store Instructions
- ▶ Shrink a Capability

OUTLINE

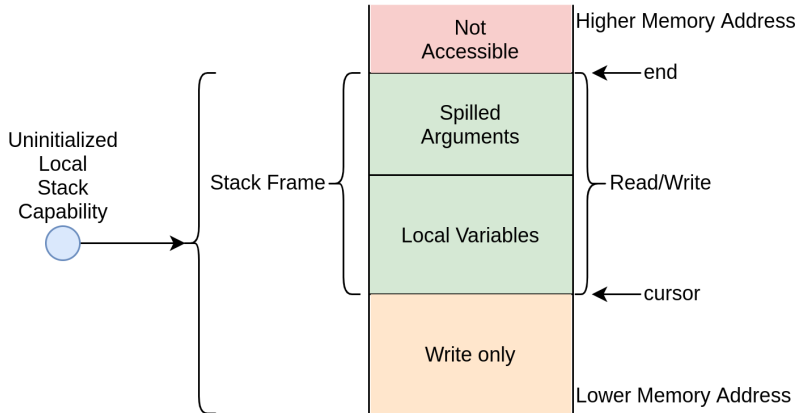
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SECURE CALLING CONVENTION

- ▶ Based on Calling Convention with Local Capabilities
 - ▶ Skorstengaard et al. (2018)
- ▶ Enforces WBCF
- ▶ Enforces LSE

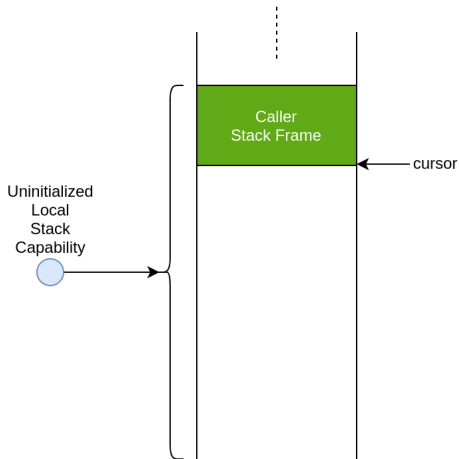
SECURE CALLING CONVENTION

STACK



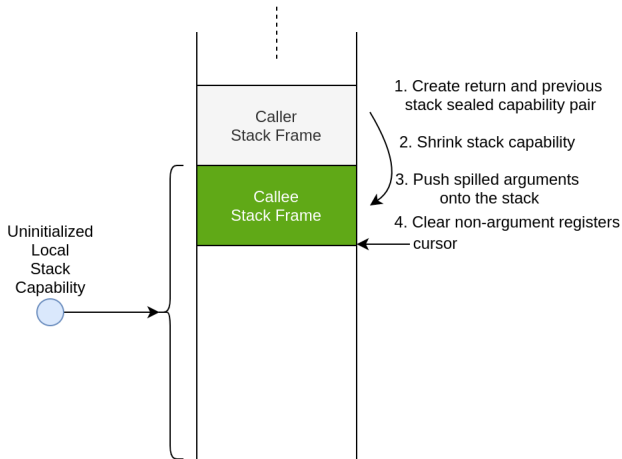
SECURE CALLING CONVENTION

INITIAL STACK



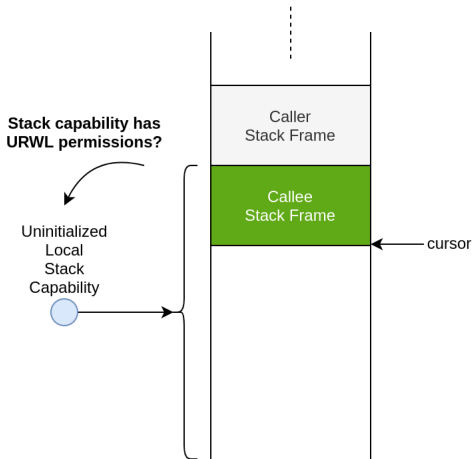
SECURE CALLING CONVENTION

FUNCTION INVOCATION



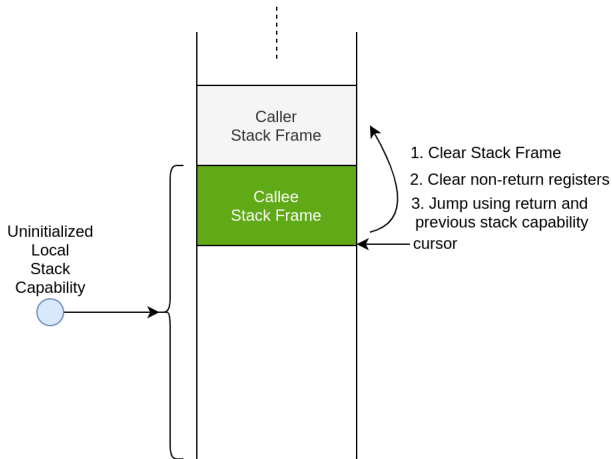
SECURE CALLING CONVENTION

FUNCTION PROLOGUE



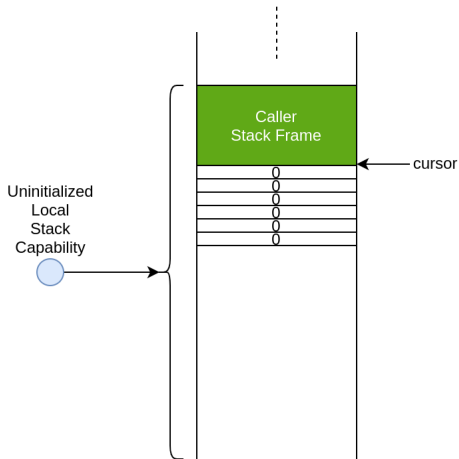
SECURE CALLING CONVENTION

FUNCTION EPILOGUE



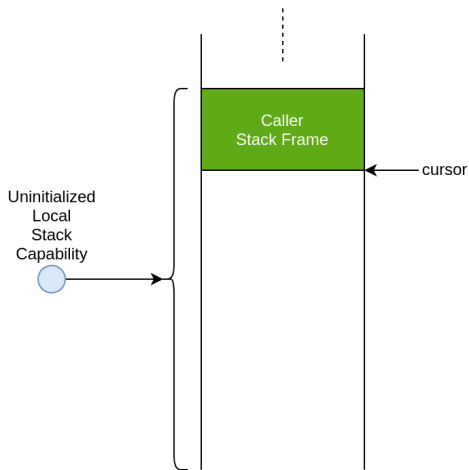
SECURE CALLING CONVENTION

FUNCTION EPILOGUE



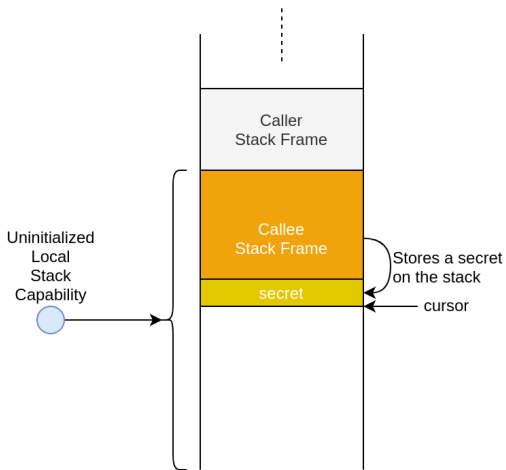
SECURE CALLING CONVENTION

EXAMPLE WITH ADVERSARY



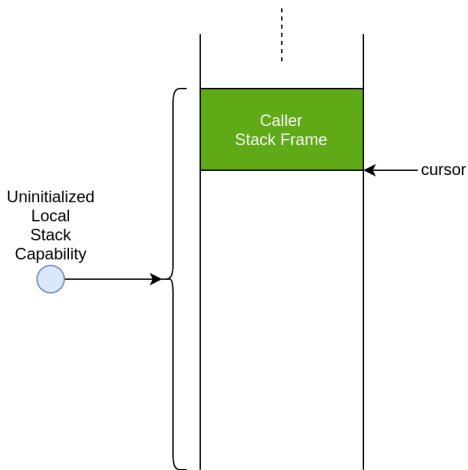
SECURE CALLING CONVENTION

EXAMPLE WITH ADVERSARY



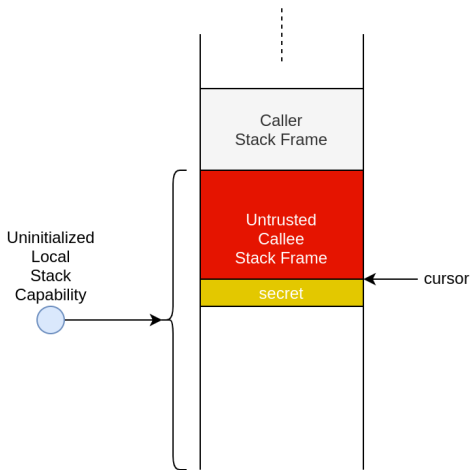
SECURE CALLING CONVENTION

EXAMPLE WITH ADVERSARY



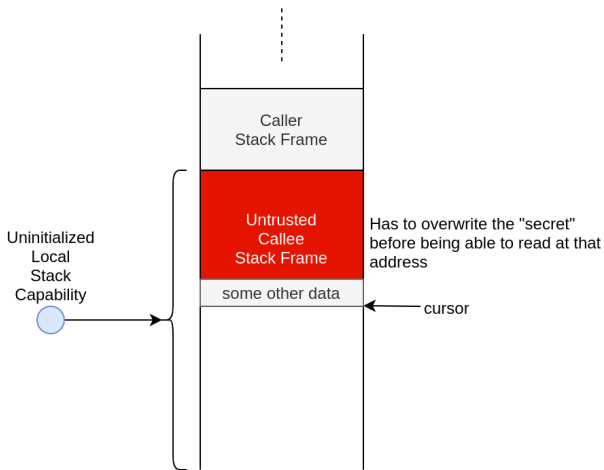
SECURE CALLING CONVENTION

EXAMPLE WITH ADVERSARY



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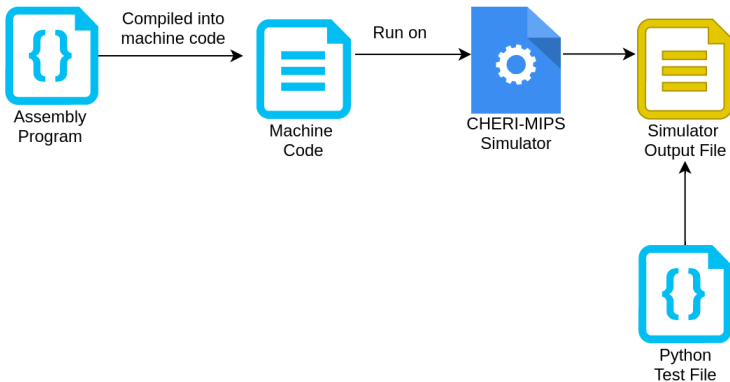
EVALUATION

ASSEMBLER

- ▶ LLVM Assembler
 - ▶ CHERI-MIPS Backend
- ▶ New instructions added

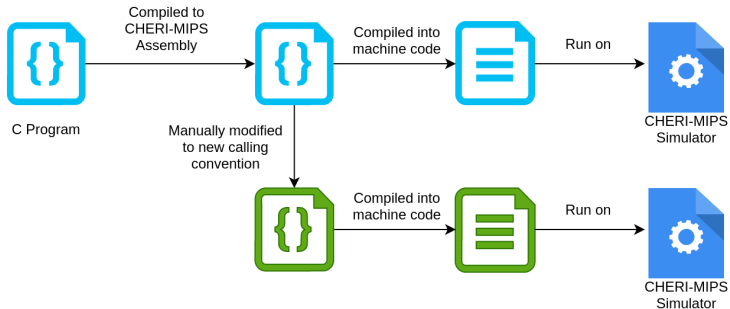
EVALUATION

UNIT TESTING INSTRUCTIONS



EVALUATION

CALLING CONVENTION



EVALUATION

EXPERIMENTS

- ▶ C Programs
 - ▶ Function calls
 - ▶ Arrays
 - ▶ Pointer arithmetic
- ▶ Semantics Preserved
- ▶ Measure execution time
- ▶ Number of instructions

EVALUATION

RESULTS

- ▶ Unit Tests Pass
- ▶ Semantics are preserved
- ▶ Overhead for **secure** calling convention
 - ▶ Stack frame clearing, depends on stack frame sizes
- ▶ Number of instructions doubles for **secure** calling convention

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FUTURE WORK

HARDWARE IMPLEMENTATION

- ▶ Should be possible
 - ▶ Uninitialized Capabilities only require one extra bit
 - ▶ New instructions similar to existing instructions
- ▶ Out of scope of thesis

FUTURE WORK

CLANG/LLVM

- ▶ Calling Convention currently not implemented in Clang/LLVM...
- ▶ ... but exploration of Clang/LLVM compiler for calling convention provided in thesis

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CONCLUSIONS

- ▶ Uninitialized Capabilities
 - ▶ Semantics
 - ▶ ISA Extension
 - ▶ Instantiated for CHERI-MIPS
- ▶ Calling Convention
 - ▶ Enforces WBCF and LSE
 - ▶ Security comes at a cost (overhead)
- ▶ Exploration of Clang/LLVM compiler
 - ▶ To implement new calling convention