StkTokens: Enforcing Well-Bracketed Control Flow and Stack Encapsulation Using Linear Capabilities

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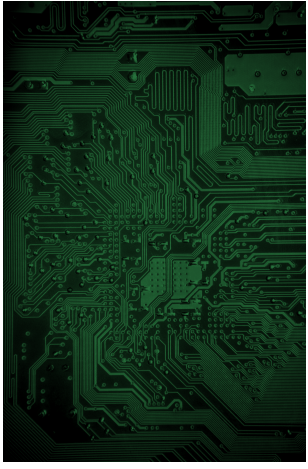
Abstractions all the way down



Abstractions all the way down

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# BB#0:
  pushq %rbp
.Ltmp0:
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.Ltmp1:
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  movl  $0, -4(%rbp)
  movb  $0, %al
  callq printf
  xorl  %ecx, %ecx
  movl  %eax, -8(%rbp)
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  popq  %rbp
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.Lfunc\_end0:
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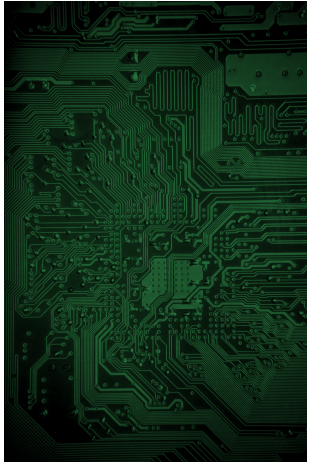

Abstractions all the way down

```c
#include <stdio.h>
int main()
{
  int t = 5;
  printf("Hello, World!");

  return 0;
}
```

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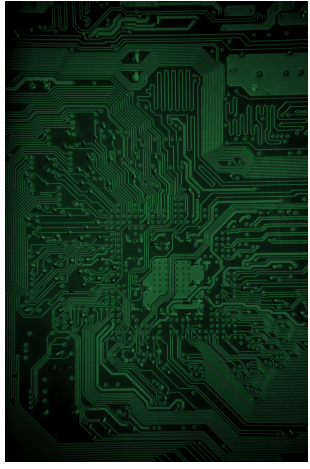

Abstractions all the way down

compilation

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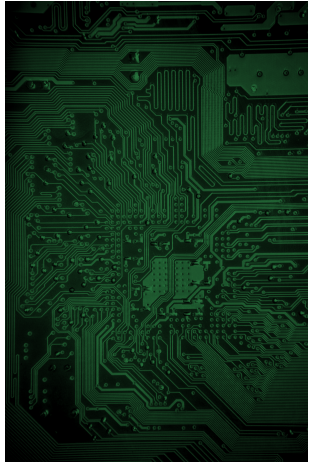

Abstractions all the way down

secure compilation

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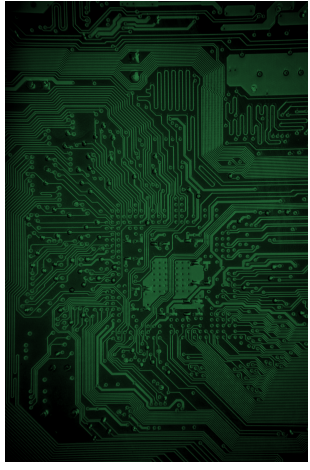

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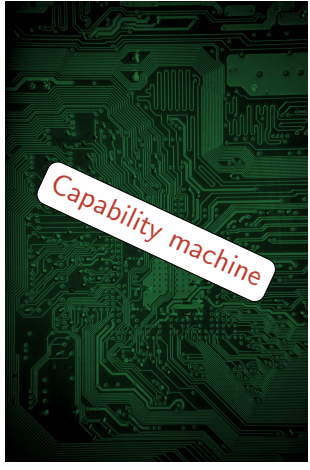

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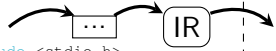


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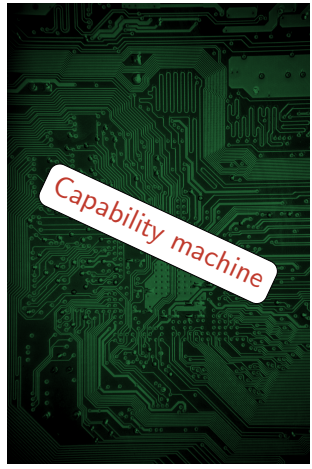

Abstractions all the way down

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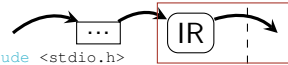


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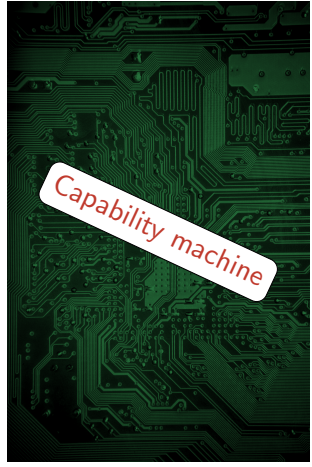

Well-bracketed control flow and local state encapsulation

```
void a()
{
    ...
    return;
}

void b()
{
    int x = 5;
    a();
    ...
    a();
    return;
}
```

Well-bracketed control flow and local state encapsulation

```
void a()
{
    ...
    return;
}
```

Function `a` cannot access variable `x`

```
void b()
{
    int x = 5;
    a();
    ...
    a();
    return;
}
```

Local-state encapsulation (LSE)

Well-bracketed control flow and local state encapsulation

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void a()
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    ...
    return;
}

void b()
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    int x = 5;
    a();
    ...
→   a();
    return;
}
```

Well-bracketed control flow (WBCF)

Well-bracketed control flow and local state encapsulation

```
→ void a()
  {
      ...
      return;
  }

  void b()
  {
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      a();
      ...
      a();
      return;
  }
```

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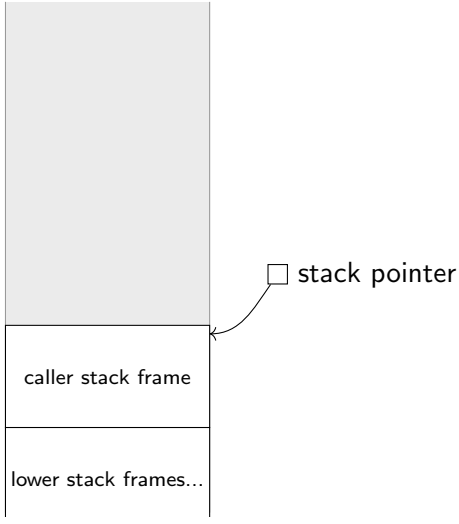
Well-bracketed control flow (WBCF)

Traditional stack pointers



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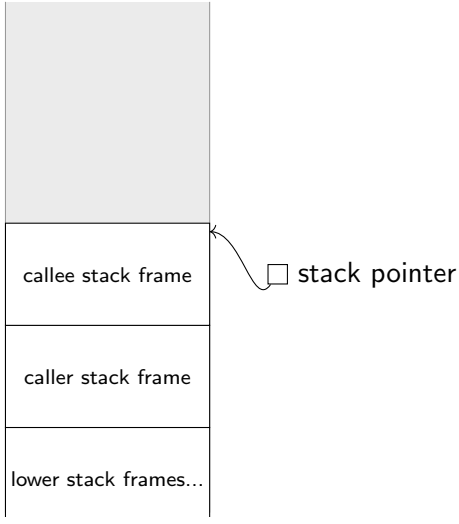

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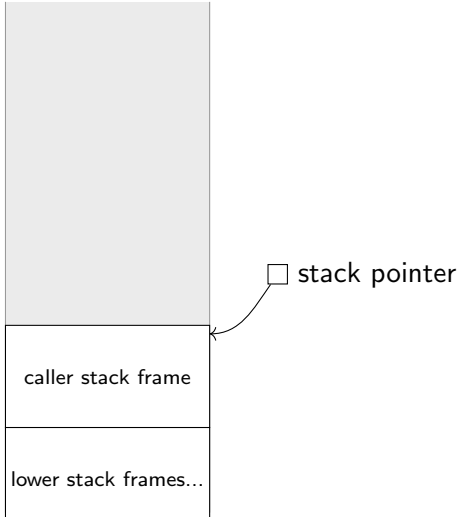

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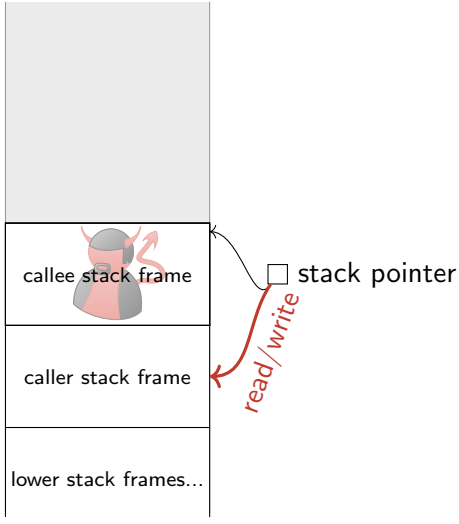

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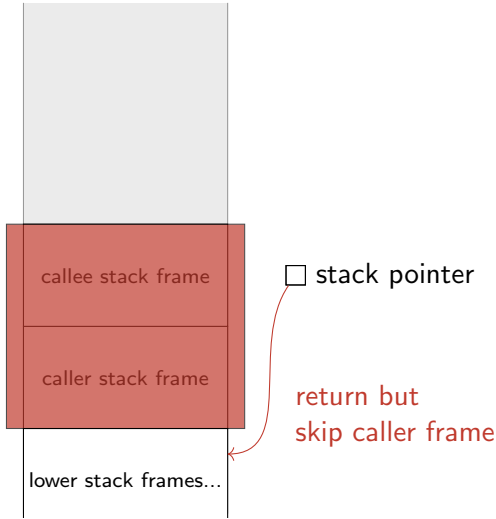
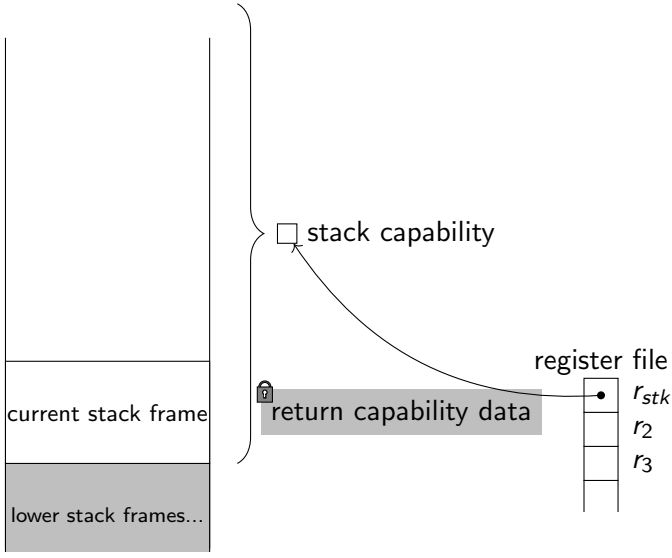


Naive stack and return capabilities



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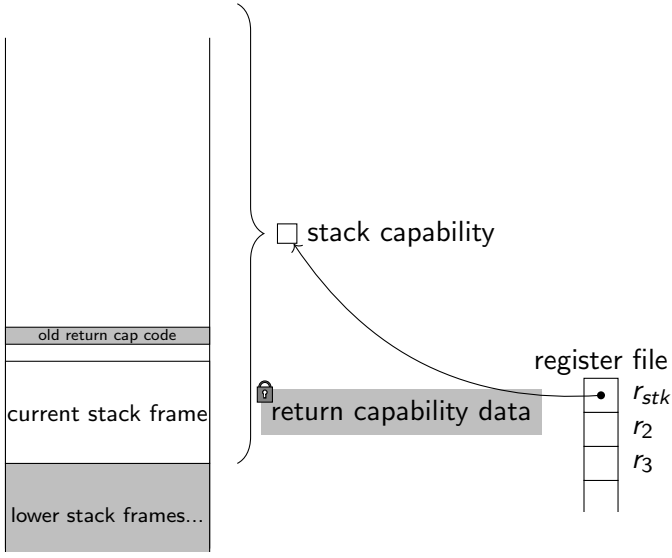

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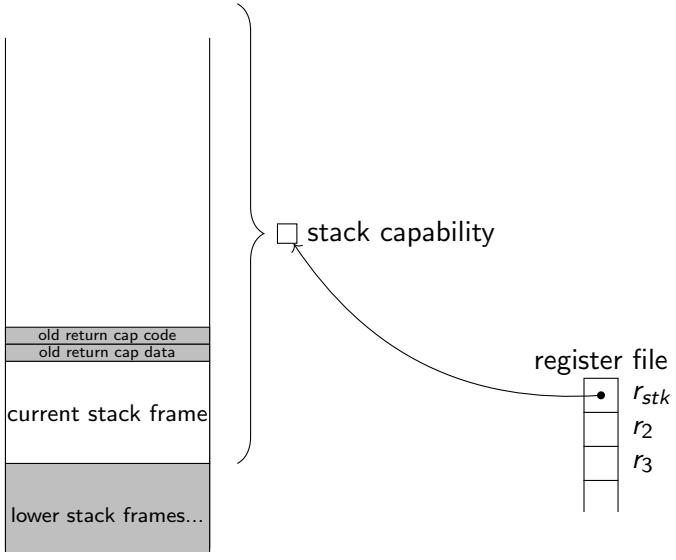

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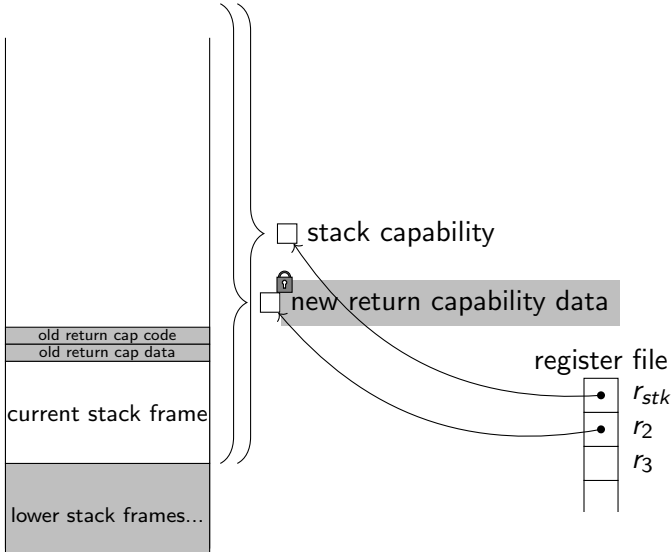

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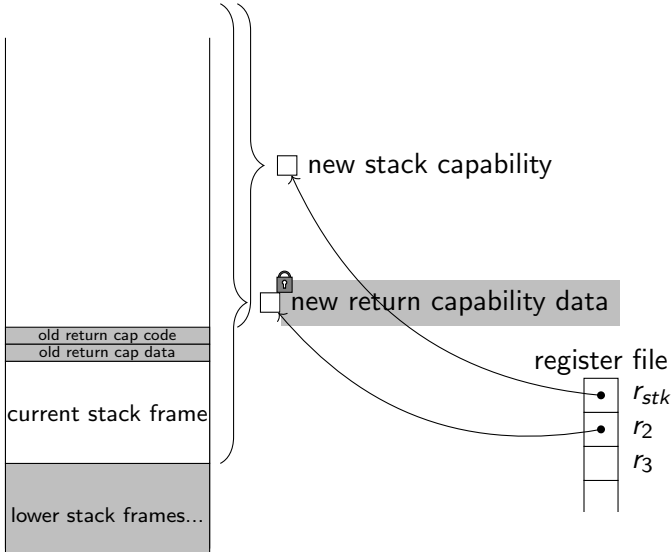

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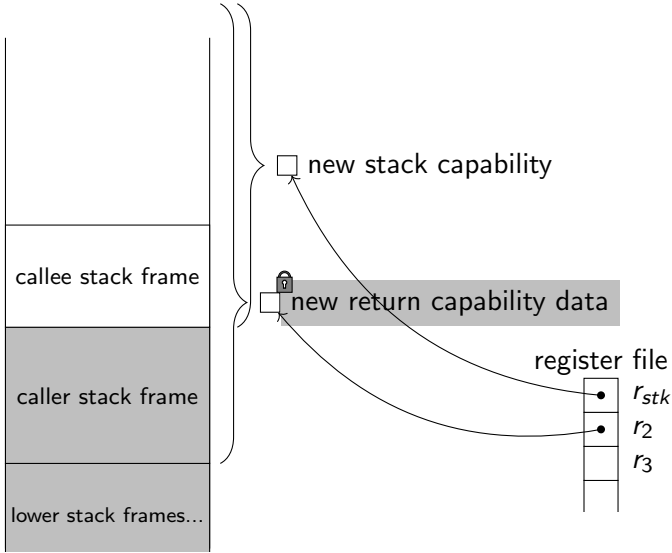
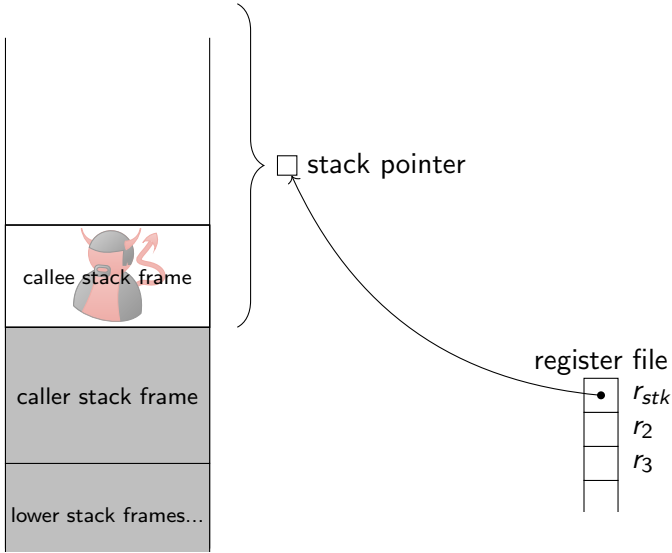


Attack on naive stack and return capabilities



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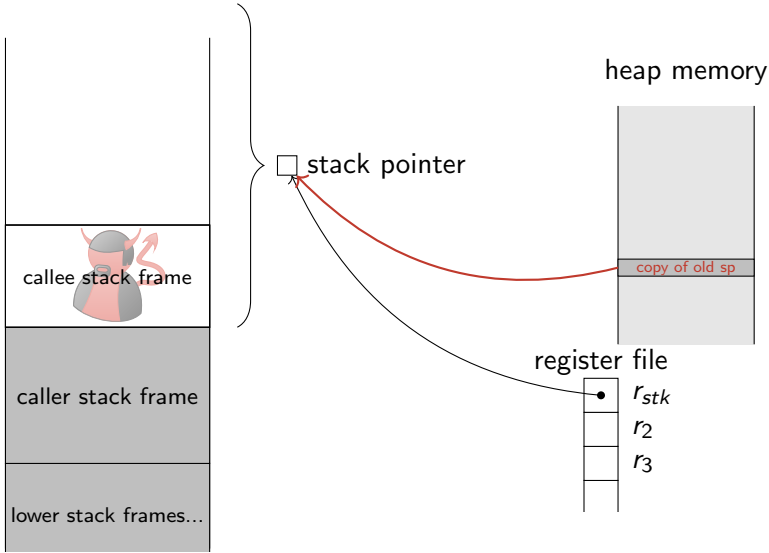

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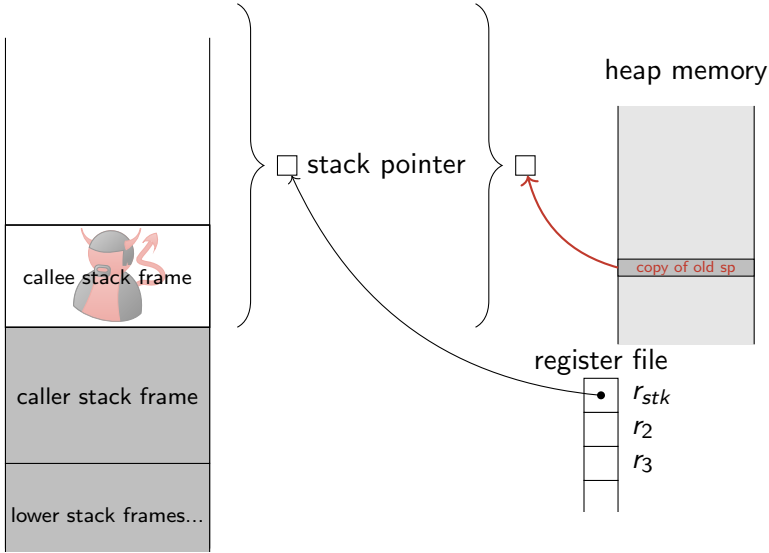

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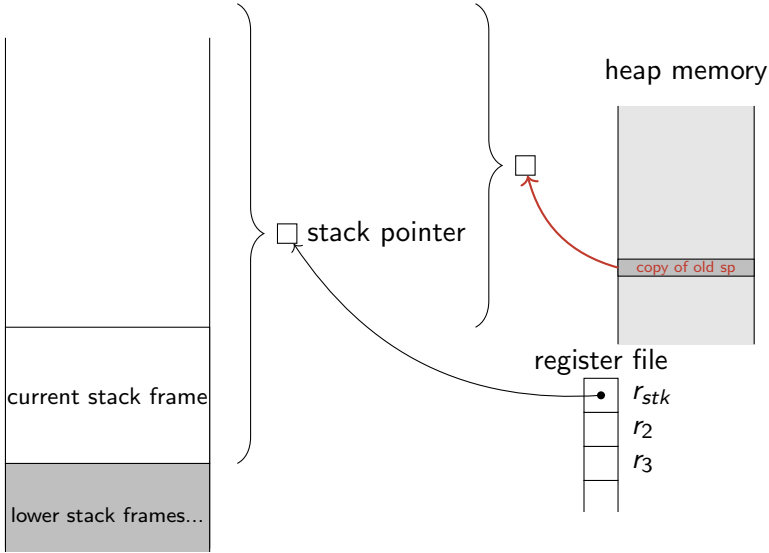

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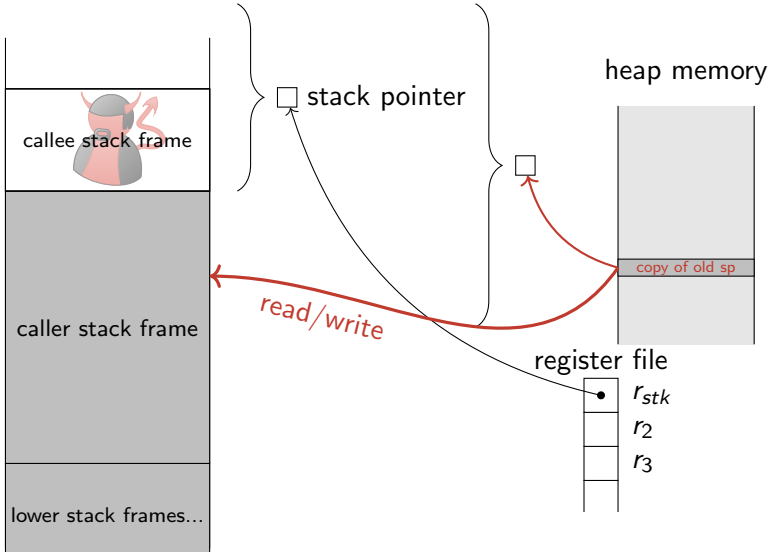
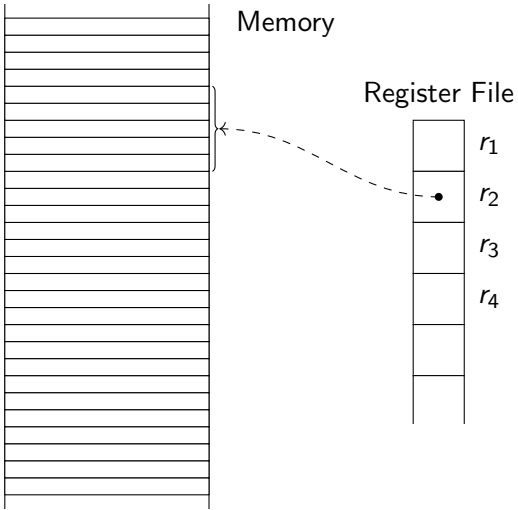


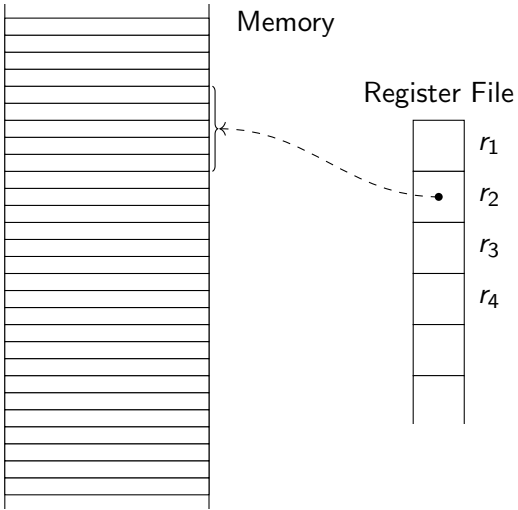
Linear capabilities



Linear capabilities

- Non-duplicable

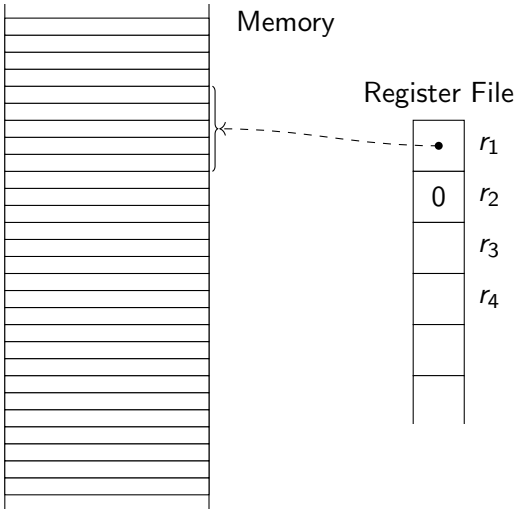
Linear capabilities



Linear capabilities

- Non-duplicable
- `move` r_1 r_2

Linear capabilities



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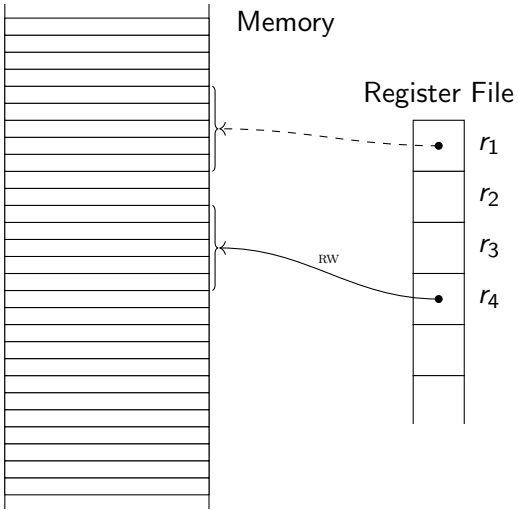
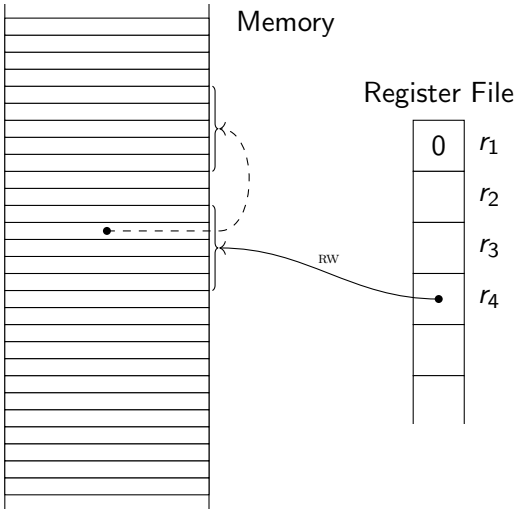


Linear capabilities

- Non-duplicable
- `move` r_1 r_2
- `store` r_4 r_1

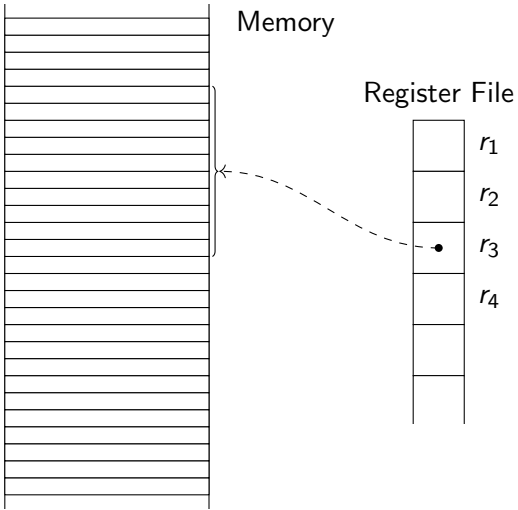
Linear capabilities



Linear capabilities

- Non-duplicable
- `move` r_1 r_2
- `store` r_4 r_1

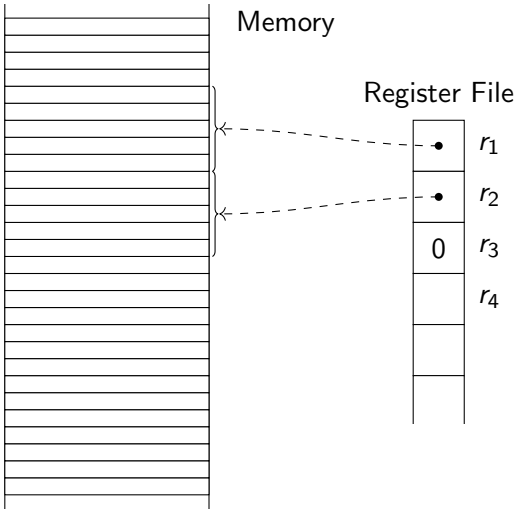
Linear capabilities



Linear capabilities

- Non-duplicable
- `move` r_1 r_2
- `store` r_4 r_1
- `split` r_1 r_2 r_3 n

Linear capabilities



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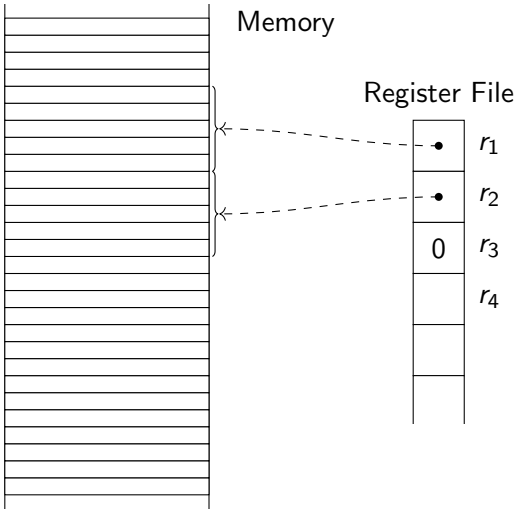

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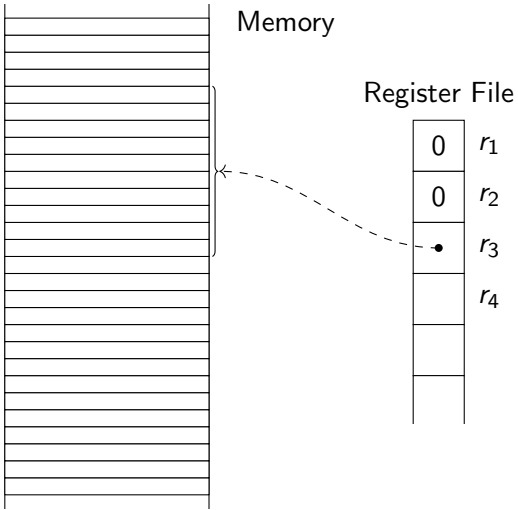

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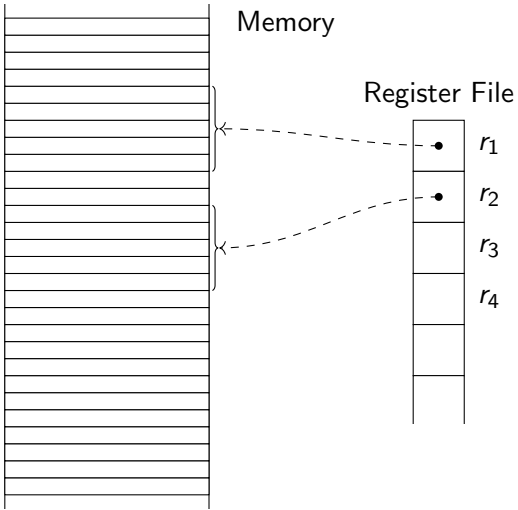

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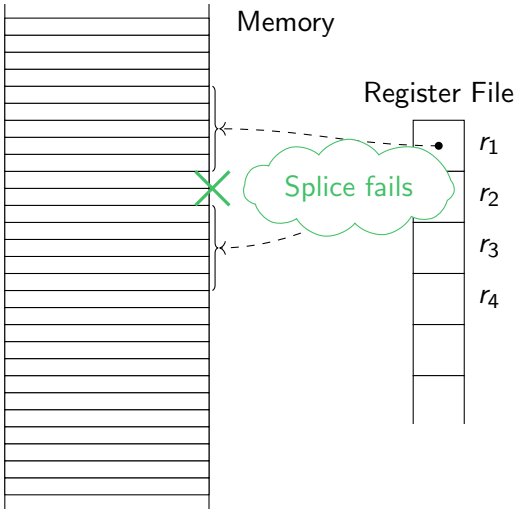

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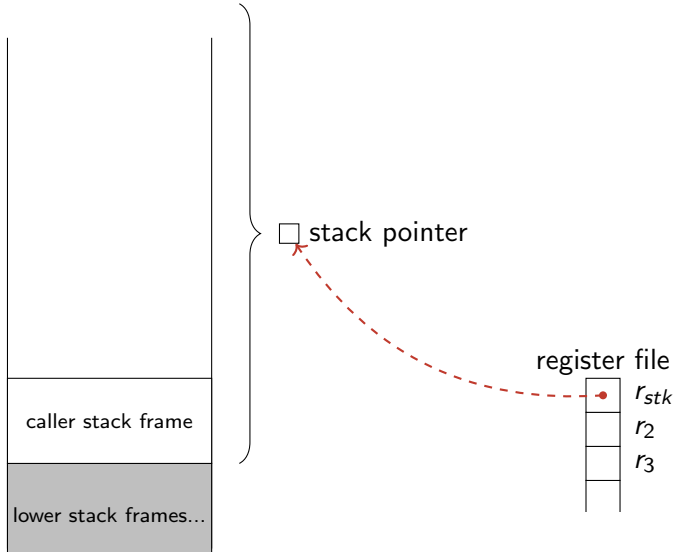
Call with StkTokens



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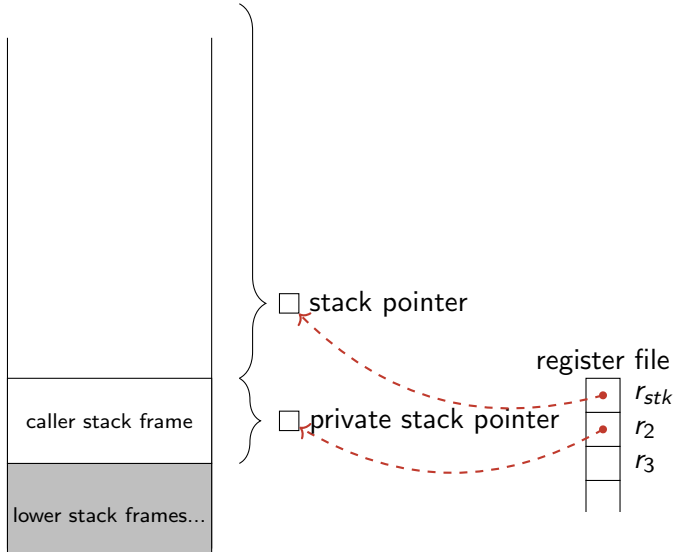

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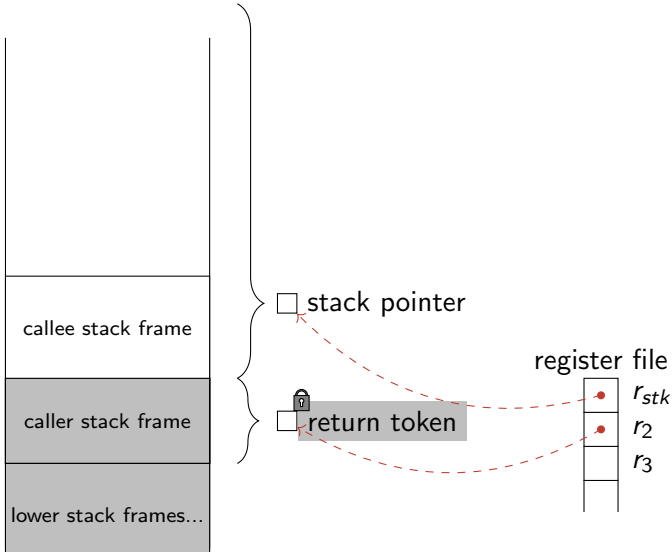

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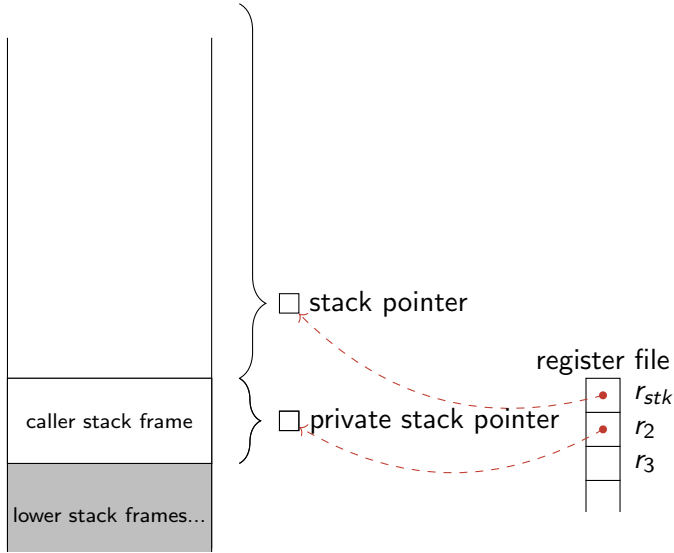

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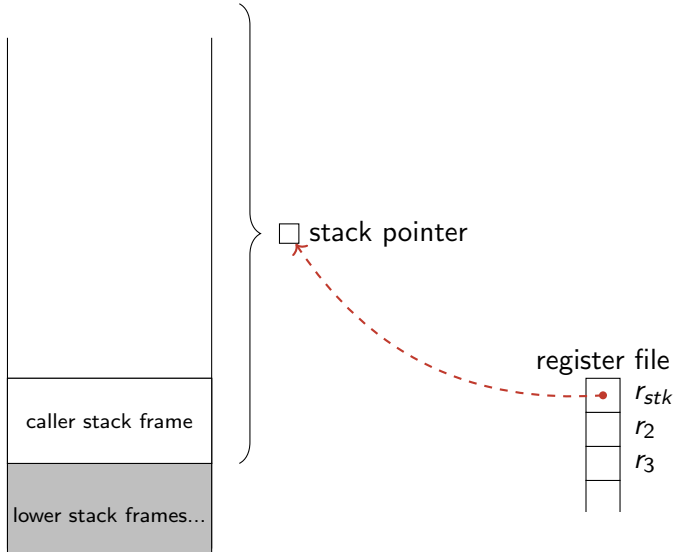
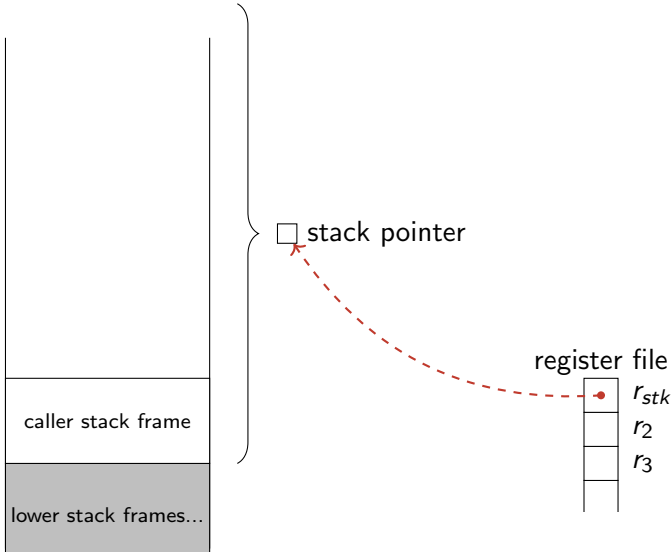


StkTokens prevents the attack



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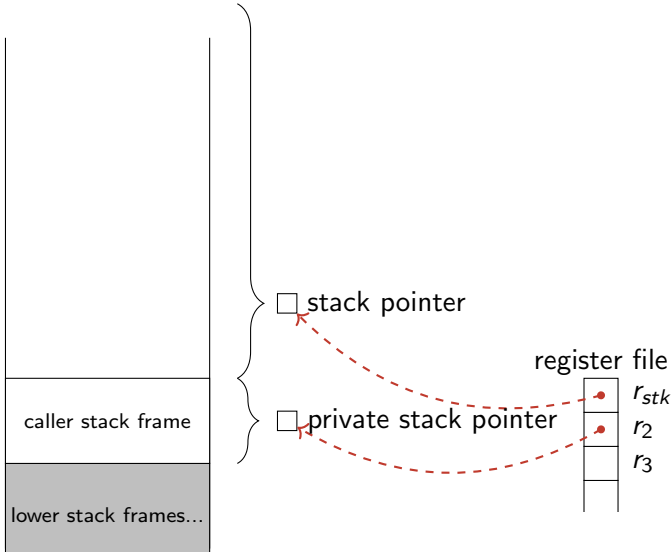

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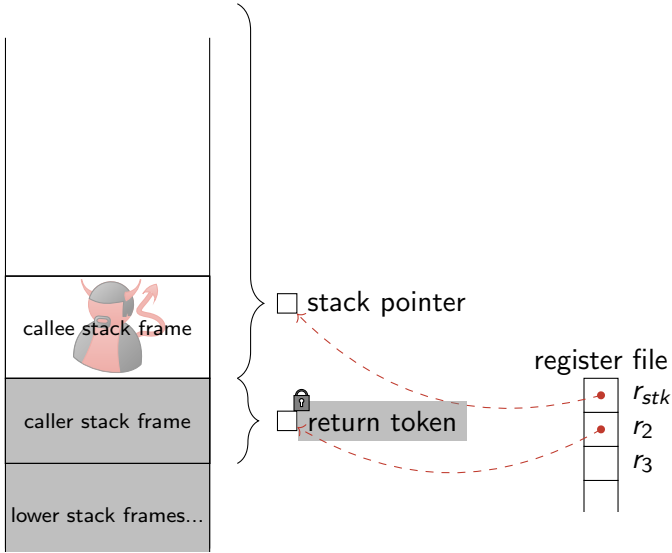

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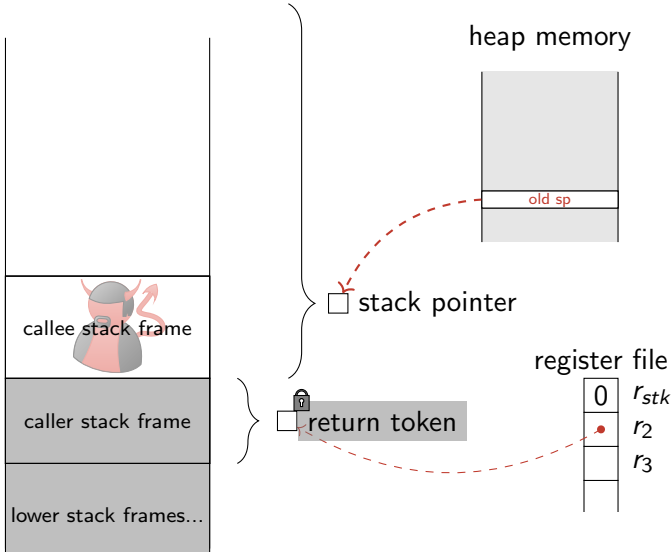

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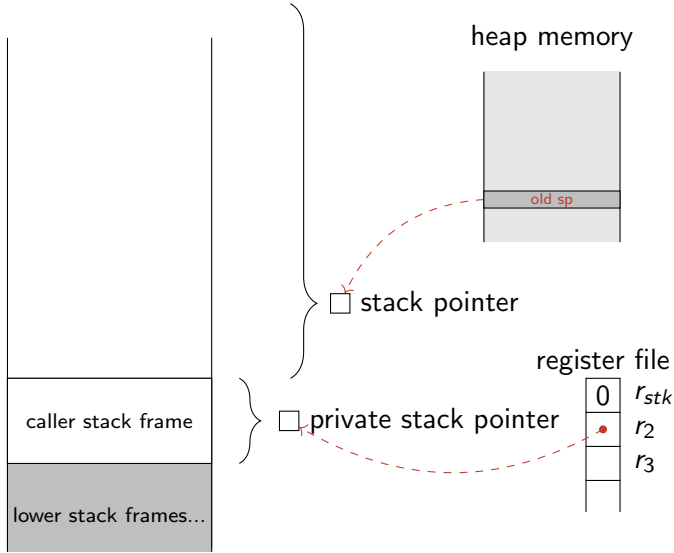

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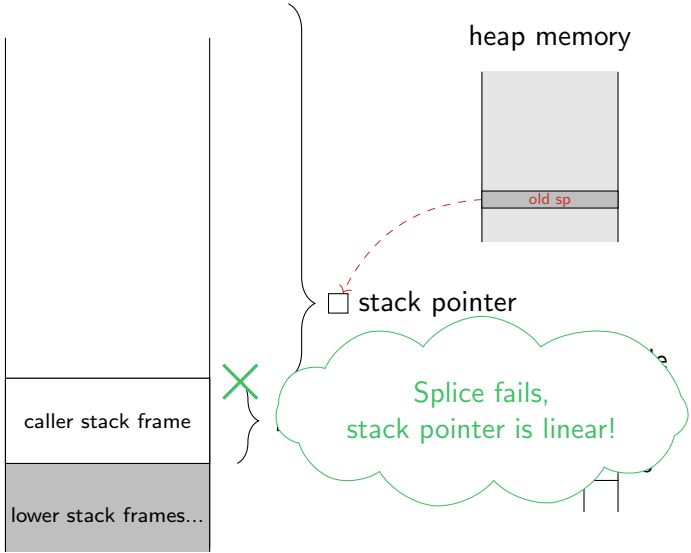

Fully-abstract overlay semantics

```
move  rtmp1 42
store rstk rtmp1
cca   rstk -1
geta  rtmp1 rstk
cca   rretc 5
move  rtmp1 pc
cca   rtmp1 -20
```

```
load  rtmp1 rtmp1
cca   rtmp1 -21
cseal rretd rtmp1
move  rretc pc
xjmp  r1 r2
cseal rretc rtmp1
move  rtmp1 0
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Linear Capability Machine

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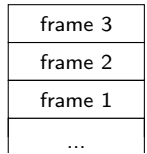
Builtin call stack



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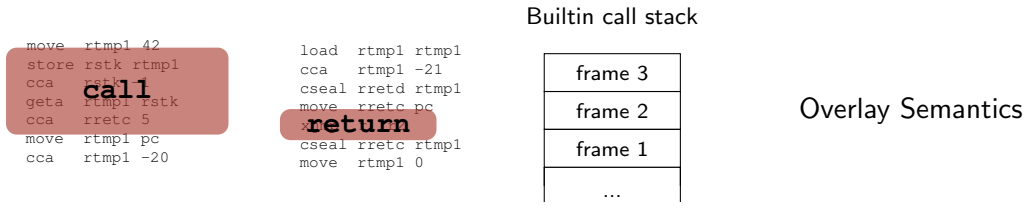

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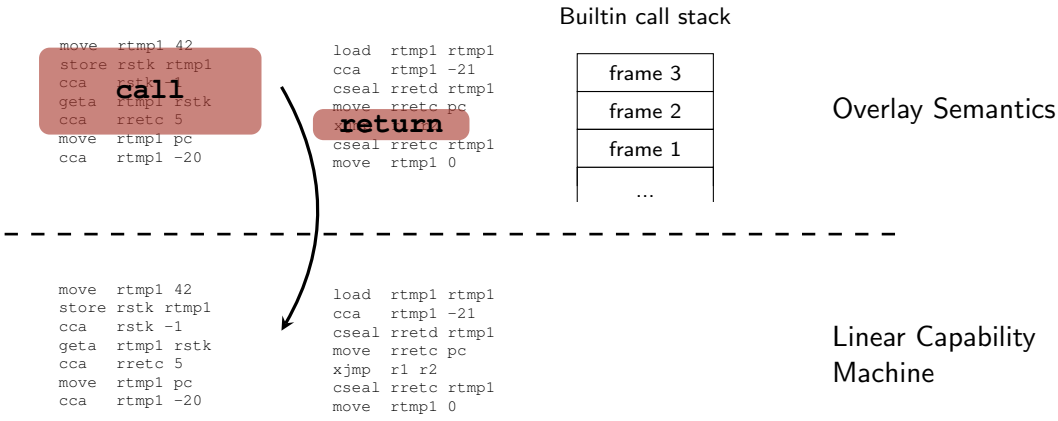

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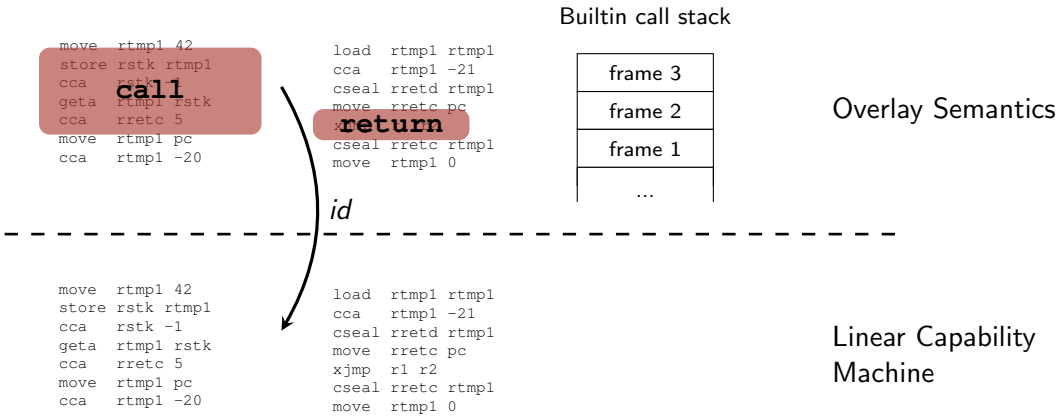


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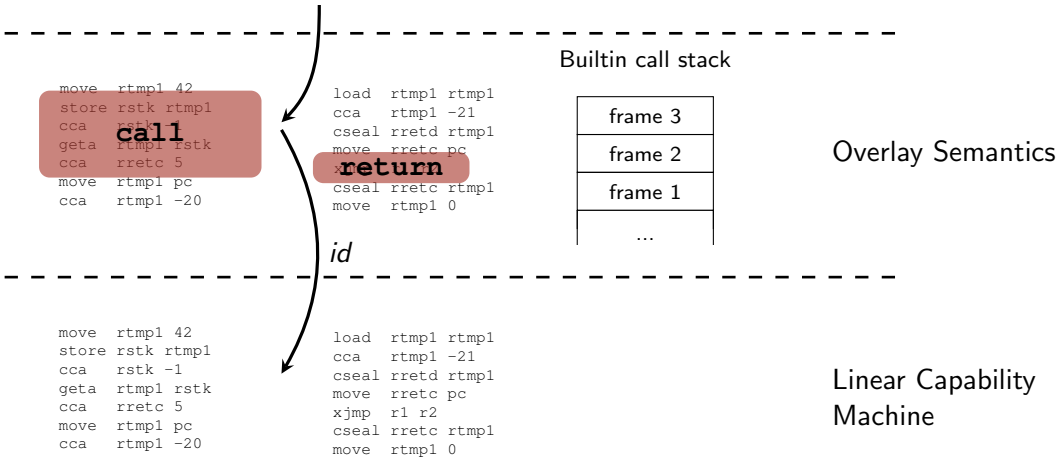
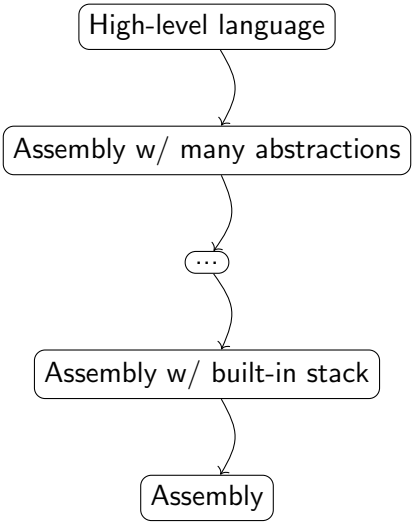


Proof sketch for a realistic secure compiler



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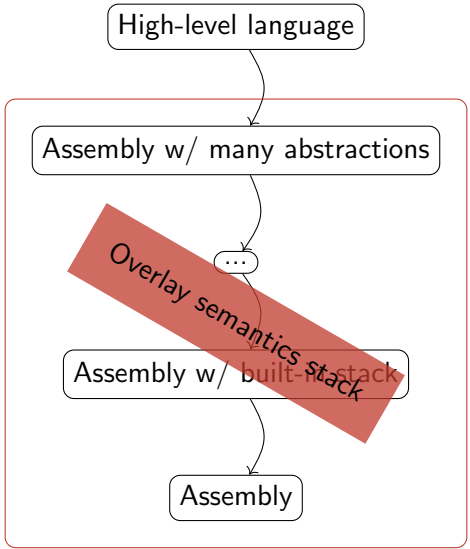

Full abstraction

Theorem (Full abstraction)

For reasonable, well-formed $comp_1$ and $comp_2$, we have

$$comp_1 \approx_{\mathrm{ctx}} comp_2 \quad \Leftrightarrow \quad comp_1 \approx_{\mathrm{ctx}} comp_2$$

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- StkTokens reasonable use of return seals
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Should be handled in earlier compiler phase

Conclusion

- StkTokens ensures well-bracketed control flow and local-state encapsulation.
- Overlay semantics used to define well-bracketed calls and local-state encapsulation.
- Capability machines may be a good target for secure compilation.

Thank you!

StkTokens summary

- Check the base address of the stack capability before and after calls.
- Make sure that local stack frames are non-empty.
- Create token and data return capability on call: split the stack capability in two to get a stack capability for your local stack frame and a stack capability for the unused part of the stack. The former is sealed and used for the data part of the return pair.
- Create code return capability on call: Seal the old program pointer.
- Reasonable use of seals: Return seals are only used to seal old program pointers, every return seal is only used for one call site, and they are not leaked.

StkTokens FAQ

- *Do you support tail calls?*
  - Yes.
- *Do you support higher-order functions?*
  - Yes.

StkTokens vs. CHERI stack

StkTokens

- Single stack
- Fine granularity of security domains
- No context switch on call
- Caller has the full responsibility for securing call
- Supports higher-order functions

CHERI stack

- Per component stack and trusted centrally-managed stack
- Call and return instructions interact with stack
- Context switch on call/return
- Local capabilities cannot cross security boundary