

# Implementing RISC-V Scalar Cryptography Extension Based on Chisel

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# Section 1

## Background

# Hardware crypto acceleration

- Crypto operations is pervasive for modern apps
  - HTTPS: when you are browsing websites
  - Bitlocker: encrypt you disk
- Imagine you are watching a 4K video from encrypted network/disk
  - Software-only can not handle this load
  - need specialized hardware!

- To drive specialized hardware, we need Instruction Set Architecture (ISA)
  - ISA is the “bridge” between hardware and software
- RISC-V is an open standard ISA
  - First developed in Berkeley around 2010
  - Unlike proprietary/private standards like x86/ARM
- RISC-V recently ratified the scalar cryptography extension
  - In Autumn 2021
  - Covers block cipher/hash function: AES/SHA/SM4/SM3

- To implement hardware, we need a hardware description language (HDL)
- Chisel is an HDL based on Scala
- Commonly used by RISC-V community
- Its syntax is more flexible compared with Verilog
  - Parameterized modules (code once, instantiate everywhere)
  - higher-order function like `map/reduce/filter`

## Section 2

### Designs

# Circuit Design based on Rocket Chip

- To implement an extension, we must have a core
- Rocket Chip as the core
  - Open source RISC-V core, 2.2k stars
  - Taped out by Sifive
- Upstreamed my design to rocket chip
  - Got feedback from Andrew Waterman, the designer of RISC-V
  - Heated discussion on this (64 comments as shown below)

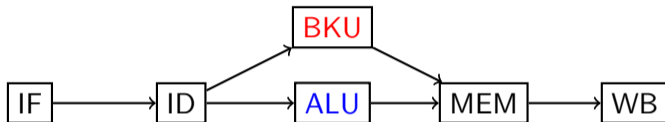
 **Zk(Zbk, Zkn, Zks)/Zb: Scalar**

 64

**Cryptography/Bitmanip Extension** ✓

#2950 opened on 19 Mar by ZenithalHourlyRate

# Five stage pipeline

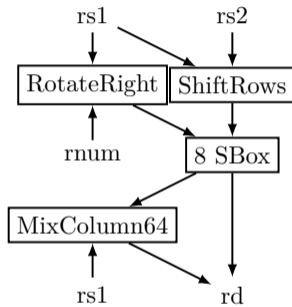


- Classical five stages: IF, ID, EXE, MEM, WB
- EXE means Execution, it often contains ALU (Arithmetic Logic Unit)
- My work: in EXE stage
  - Add BKU (Bitmanip Crypto Unit)
  - Replace ALU with ABLU (Arithmetic Bitmanip Logic Unit)

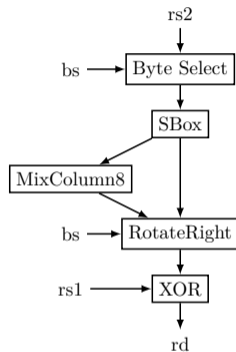


- BKU: Implement bitmanip/scalar crypto extensions
  - Zb: Bit manipulation like rotation, crossbar
  - Zkn: NIST cipher suite, AES and SHA256/SHA512
  - Zks: ShangMi cipher suite, SM4 and SM3
- ABLU: merge common logic of bitmanip into ALU
  - ANDN:  $a \& \sim b$
  - Can just be implemented along side AND:  $a \& b$
  - Result:  $a \& \text{Mux}(\sim b, b)$
  - Reusing 64 and gates
- My design can be used by both 32bit and 64bit architecture (thanks to Chisel)
- My design has small hardware cost
  - Merged many common logics
  - Area of an multiplier/divider

# Merged logics



(a) AES for RV64



(b) AES for RV32

- Merged several instructions into one datapath
- Reuse common module between architecture (thanks to Chisel)

# Software Design based on OpenSSL

- To evaluate my circuit design, I programmed corresponding software
- In **Assembly** language
  - performant crypto needs hand-written asm
- Exploit crypto ISA extension
  - Details and examples in my thesis
- Based on OpenSSL
  - widely-used crypto software lib
- Upstreamed my design to OpenSSL
  - 9 PRs, 3 merged

The screenshot displays a list of GitHub pull requests (PRs) related to RISC-V implementations. Each entry includes a title, a status indicator (checkmark or 'x'), a label (e.g., 'branch: r', 'approval: ready', 'triaged: bug', 'severity'), and a brief description of the PR's history and status.

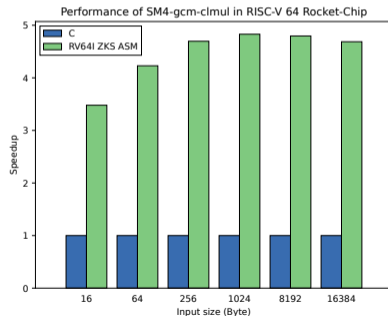
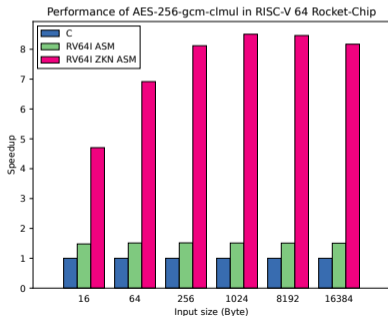
- Add AES implementation in RISC-V64 Zkn asm** ✓ branch: r  
#18197 opened on 28 Apr by ZenithalHourlyRate 5 of 9 tasks
- Make IV/buf in prov\_cipher\_ctx\_st aligned** ✓ approval: ready  
#18267 by ZenithalHourlyRate was closed 25 days ago • Approved
- Fix compilation for RISC-V SHA256/SHA512 inline asm** ✓ triaged: bug  
#18275 by ZenithalHourlyRate was closed 25 days ago • Approved
- Add SM4 implementation in RISC-V Zks asm** ✗  
#18285 opened 26 days ago by ZenithalHourlyRate • Draft 5 tasks
- Add SM3 implementation in RISC-V Zksh inline asm** ✓ a  
#18287 opened 25 days ago by ZenithalHourlyRate • Approved 2 tasks
- Add ROTATE inline RISC-V zbb/zbkb asm for chacha** ✓ 4  
#18289 opened 25 days ago by ZenithalHourlyRate • Approved 2 tasks
- Add ROTATE inline RISC-V zbb/zbkb asm for DES** ✓ appn  
#18290 opened 25 days ago by ZenithalHourlyRate • Approved 2 tasks
- Add AES implementation in RISC-V 32 Zkn asm** ✓ severity  
#18308 opened 23 days ago by ZenithalHourlyRate • Draft 3 tasks
- Add riscv64 asm\_arch to BSD-riscv64 target** ✓ approval: re  
#18309 by ZenithalHourlyRate was closed 12 days ago • Approved 2 tasks

## Section 3

# Evaluation

# Evaluation

- Running in xc7k325tffg900-2 FPGA, 100 MHz
- Baseline: software-only OpenSSL
- Target: Hardware accelerated OpenSSL
- For RV64, up to **10X** for AES, 5X for SM4
- For RV32, up to 4X for AES, 3.7X for SM4



## Section 4

Q&A