Secure Calling Convention with Uninitialized Capabilities

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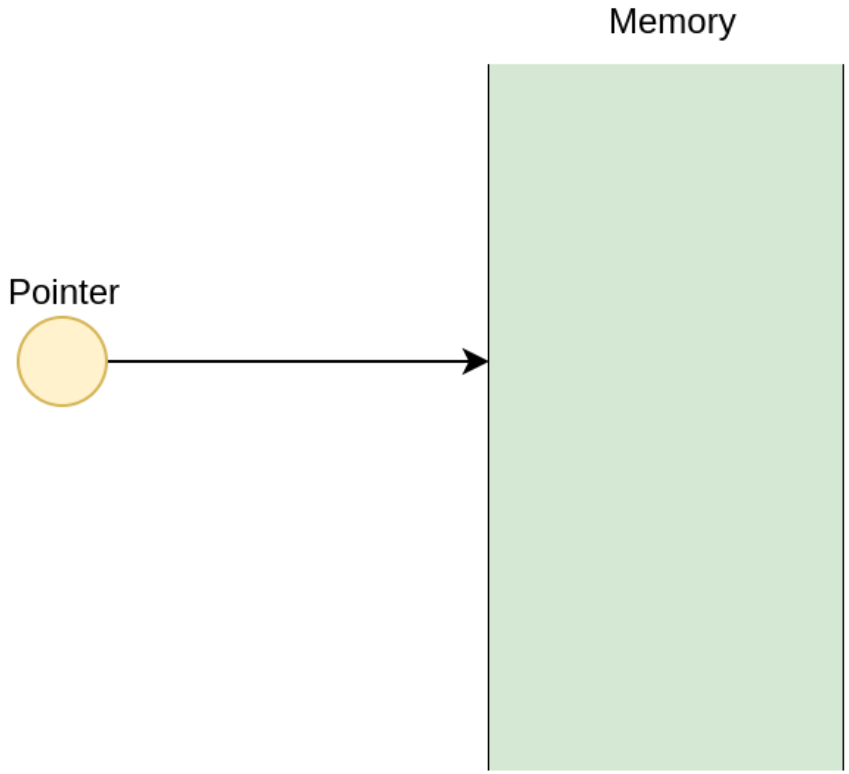
Supervisor: Thomas Van Strydonck
Supervisor: Dr. Steven Keuchel

VUB VRIJE UNIVERSITEIT BRUSSEL

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

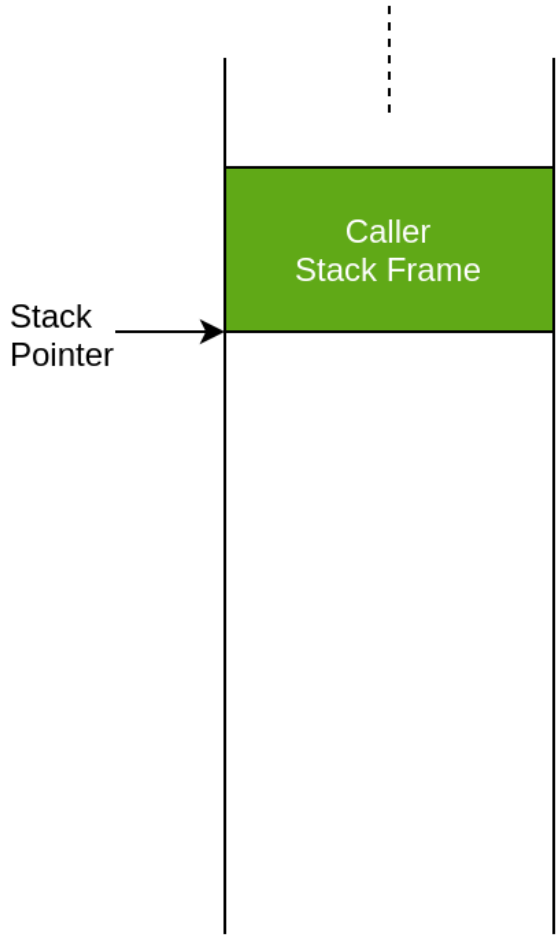


Figure: Stack at some point of a program

CALLING CONVENTION WITH POINTERS

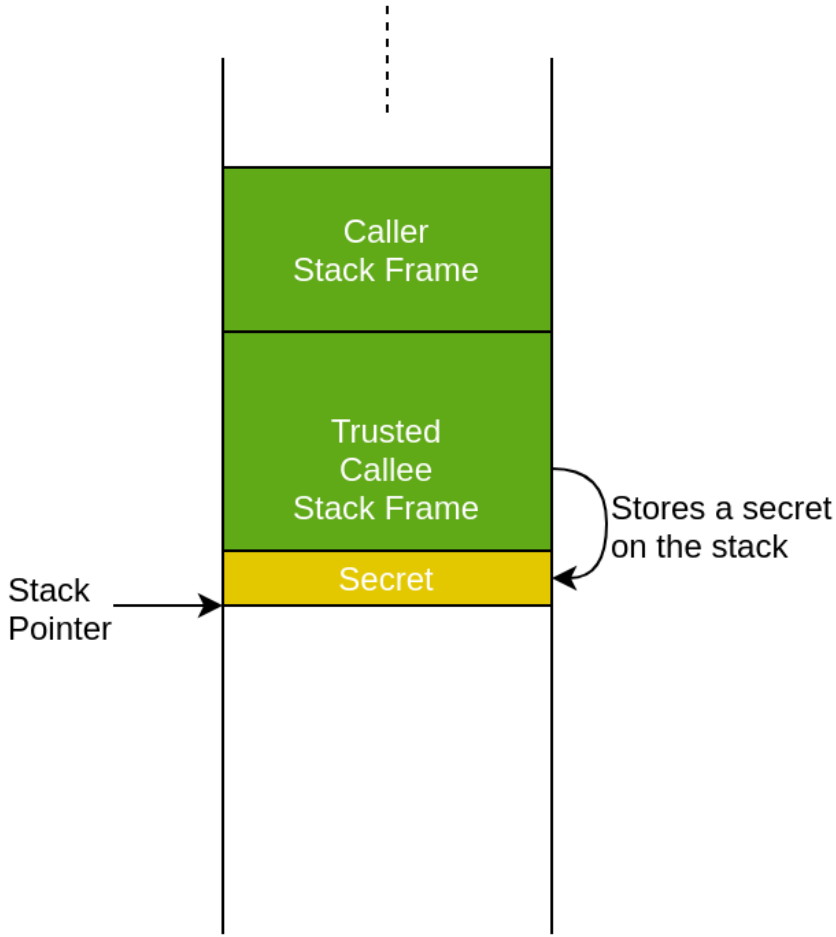


Figure: Stack after calling a function

CALLING CONVENTION WITH POINTERS

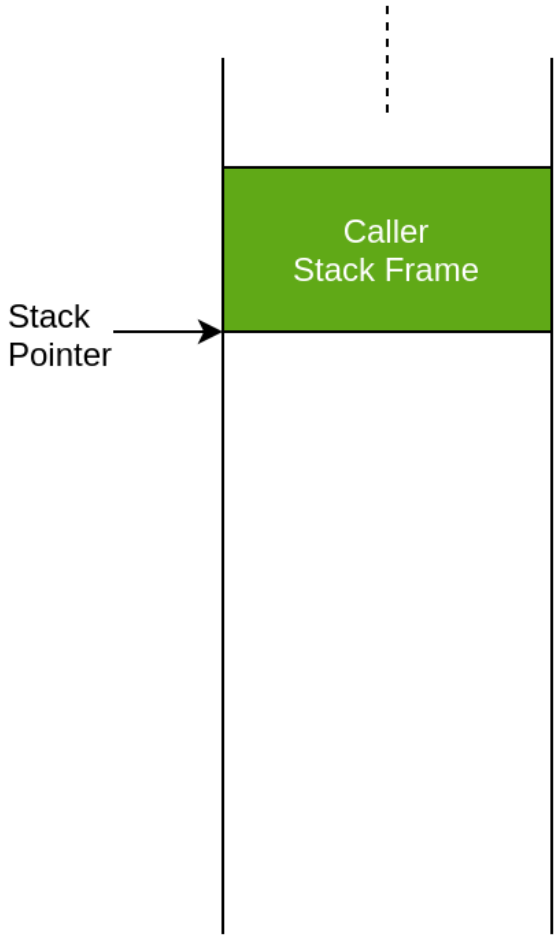


Figure: Callee returns

CALLING CONVENTION WITH POINTERS

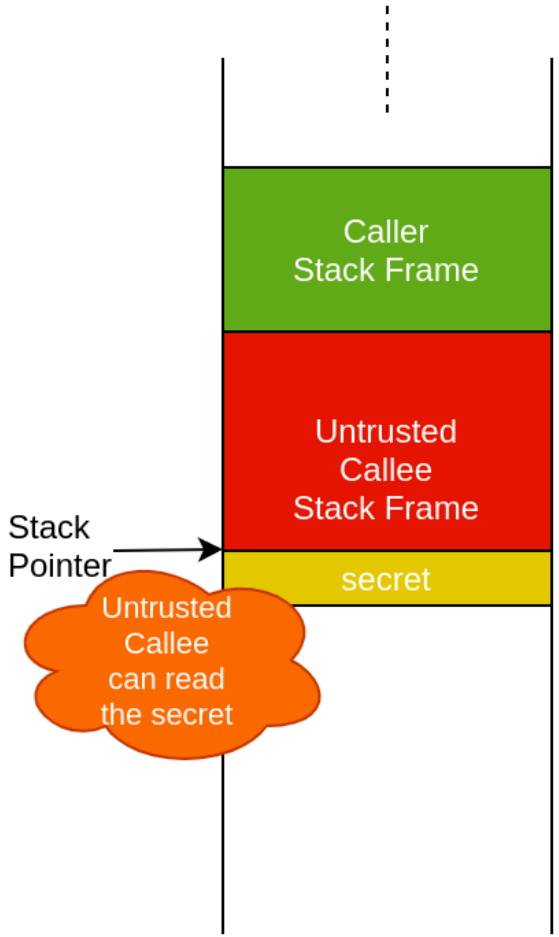


Figure: Caller invokes untrusted function

CAPABILITY MACHINES

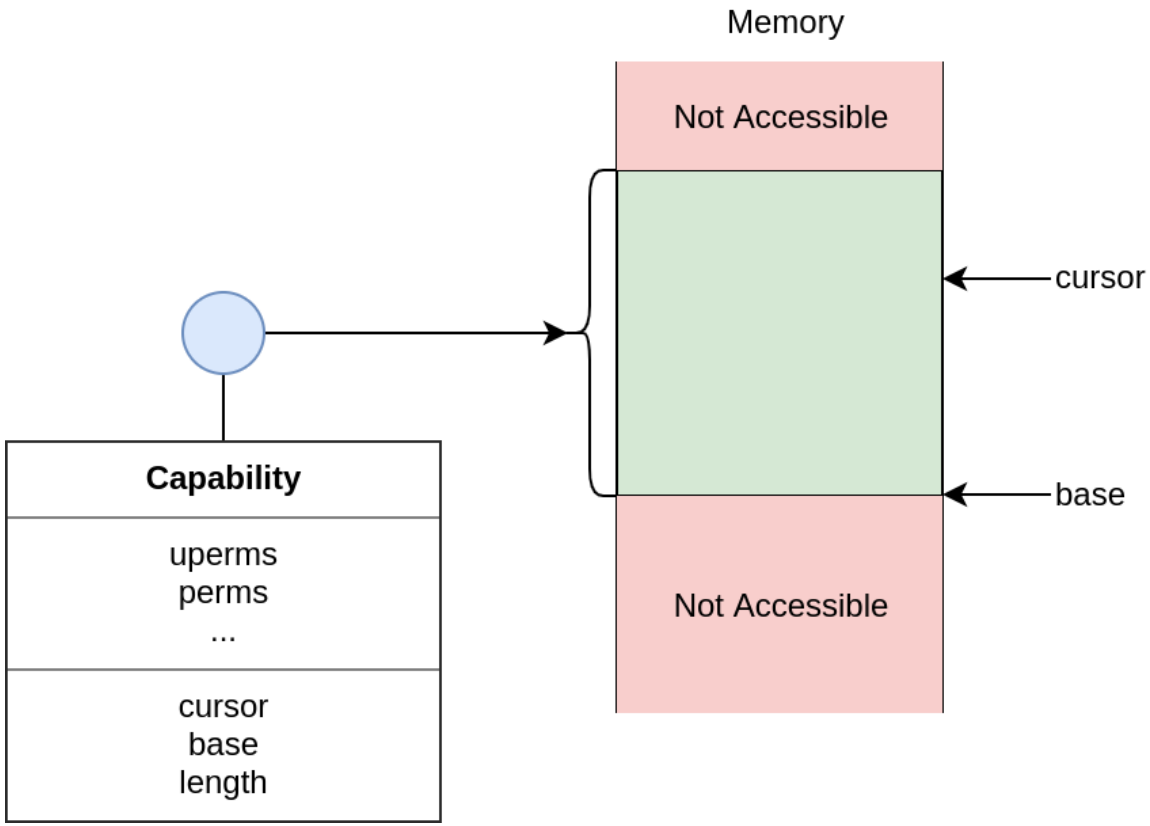


Figure: Capability for a region of memory

- Bounds
- Permissions

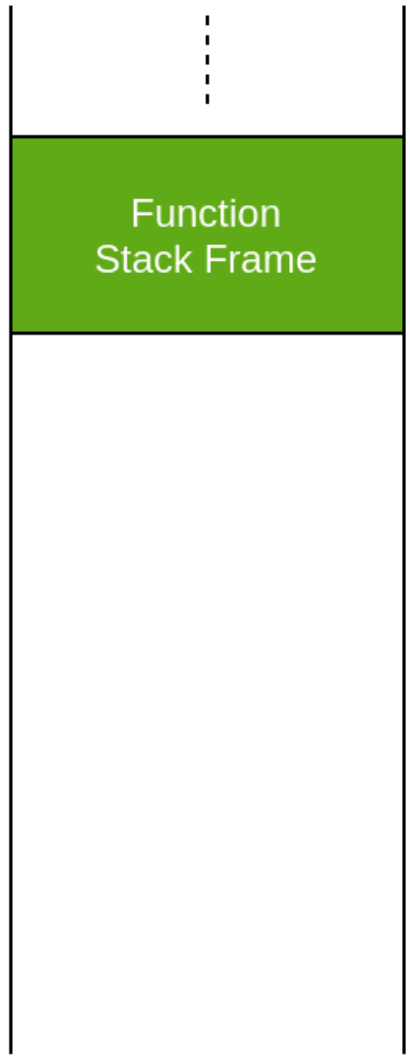
CHERI

- Capability extension to Instruction Set Architectures
- Hardware implementation
  - Capability instructions
- Backwards compatibility
- Software stack
  - CLang/LLVM, CHERIBSD, QEMU Emulator

RELATED WORK

- 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)
  - Difficult to implement in hardware

WELL-BRACKETED CONTROL FLOW



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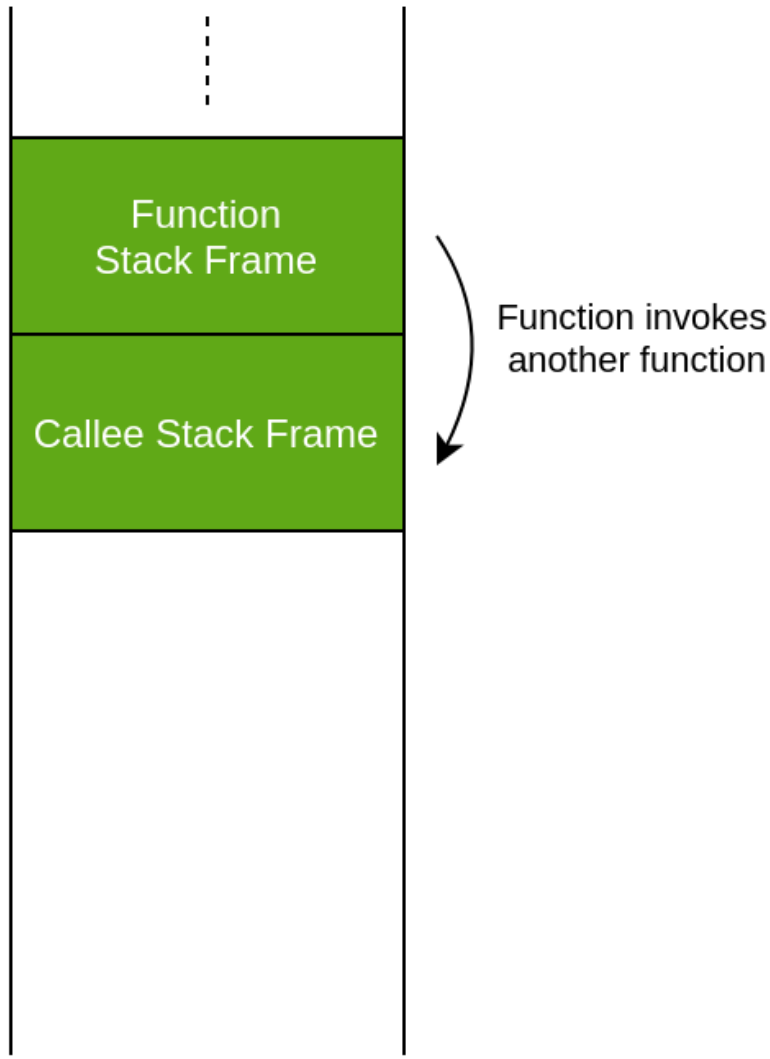

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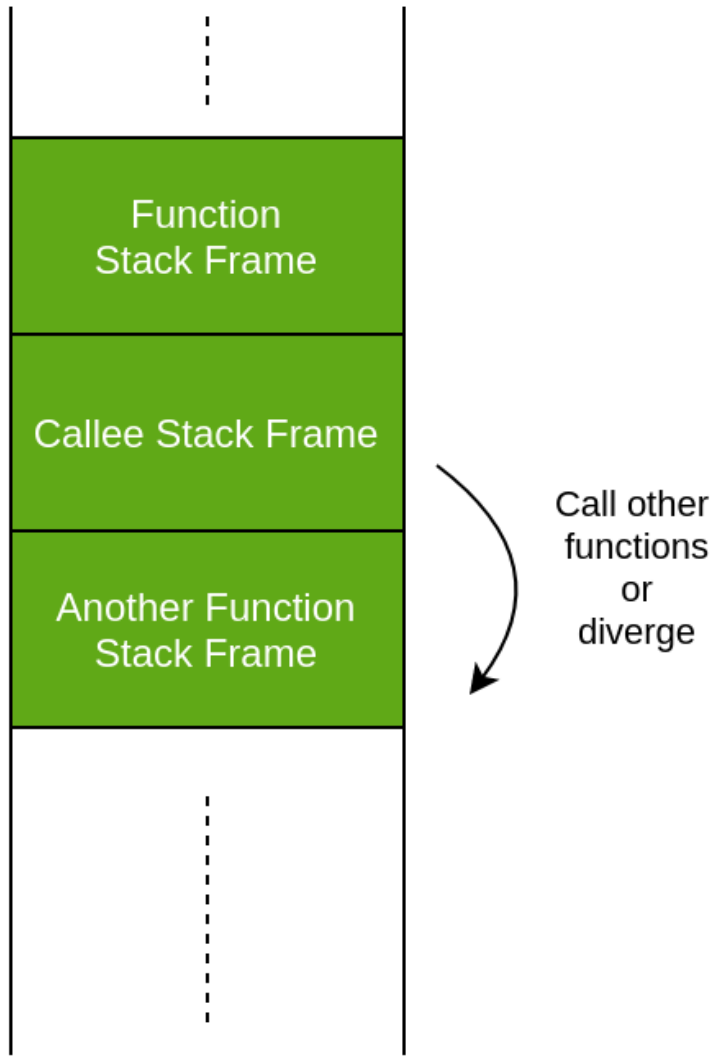

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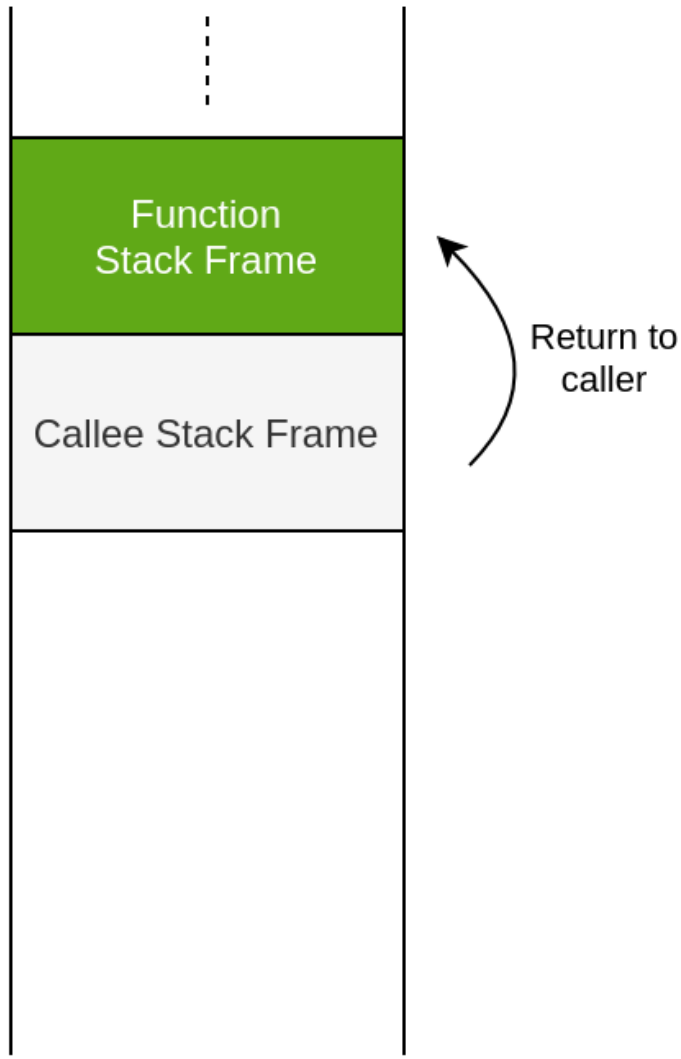

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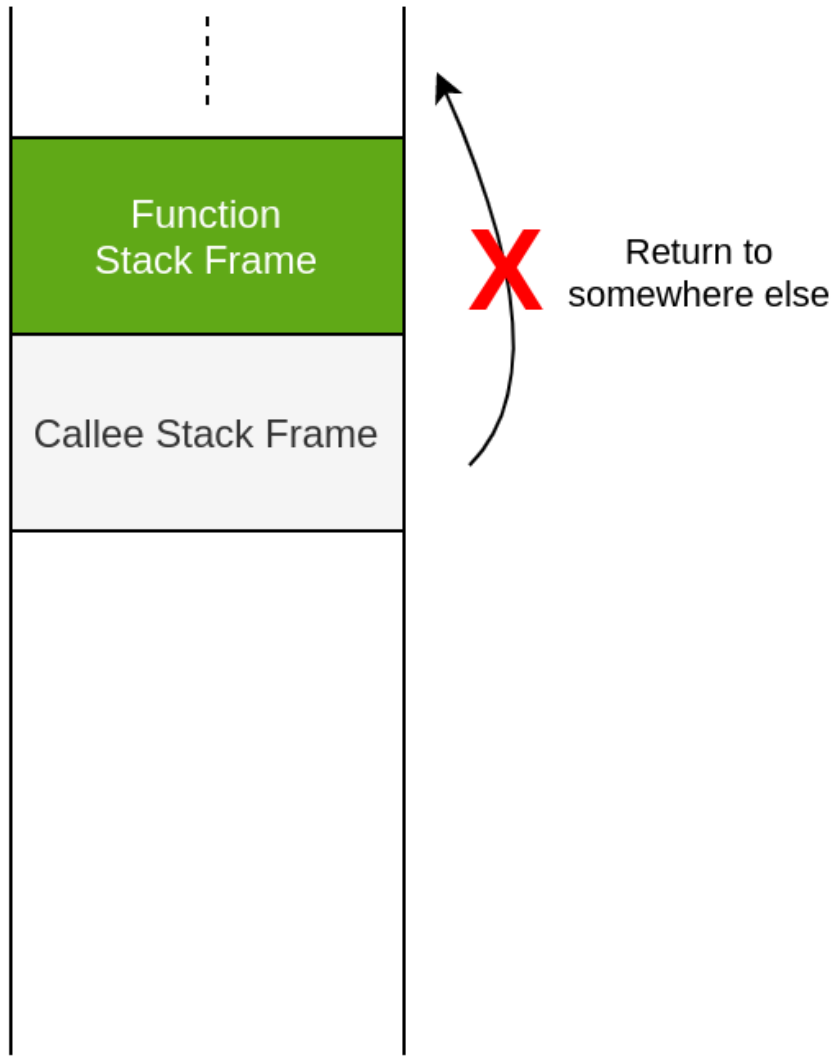
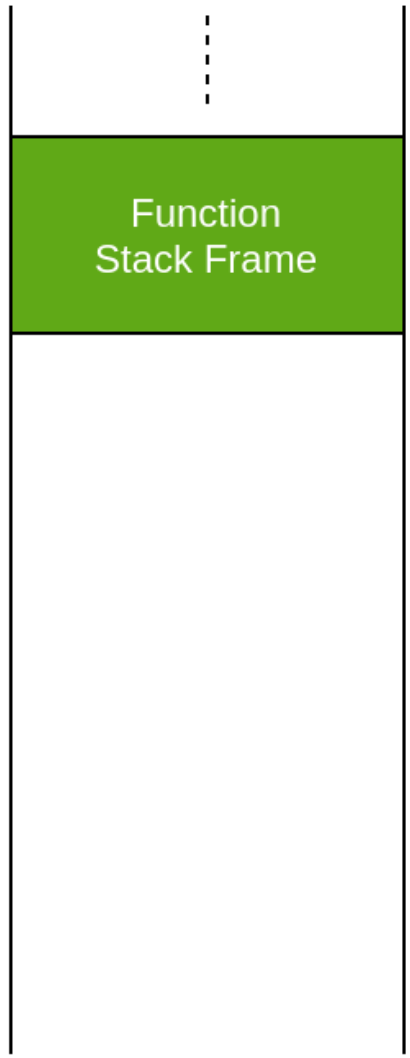


LOCAL STATE ENCAPSULATION



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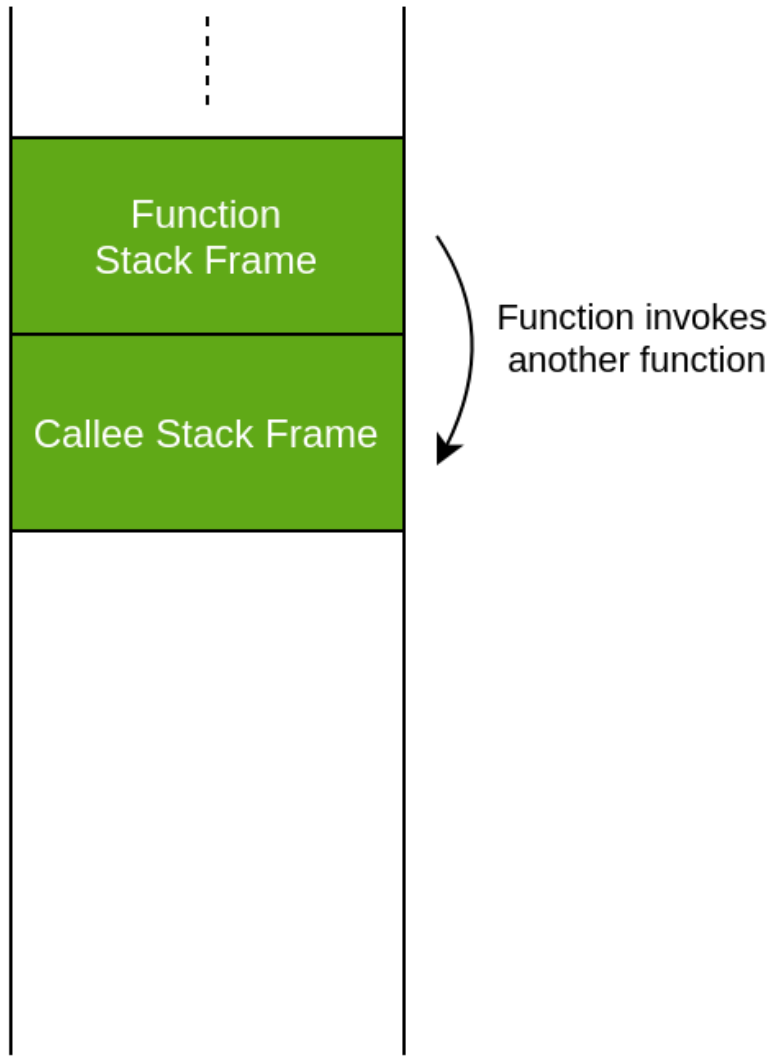

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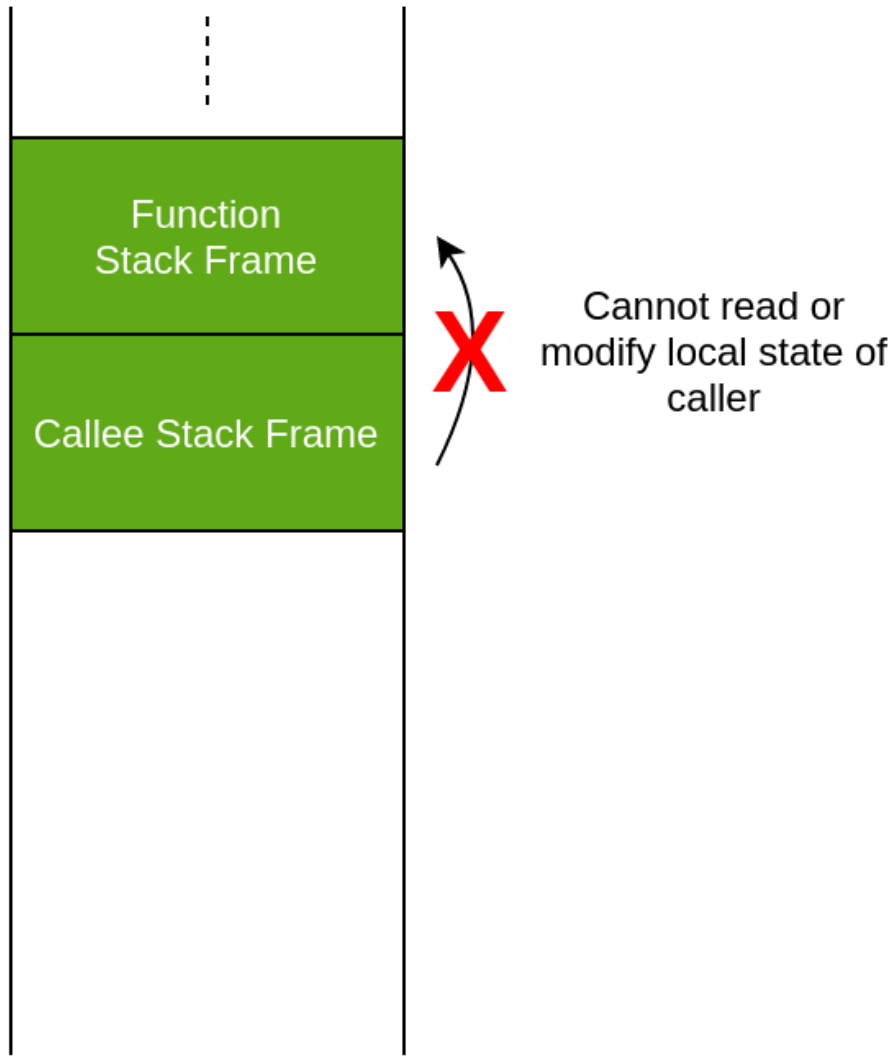

POPL21 PAPER

- "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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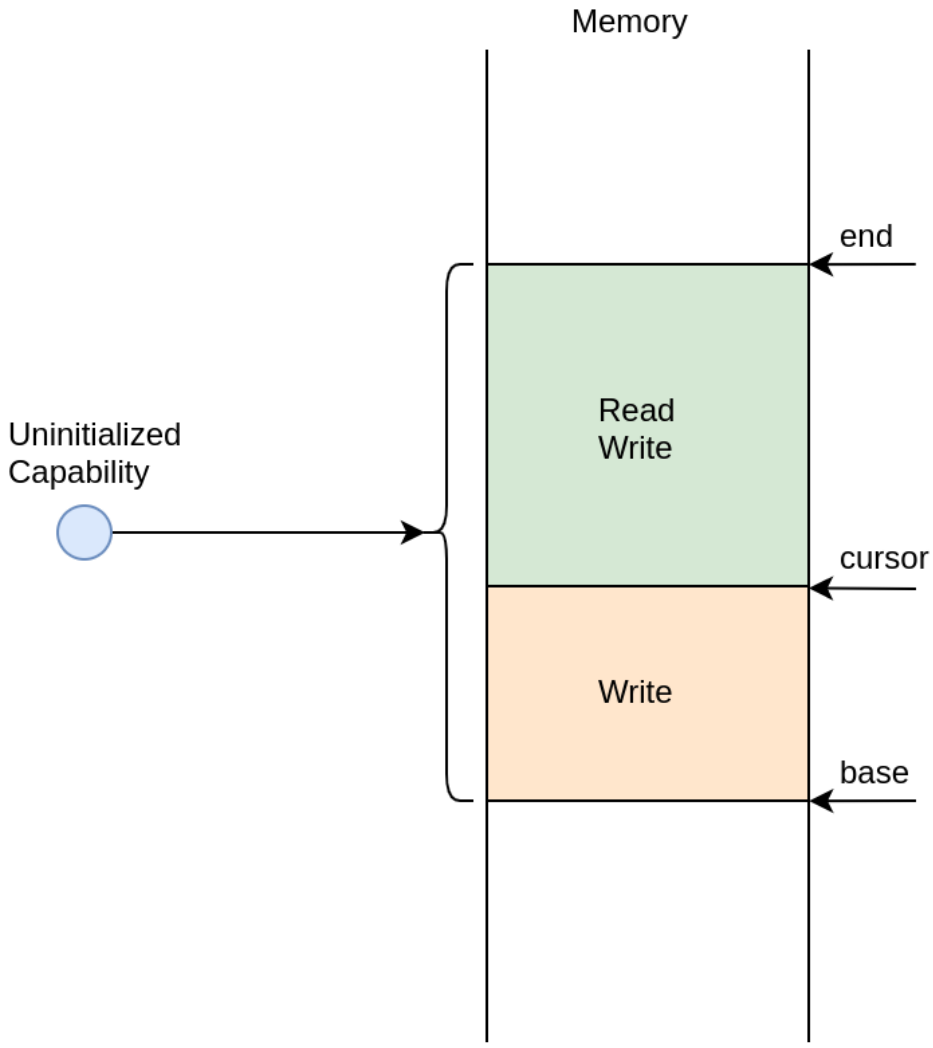
UNINITIALIZED CAPABILITIES

CONCEPT



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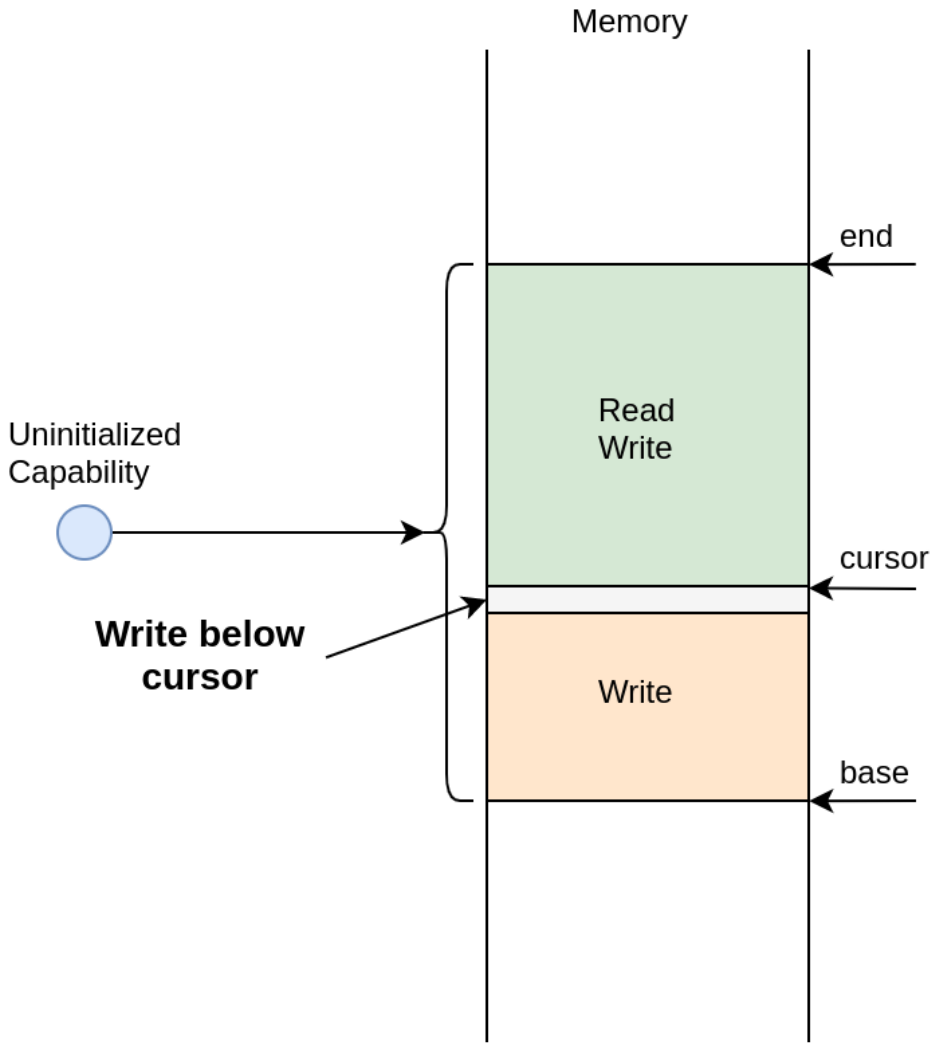

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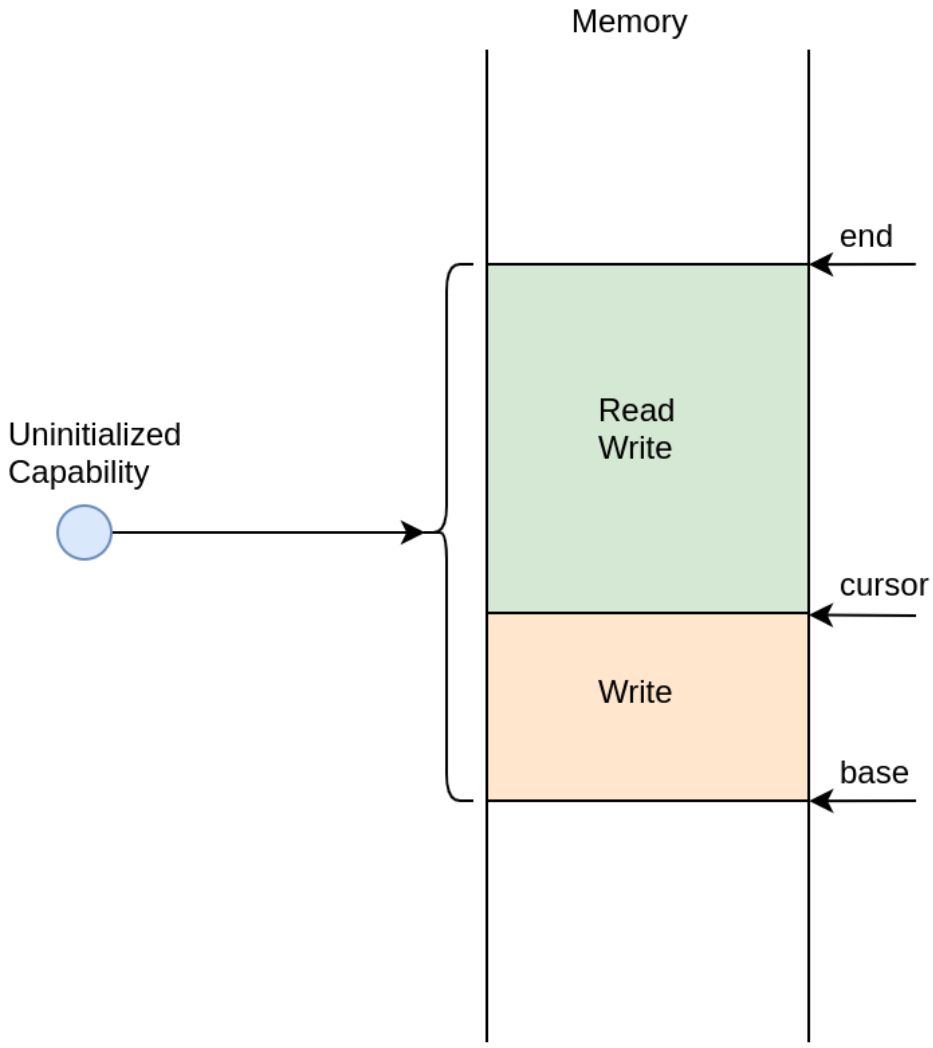
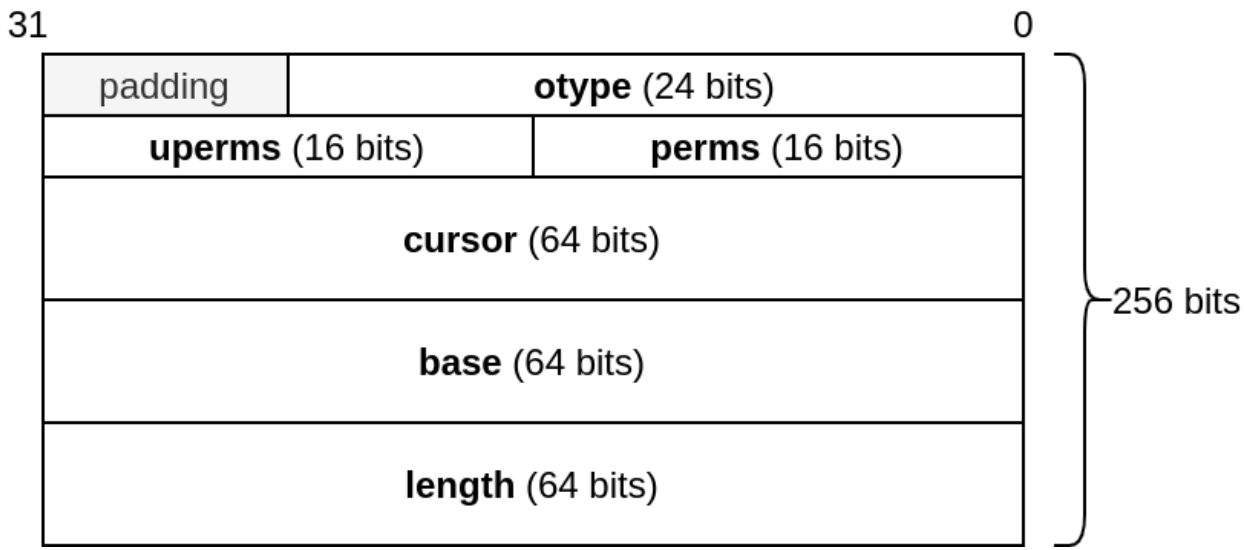


UNINITIALIZED CAPABILITIES

IMPLEMENTATION OVERVIEW: PERMISSION BIT



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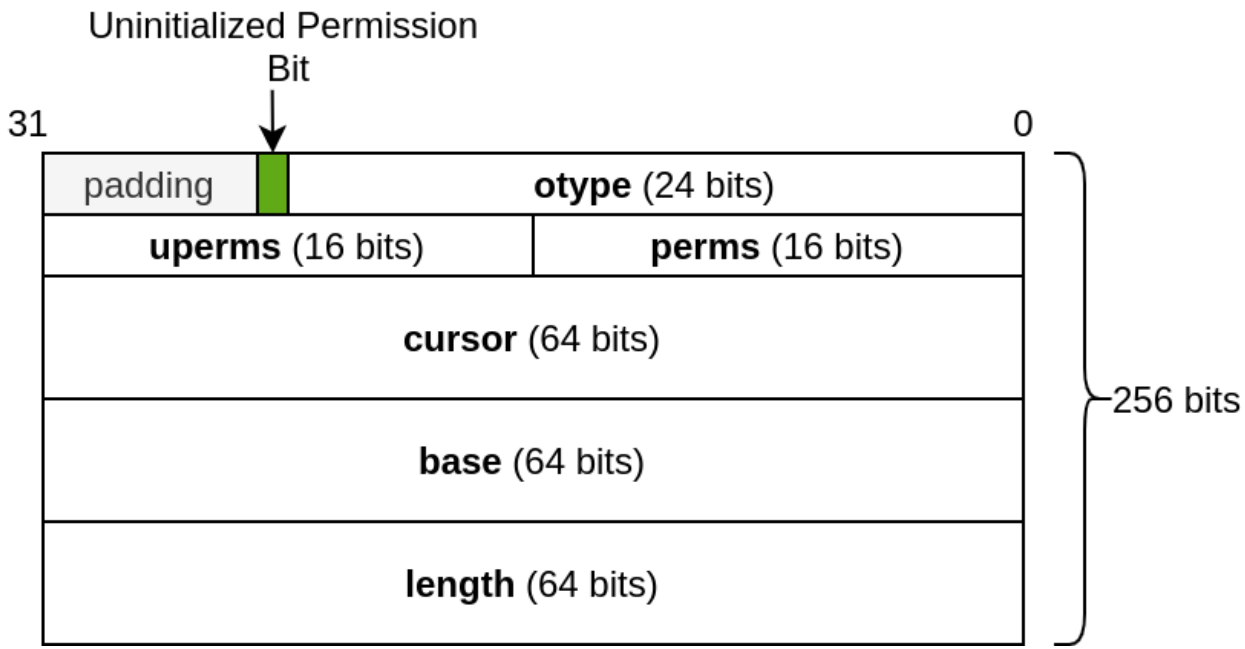

UNINITIALIZED CAPABILITIES

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 modify 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

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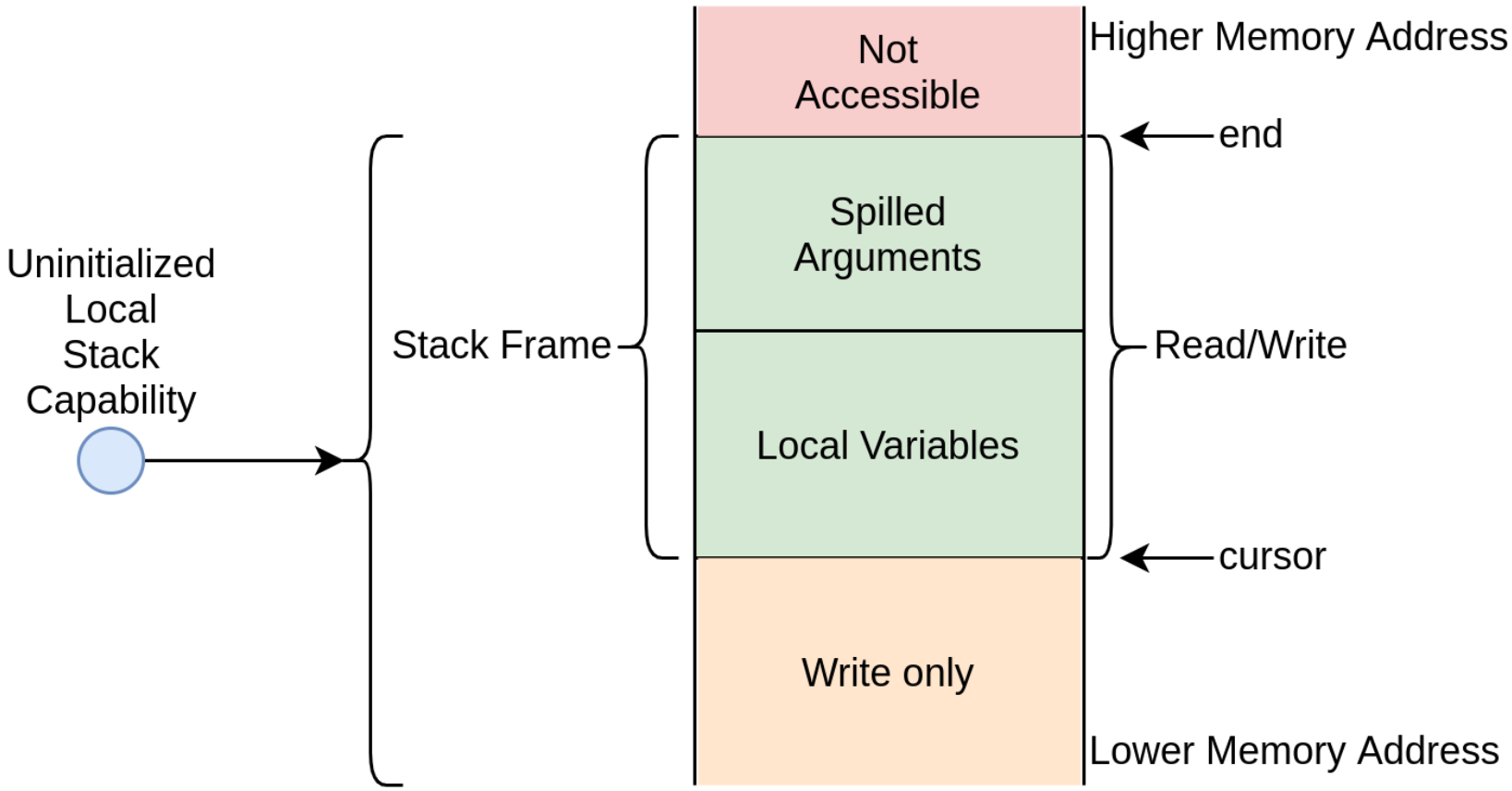
SECURE CALLING CONVENTION

- Based on Calling Convention with Local Capabilities
  - Skorstengaard et al. (2018)
- Enforces Well-Bracketed Control Flow (WBCF)
- Enforces Local State Encapsulation

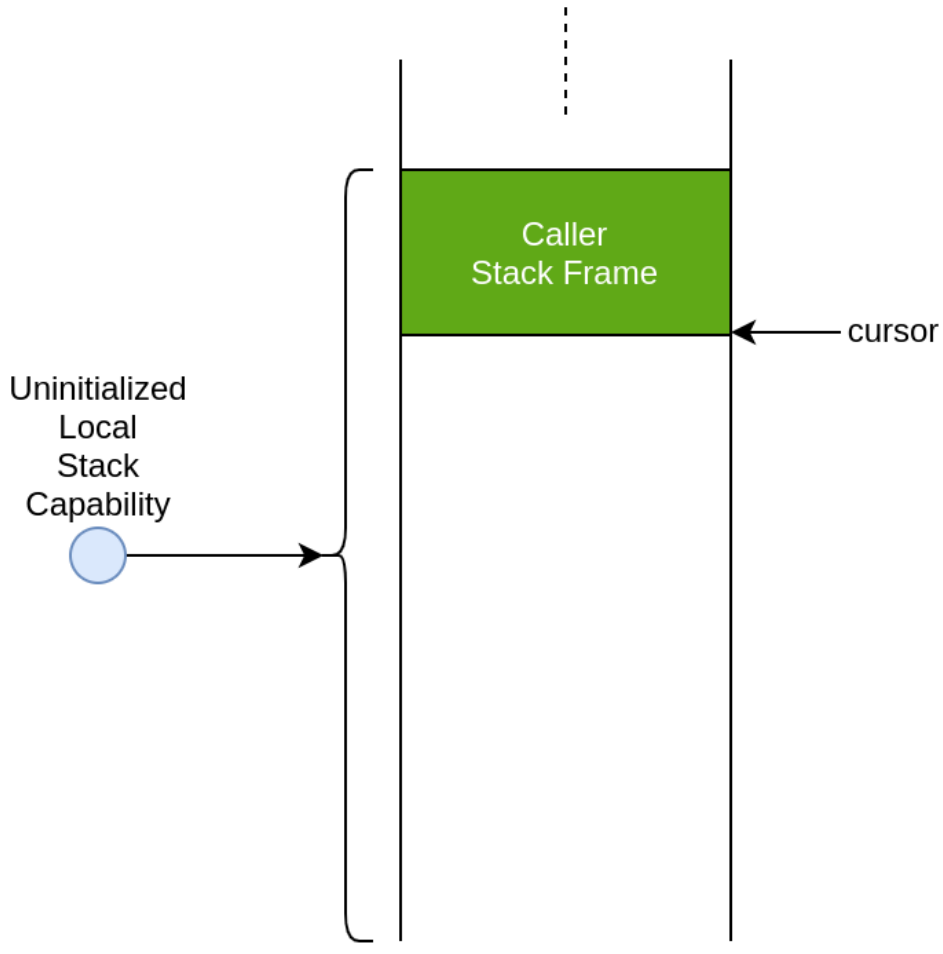
SECURE CALLING CONVENTION

STACK



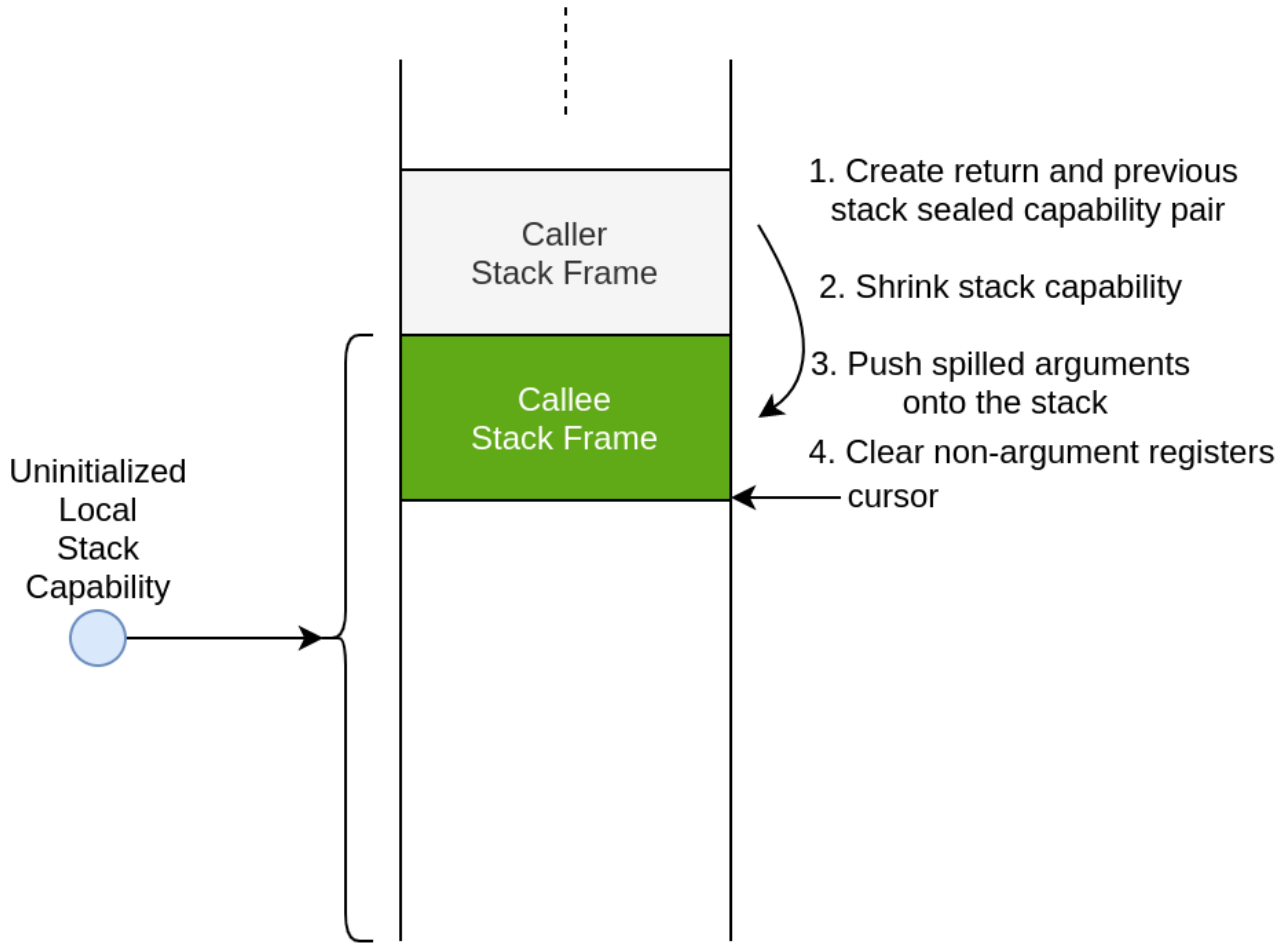
SECURE CALLING CONVENTION

INITIAL STACK



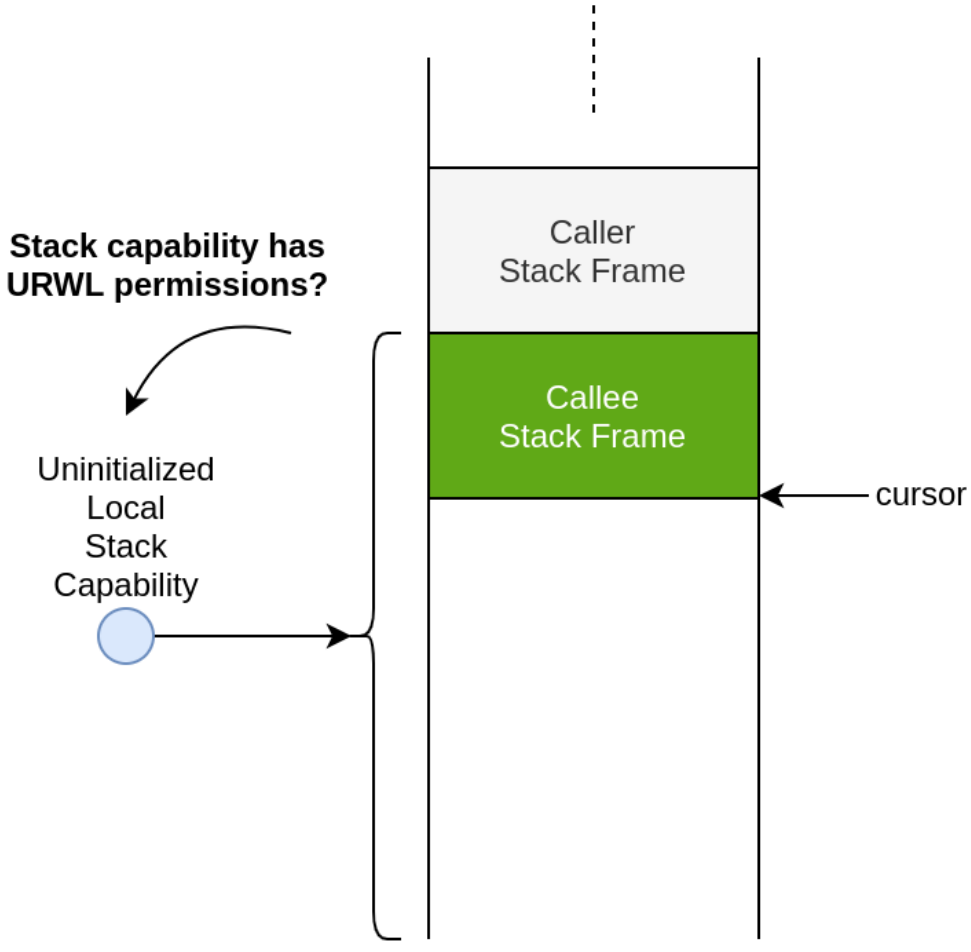
SECURE CALLING CONVENTION

FUNCTION INVOCATION



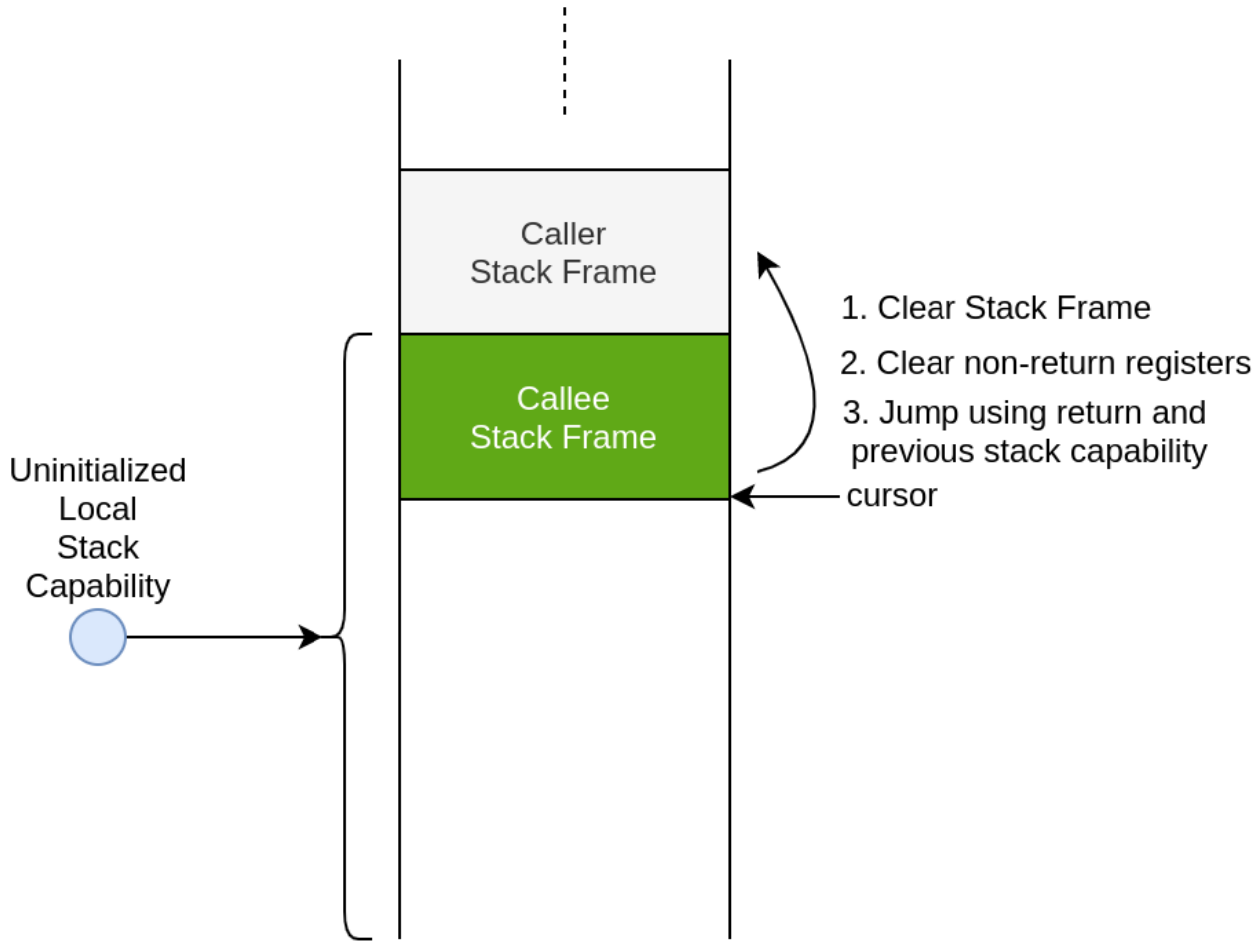
SECURE CALLING CONVENTION

FUNCTION PROLOGUE



SECURE CALLING CONVENTION

FUNCTION EPILOGUE



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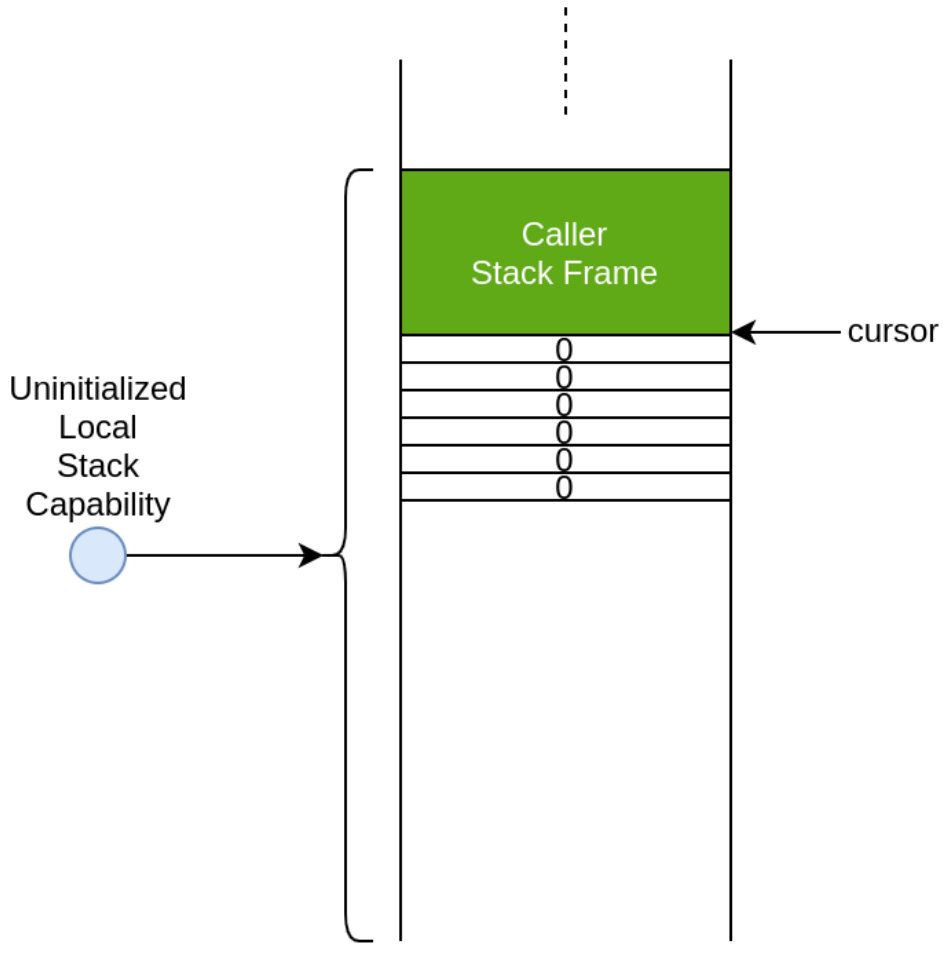
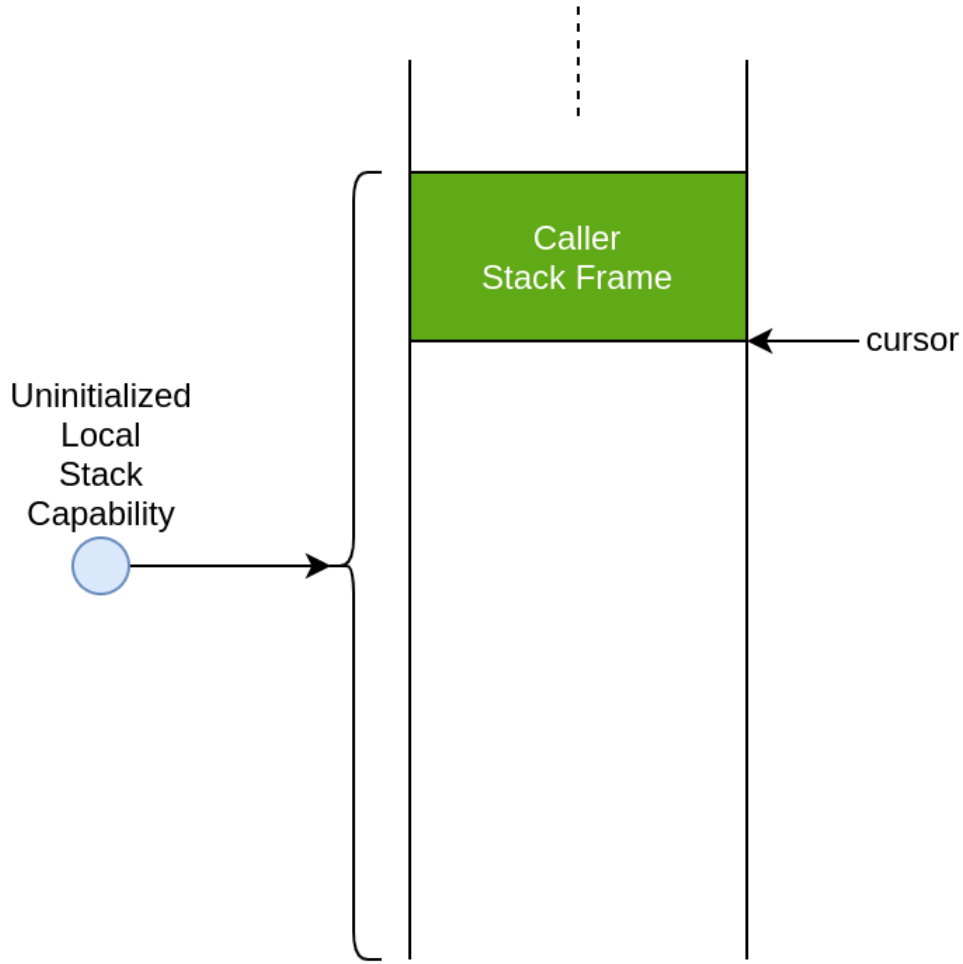


SECURE CALLING CONVENTION

EXAMPLE WITH ADVERSARY



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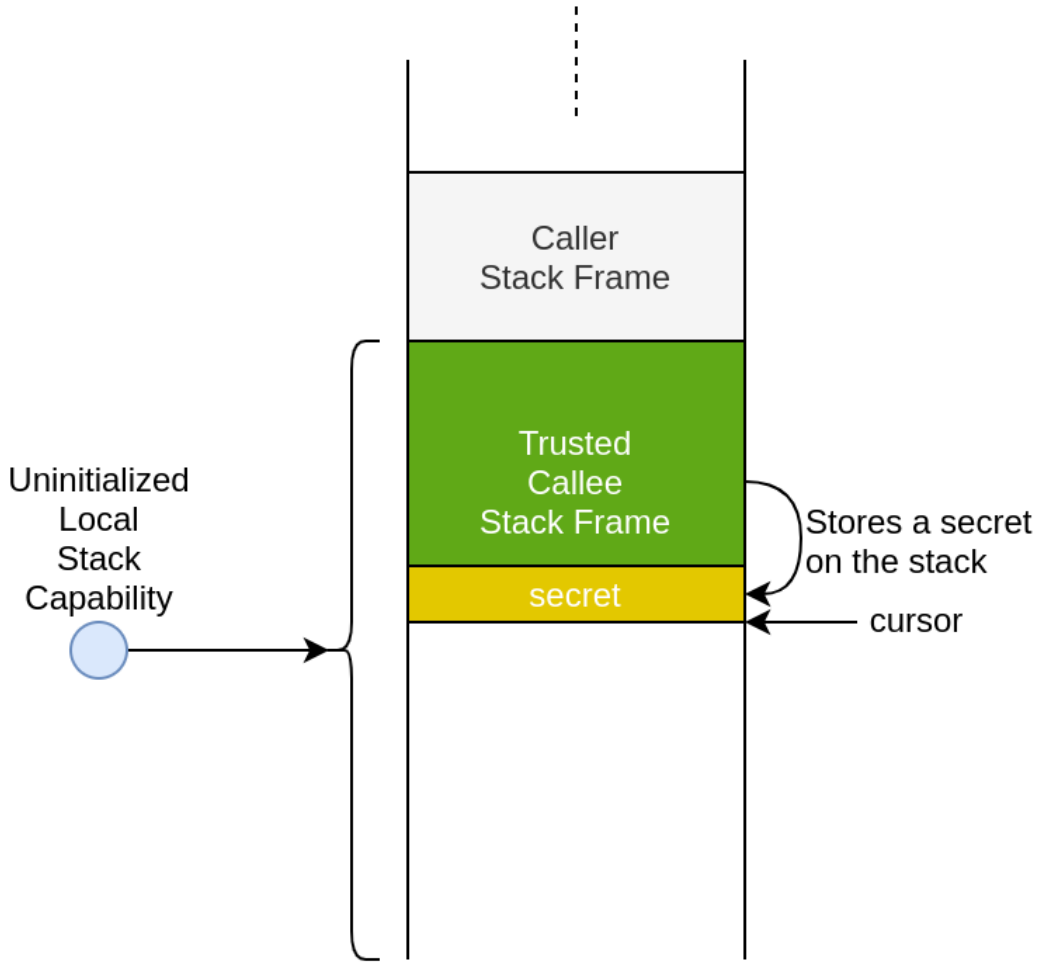

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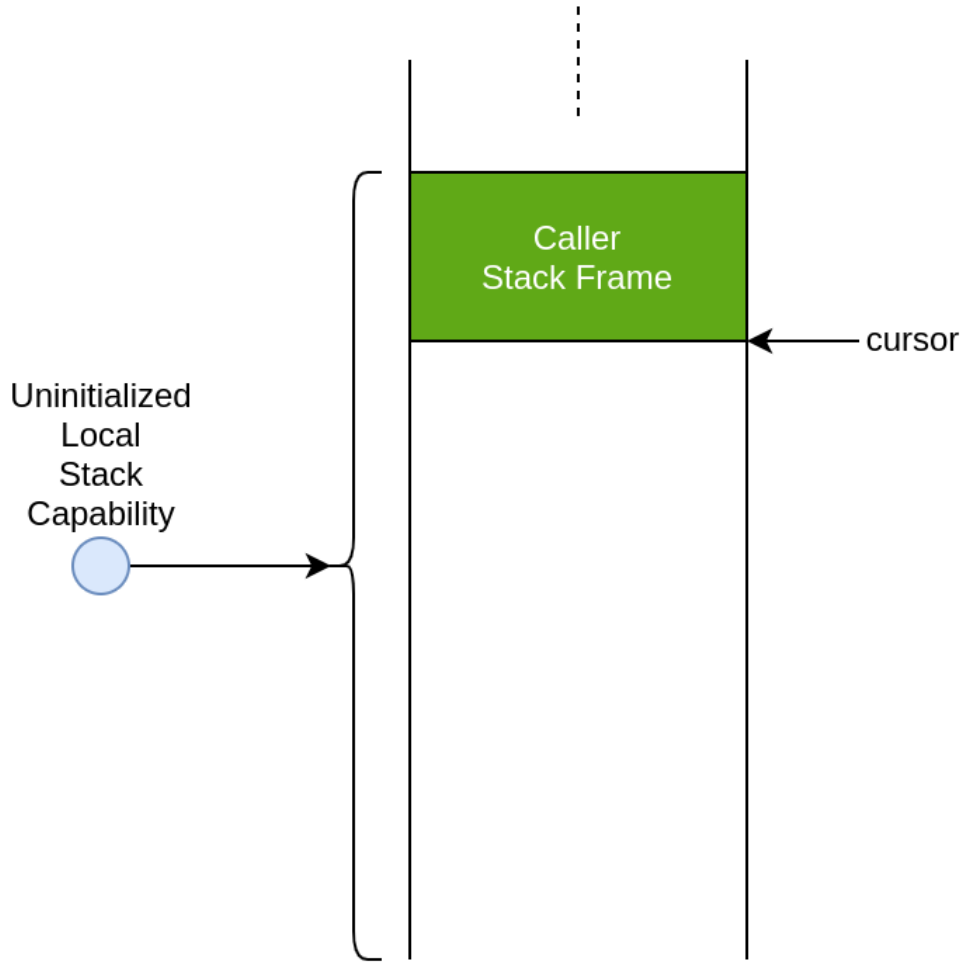

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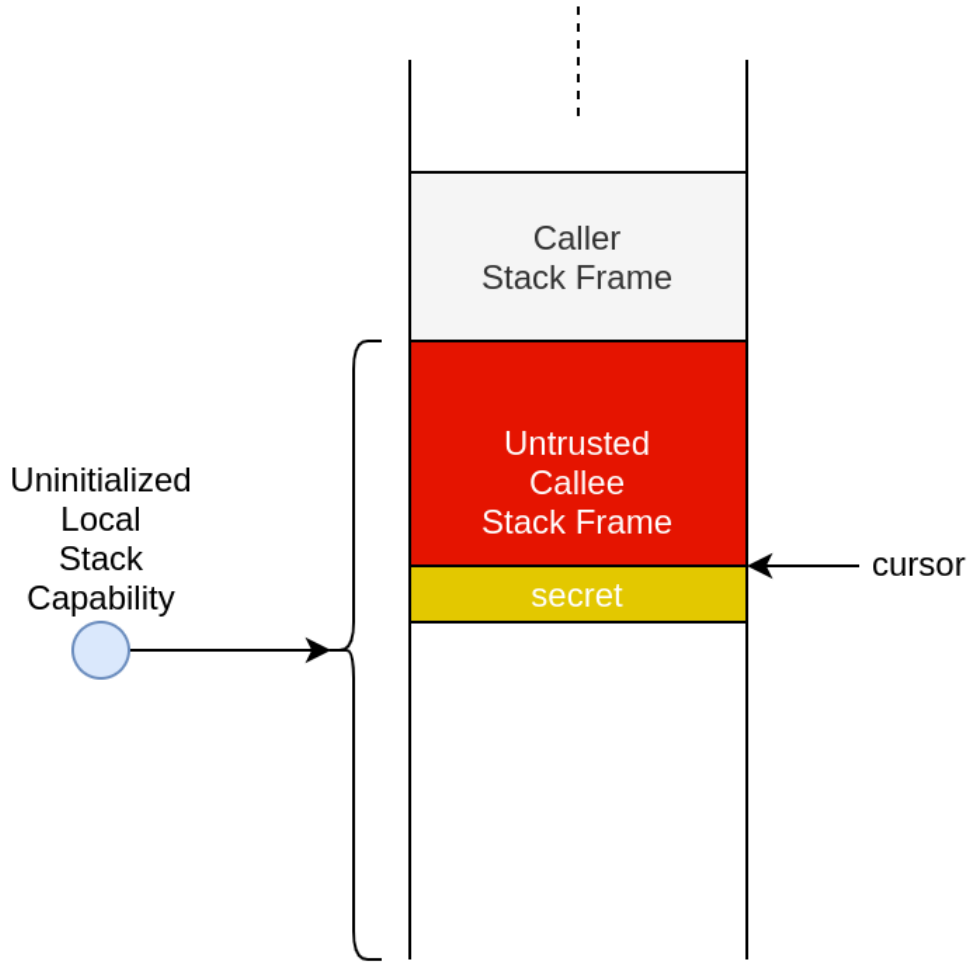

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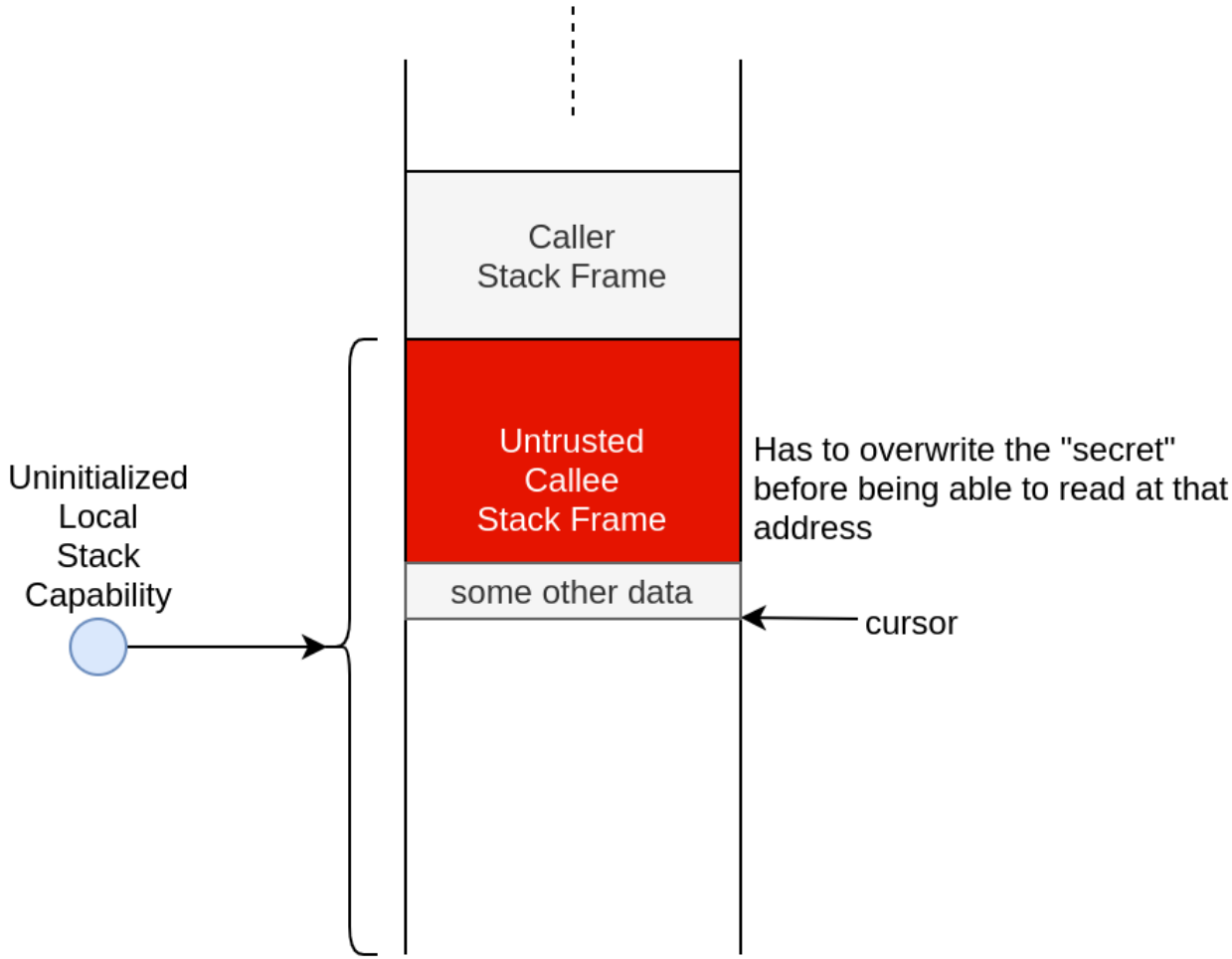

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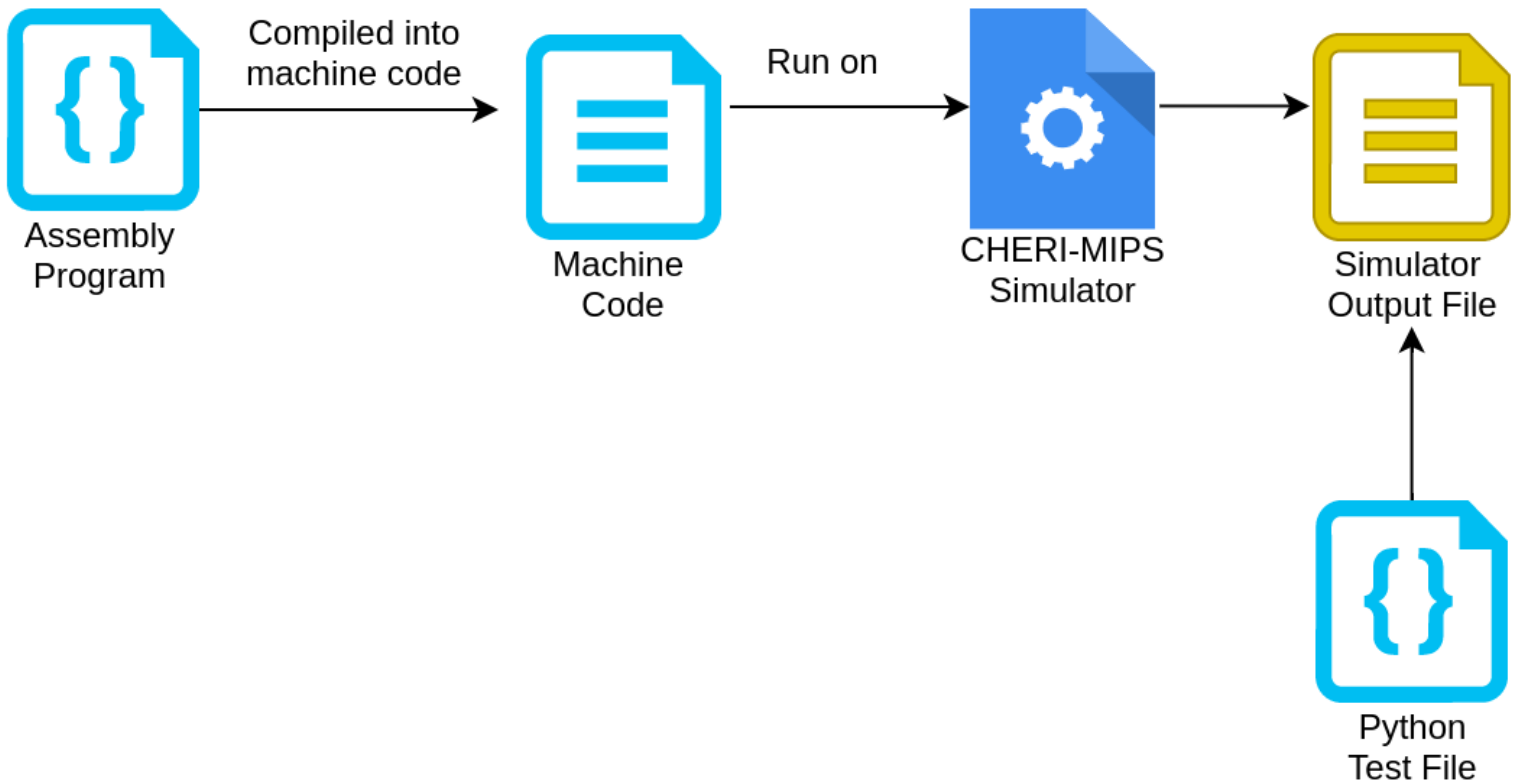
EVALUATION

ASSEMBLER

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

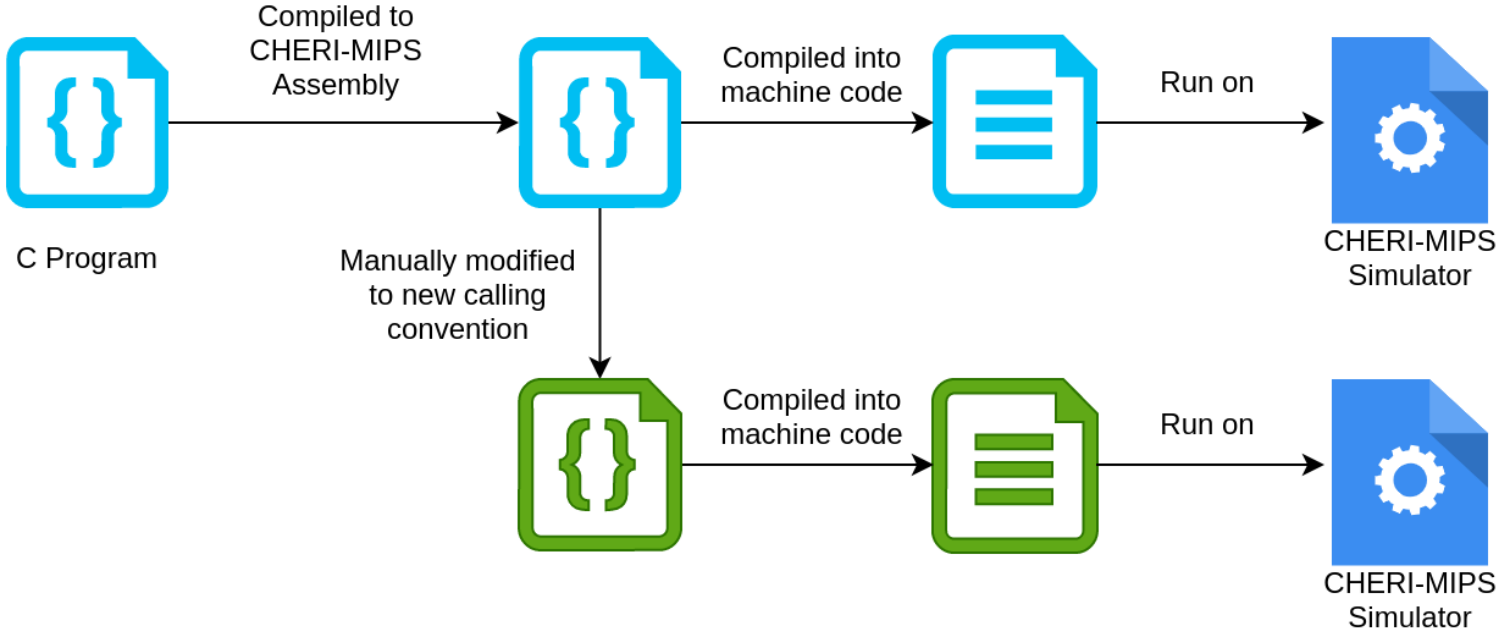
EVALUATION

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