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A Security Policy Definition Language, Semantics, and Open Source Tools

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Overview

How can we concisely and uniformly express fine-grained security policies?

The plan in three parts:

1. Introduction to our domain-specific language (DSL) for security policies.

2. DSL simulation tools for RISC-V.

3. DSL hardware enforcement on RISC-V.

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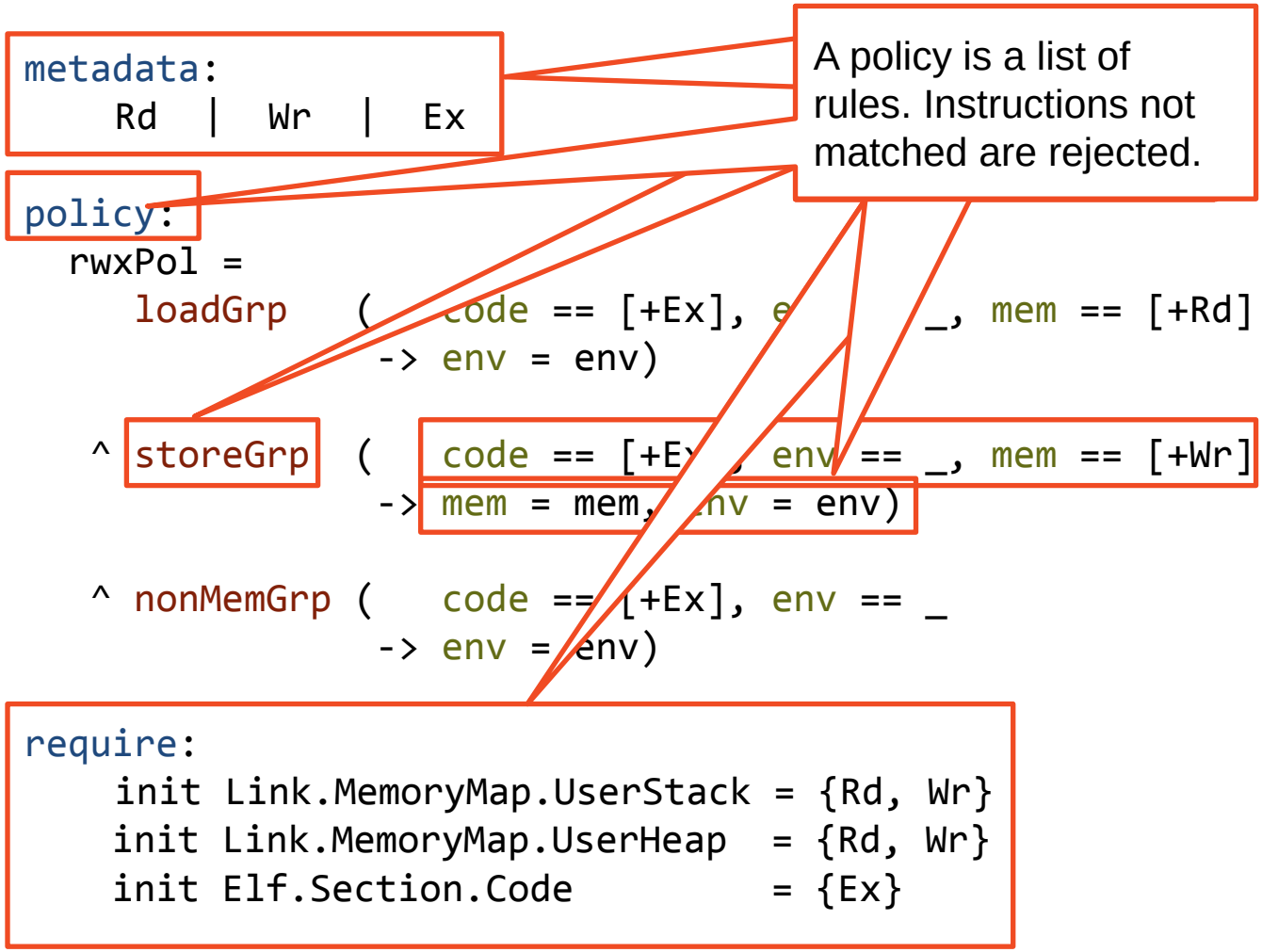
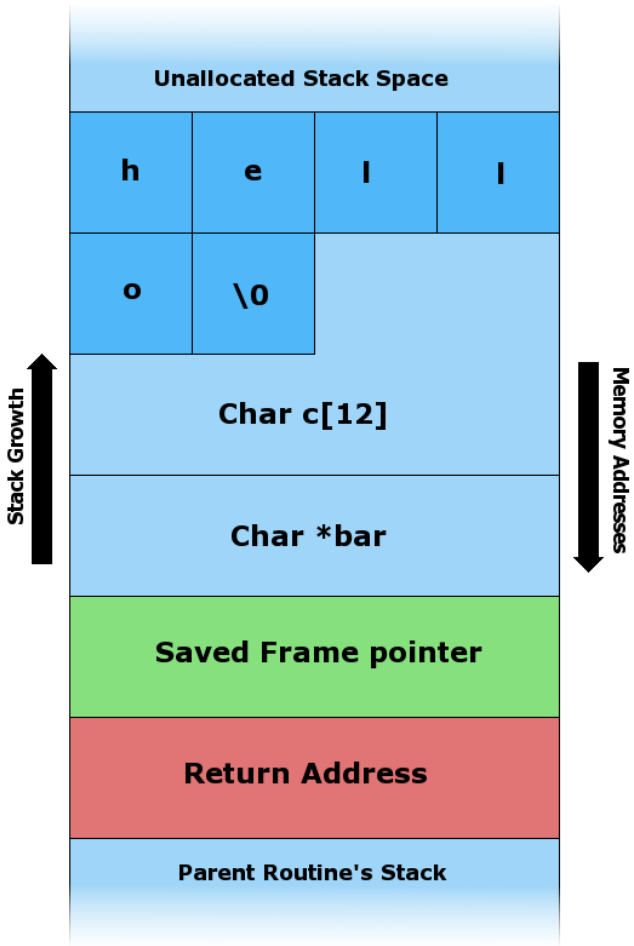
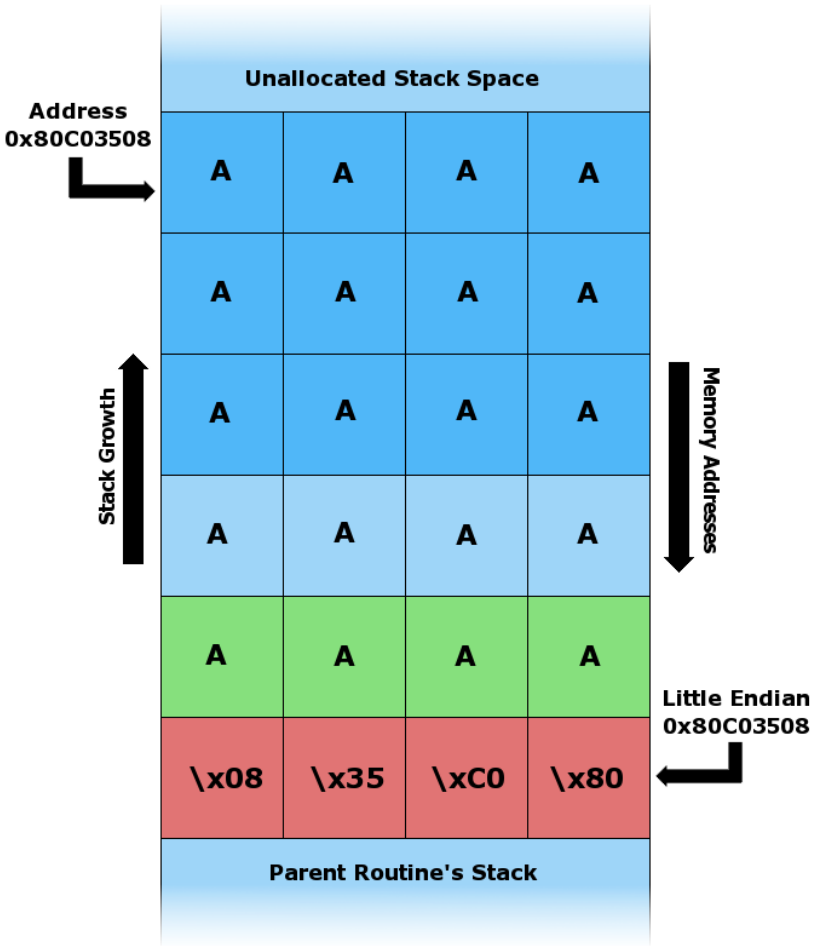
1) A Security Policy DSL

Example: A policy for RWX permissions



Example: Stack Buffer Overflow





Stack Protection Policy

- Tag memory containing function prologue and epilogue code.
- No other code may touch stack frame.

```
metadata:
    Frame  |  Prologue  |  Epilogue

policy:
  stackPol =
     // Prologue creates stack Frame
     storeGrp  (   code == [+Prologue], mem == _, env == _
                -> mem = {Frame})

     // Other code can't touch Frame
   ^ storeGrp (   code == [-Prologue, -Epilogue], mem == [+Frame]
               -> fail "Illegal stack access")

     // Epilogue clears Frame, allow other writes, ...
   ...
```

Example: Simple CFI

- Statically determine legal jump destinations.
- Dynamically check each jump.

```
metadata:
    Target  |  Jumping

policy:
  stackPol =
     // jump instructions set “Jumping”
     jumpGrp  (env == _ -> env = env[+Jumping])

     // Landing on legal target clears “Jumping”
   ^ allGrp   (   code == [+Target], env == [+Jumping]
                -> env = env[-Jumping])

     // Landing elsewhere is a violation
   ^ allGrp   (   code == [-Target], env == [+Jumping]
                -> fail "Illegal jump")
   ^ ...
```

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2) DSL Simulation Tools for RISC-V

Open Source Simulation Tools

- Our simulator runs RISC-V programs with policy enforcement.
- Built on QEMU, plugin does policy checks.
- Many policies and test programs.
  - FreeRTOS webserver with application-specific policies.
  - Initial seL4 support.
- Open-source, MIT license, we'd love collaborators:
  - **https://github.com/draperlaboratory/hope-tools**

RISC-V Emulation with Policies

- Simulator detects policy violations in application.
- Provides user feedback on location and cause of violation.

```
cjc1527@leopard> cat pex.log
Policy Violation:
    PC = 20451ad0    MEM = 80502dd8
Metadata:
    Env   : {}
    Code  : {storeGrp}
    Op1   : {}
    Op2   : {}
    Op3   : -0-
    Mem   : {Frame}
Explicit Failure
Illegal stack access
MSG: End test.
cjc1527@leopard>
```

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Metadata Support in GDB

- Simulator supports GDB.
- New commands to inspect metadata as application runs.

```
(gdb) metadata
Metadata related commnads:
   pvm       - print violation message
   env-m     - get the env metadata
   reg-m n   - get register n metadata
   csr-m a   - get csr metadata at addr a
   mem-m a   - get mem metadata at addr a
Watchpoints halt simulation when metadata changes
   env-mw    - set watch on the env metadata
   reg-mw n  - set watch on register n metadata
   csr-mw a  - set watch on csr metadata at addr a
   mem-mw a  - set watch on mem metadata at addr a
(gdb) mem-m 0x20417688
 {loadGrp, notMemGrp}
(gdb)
```

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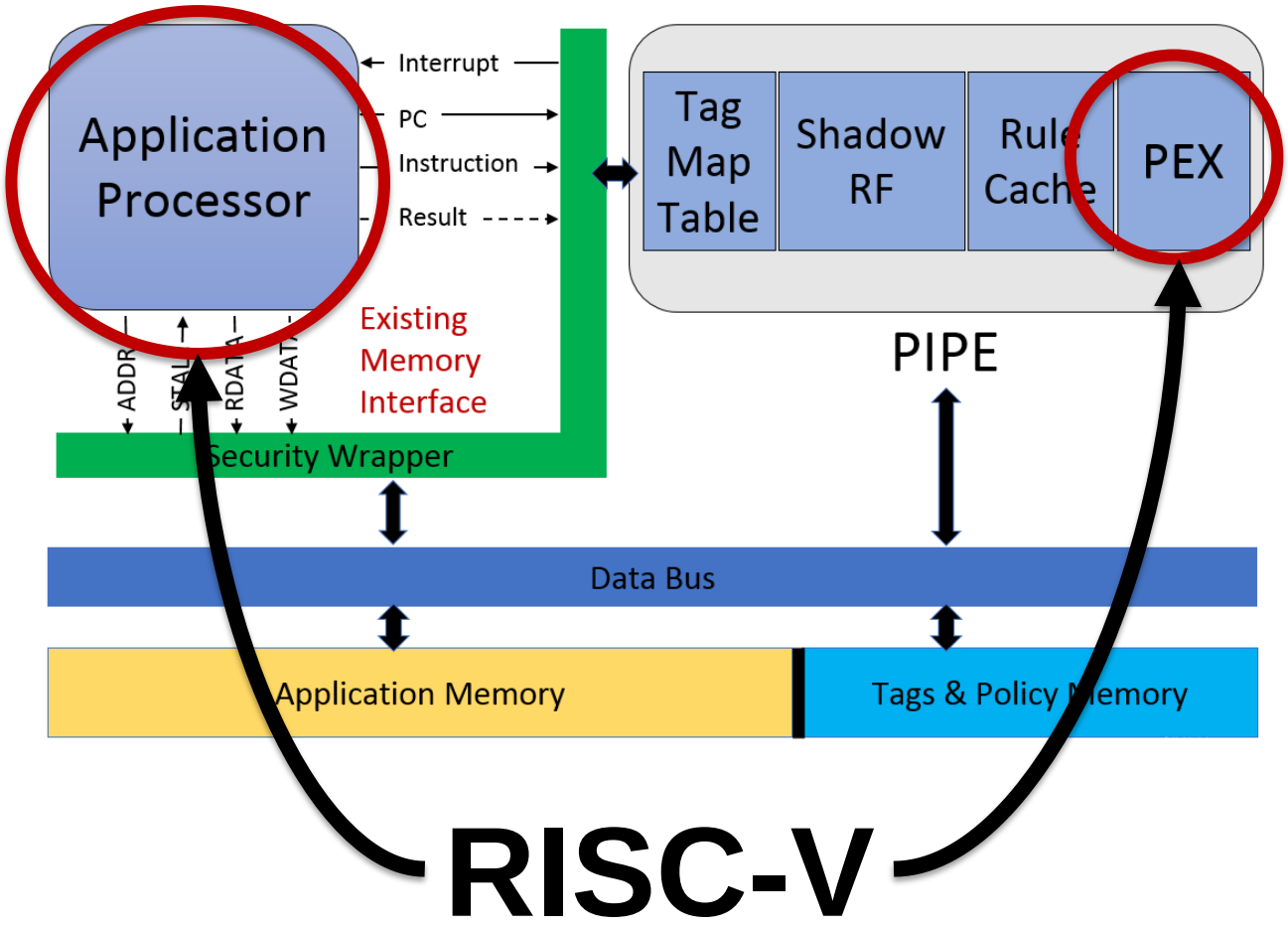
3) DSL Hardware Enforcement on RISC-V

PIPE Hardware Diagram

- PIPE: Processor Interlocks for Policy Enforcement



HW Availability

- Dover and Draper have collaborated on the design of PIPE.
- Dover offers a performant, commercial version, called CoreGuard.

- Draper integrates PIPE for government customers in defense systems.

Conclusion

- Summary:
  - DSLs can make security policies easier to write, understand, and verify.
  - You can play with our open simulation tools today:
    - https://github.com/draperlaboratory/hope-tools
  - Talk to us about performant HW implementations for RISC-V (and other architectures)

  - Greg Sullivan : gregs@dovermicrosystems.com
  - Chris Casinghino: ccasinghino@draper.com

Thanks!

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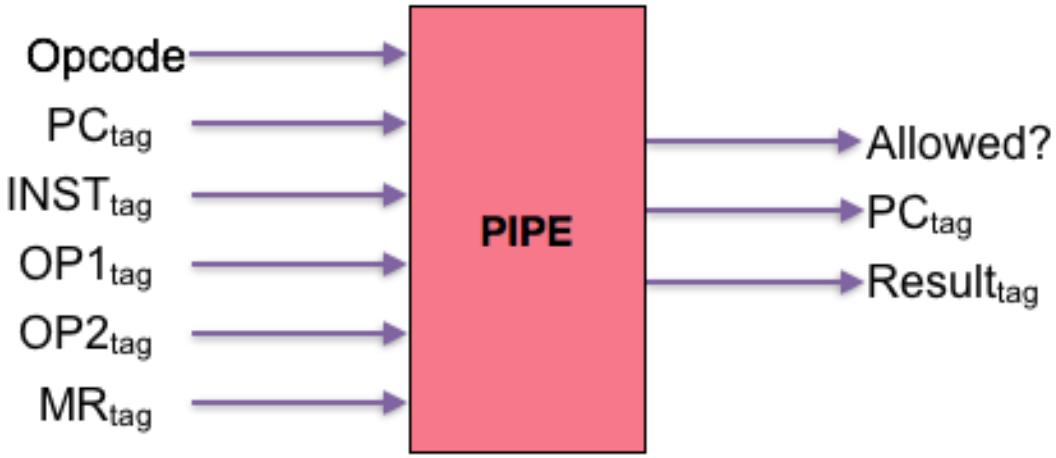
Backup

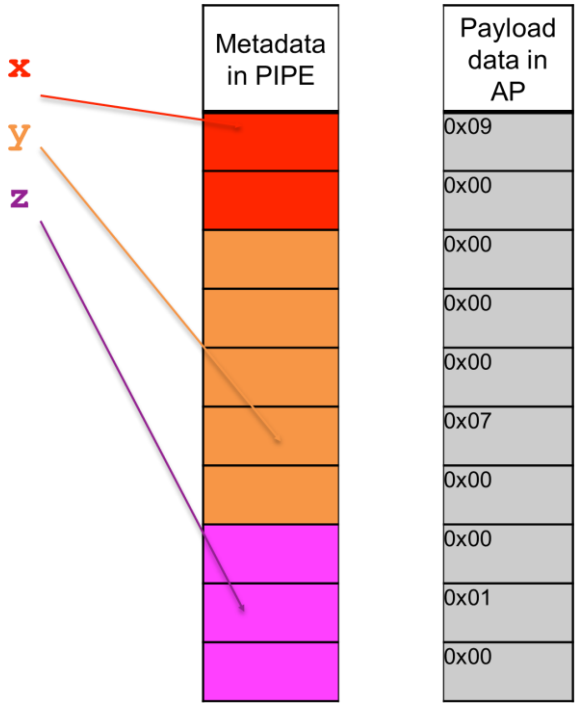
PIPE hardware

- PIPE: Processor Interlocks for Policy Enforcement
- Runs in parallel with application processor.
- Generates application processor interrupt if policy violation occurs.
- Creates unassailable hardware interlock blocking execution of bad instructions.
- Cache keeps performance high.



Example: Heap Memory Safety

- **Policy Goal:** enforce spatial and temporal safety
- **Method:** “color” pointers and memory
  - On allocation, add colors to the region and the pointer.
  - Recolor on free.
- **Policy:**
  - On access, pointer and memory colors must match.




```
z = malloc(3);
z[1] = 0x01;
y = malloc(5);
y[3] = 0x07;
x = malloc(2);
x[0] = 0x09;
x[2] = 0xbad; //FAIL
```

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Heap Safety Policy

- Tags can carry data values, allowing us to implement this color scheme.

```
type:
    data Color = Int (20)

metadata:
    ApplyColor | NewColor | Pointer Color | Cell Color | ...

policy:
   // Generate new color during malloc
     storeGrp(   code == [ApplyColor], mem == [NewColor]
              -> mem = mem[(Pointer new)])

   // Allow load if colors match
   ^ loadGrp(   mem == [Cell color], addr == [Pointer color]
             -> res = mem[-(Cell _)])

   ...
```

Policy Language Continued

- Users may define new “opgroups”.
  - Group instructions in the way that makes sense for your policy.
  - Keeps policy rules somewhat ISA-agnostic.

- Language implemented in Haskell.
  - We generate C and compile to RISC-V binaries.
  - Lots of room left to optimize.

- Language has formal operational semantics.
  - Future goal: prove implementation correct.