SAND2009-5511C

Partial Reconfiguration via Configuration Scrubbing

Jonathan Heiner, Benjamin Sellers, Michael Wirthlin
Brigham Young University
Provo, Utah

Jeff Kalb
Sandia National Laboratory
Albuquerque, New Mexico

This work was supported by Sandia National Laboratories and the National Nuclear Security Administration Office of Nonproliferation Research and Development, NA-22

BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

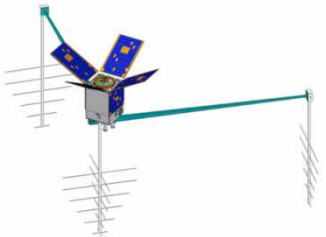
SRAM FPGAs in Space

- Reconfigurable
  - Multiplexing Designs, Fault Avoidance, Replace design flaws
- Application Specific Computing
  - Sensor processing, compression, soft processor computing

Venus Express, TU Braunschweig

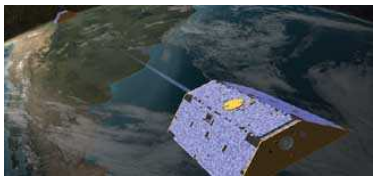
FedSat, Univ. South Australia

OPTUS-C1, Raytheon



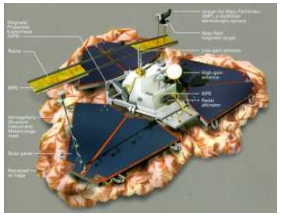
CFESat
Los Alamos National lab

SpaceCube, NASA GSFC



GRACE, NASA GSFC

MARS Rover, NASA JPL



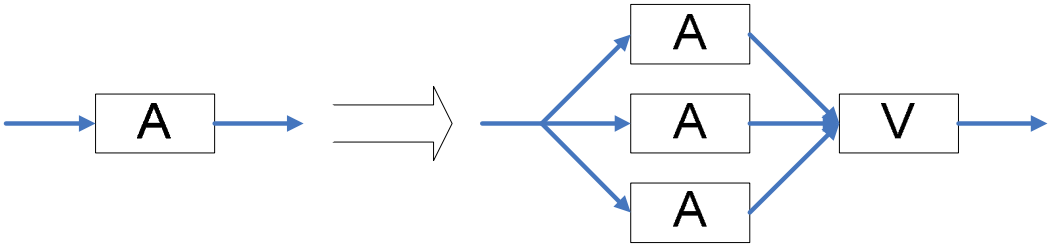
MARS Lander, NASA GSFC

BYU
BRIGHAM YOUNG
UNIVERSITY

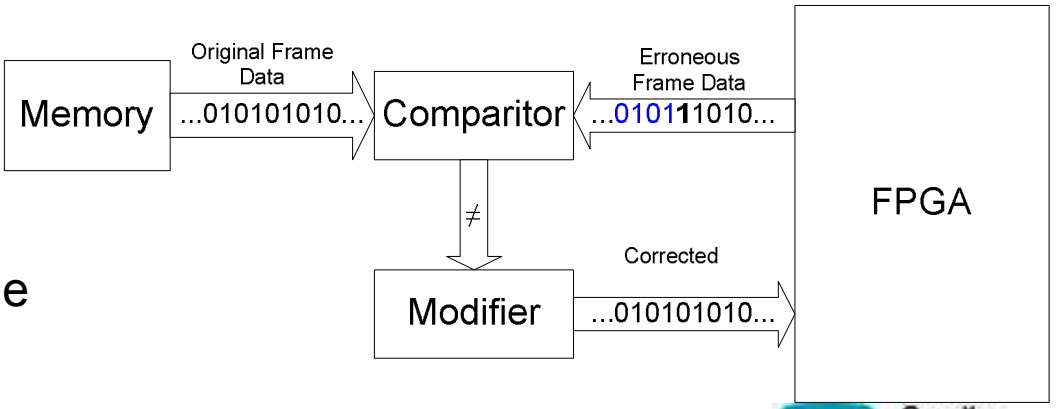
Sandia National Laboratories

FPGA Fault Tolerant Strategy

- FPGAs provide SEU mitigation through redundancy and scrubbing
- Triple Modular Redundancy (TMR)
  - Triplicate module to introduce redundancy
  - Vote on outputs of triplicated module
  - Use greatest common result



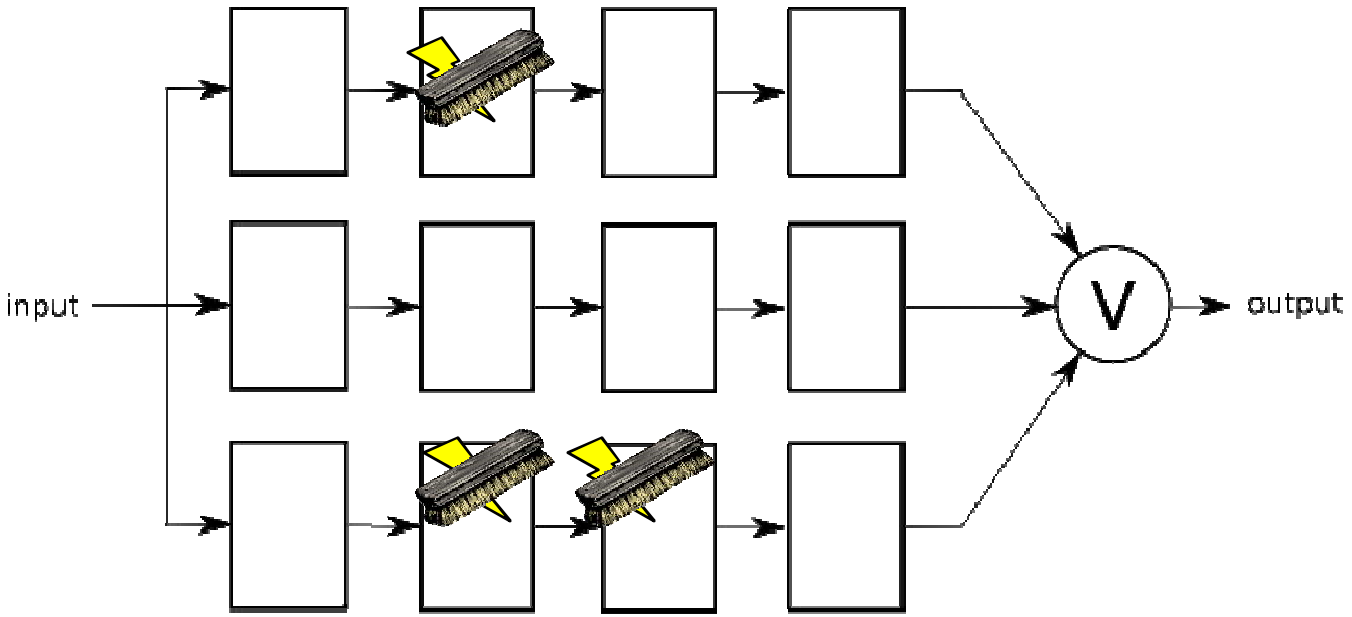
- Configuration Scrubbing
  - Readback frame data
  - Compare frame to original
  - Correct erroneous bits in frame
  - Writeback frame to FPGA



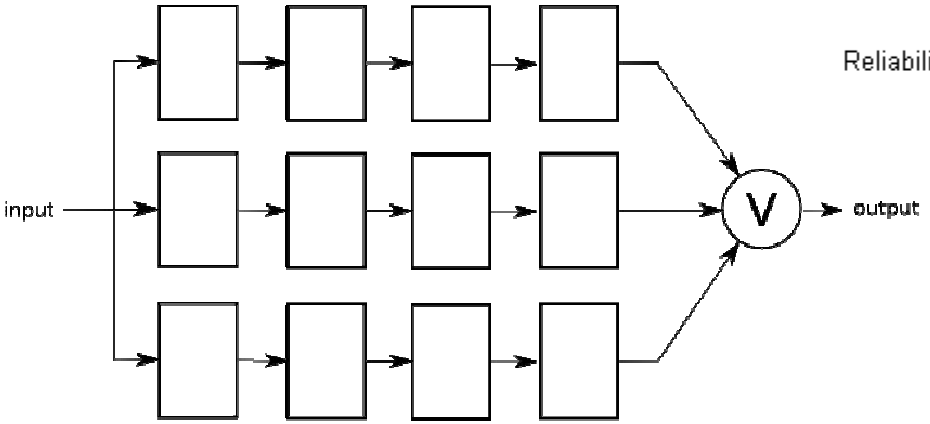
BYU
BRIGHAM YOUNG UNIVERSITY

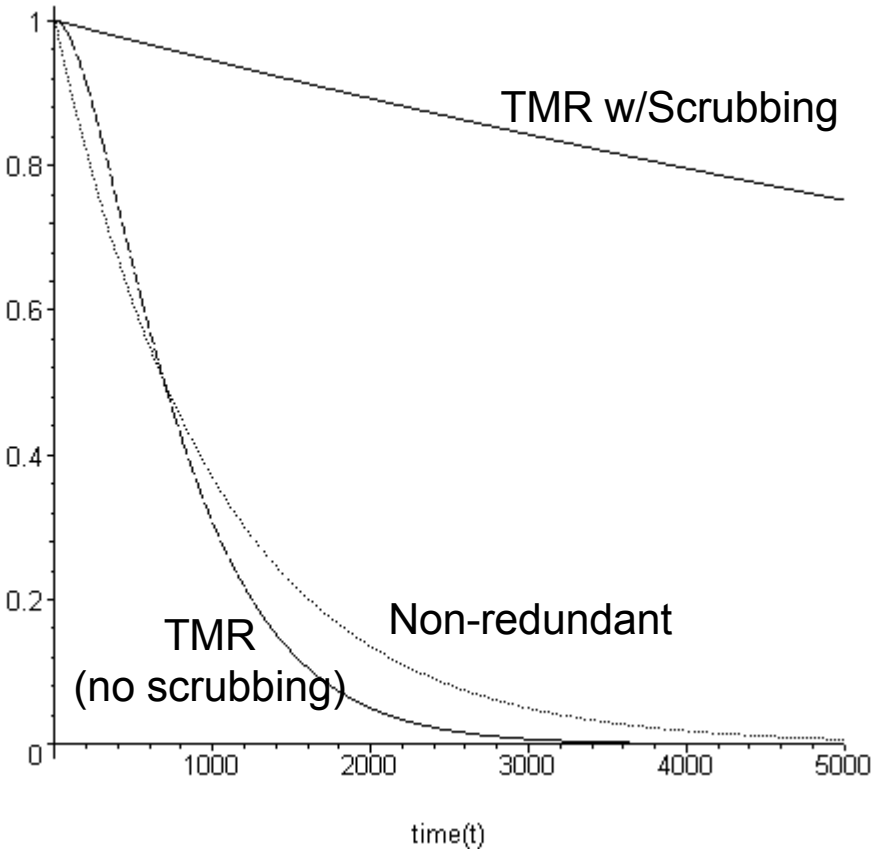
Sandia National Laboratories

TMR & Scrubbing Example



TMR & Scrubbing Reliability

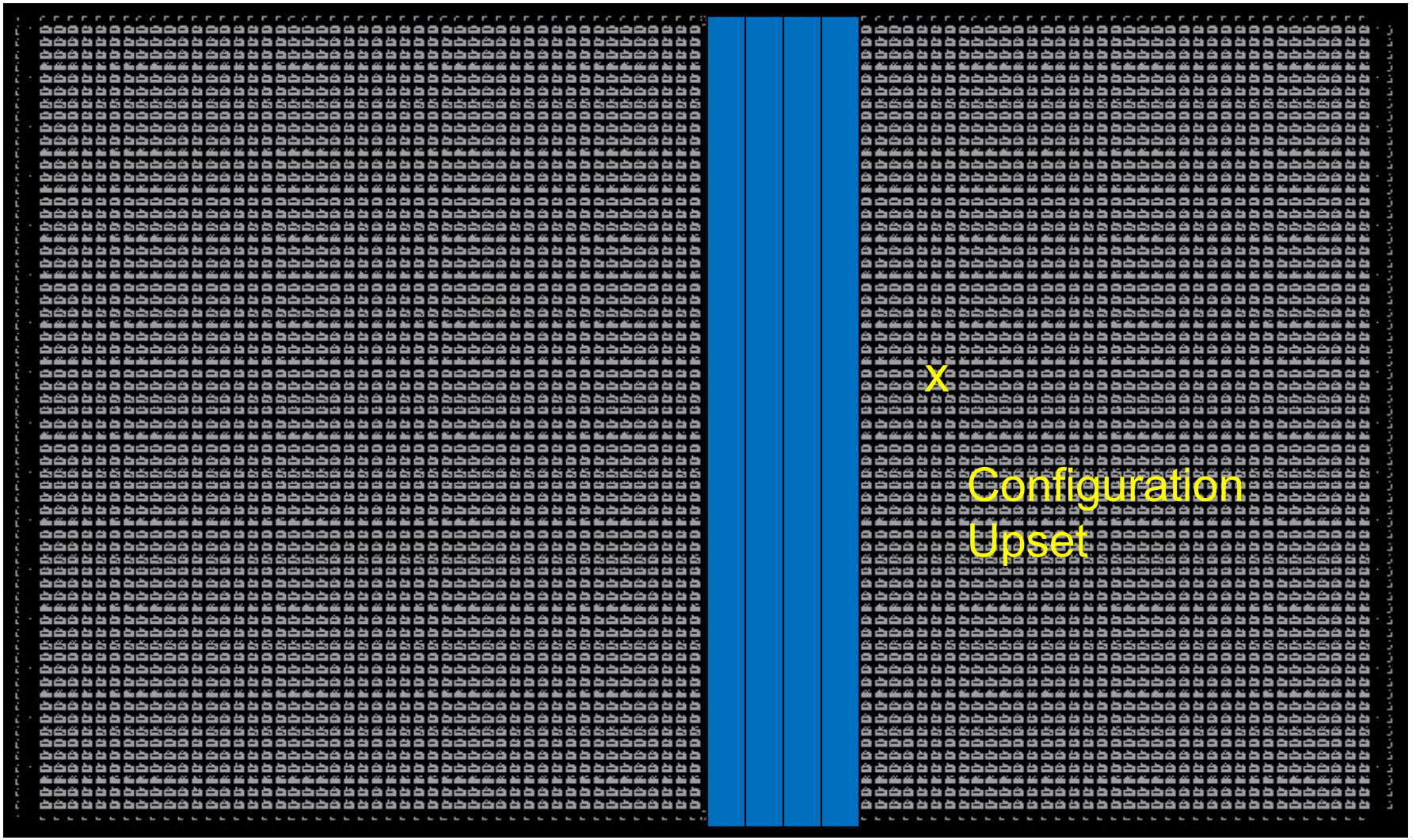




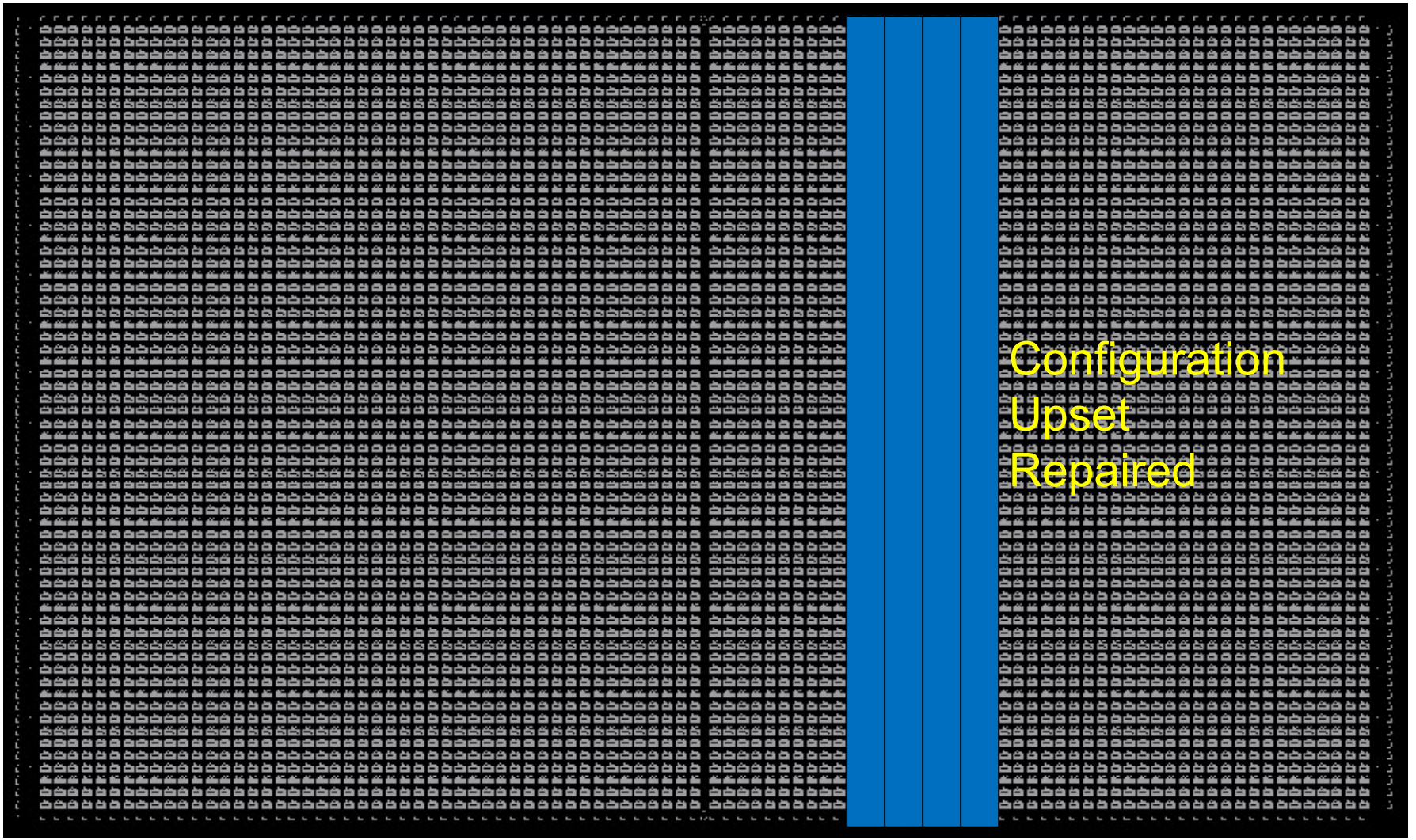
BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

Configuration Scrubbing Example



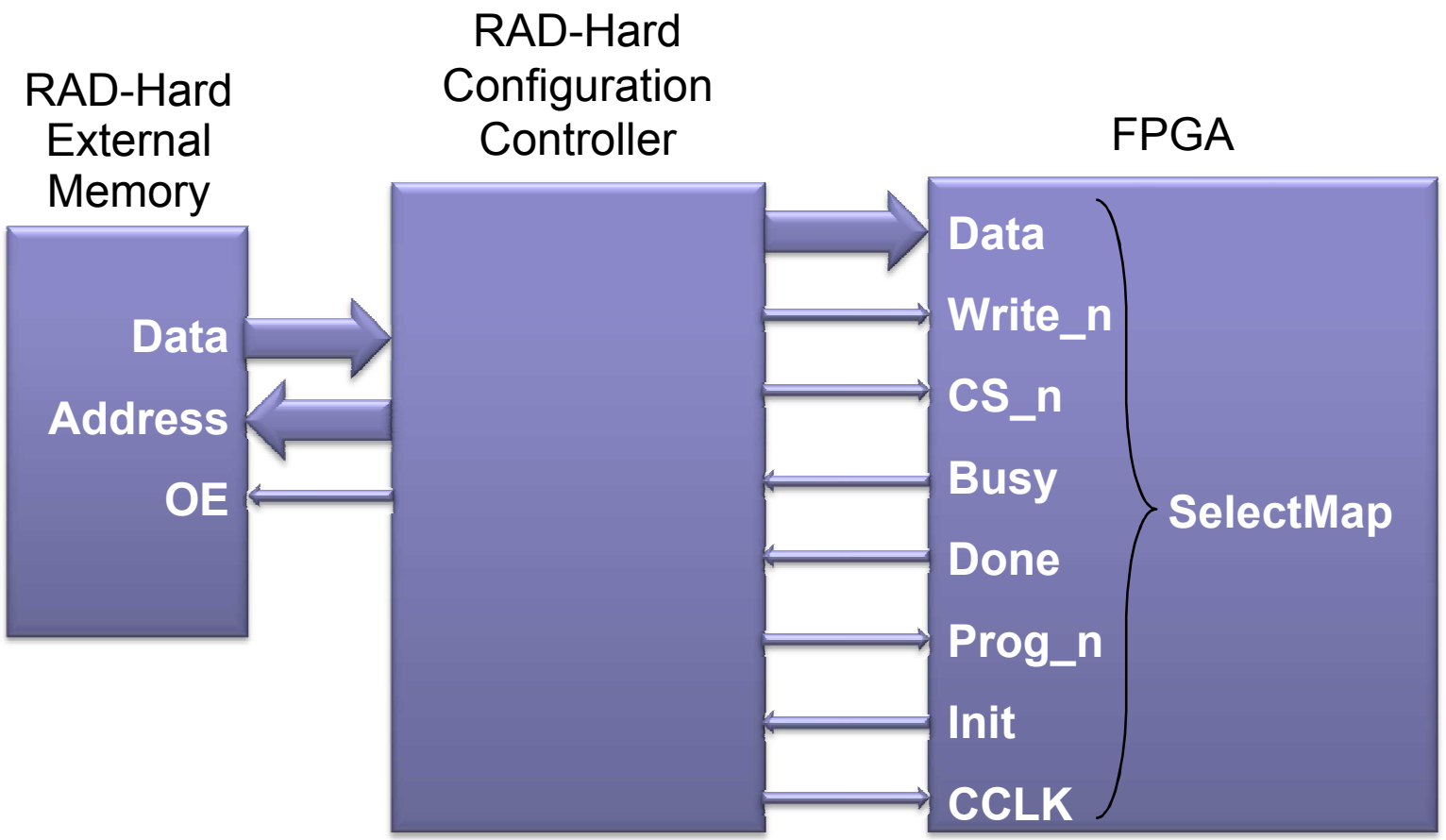
Configuration Scrubbing Example



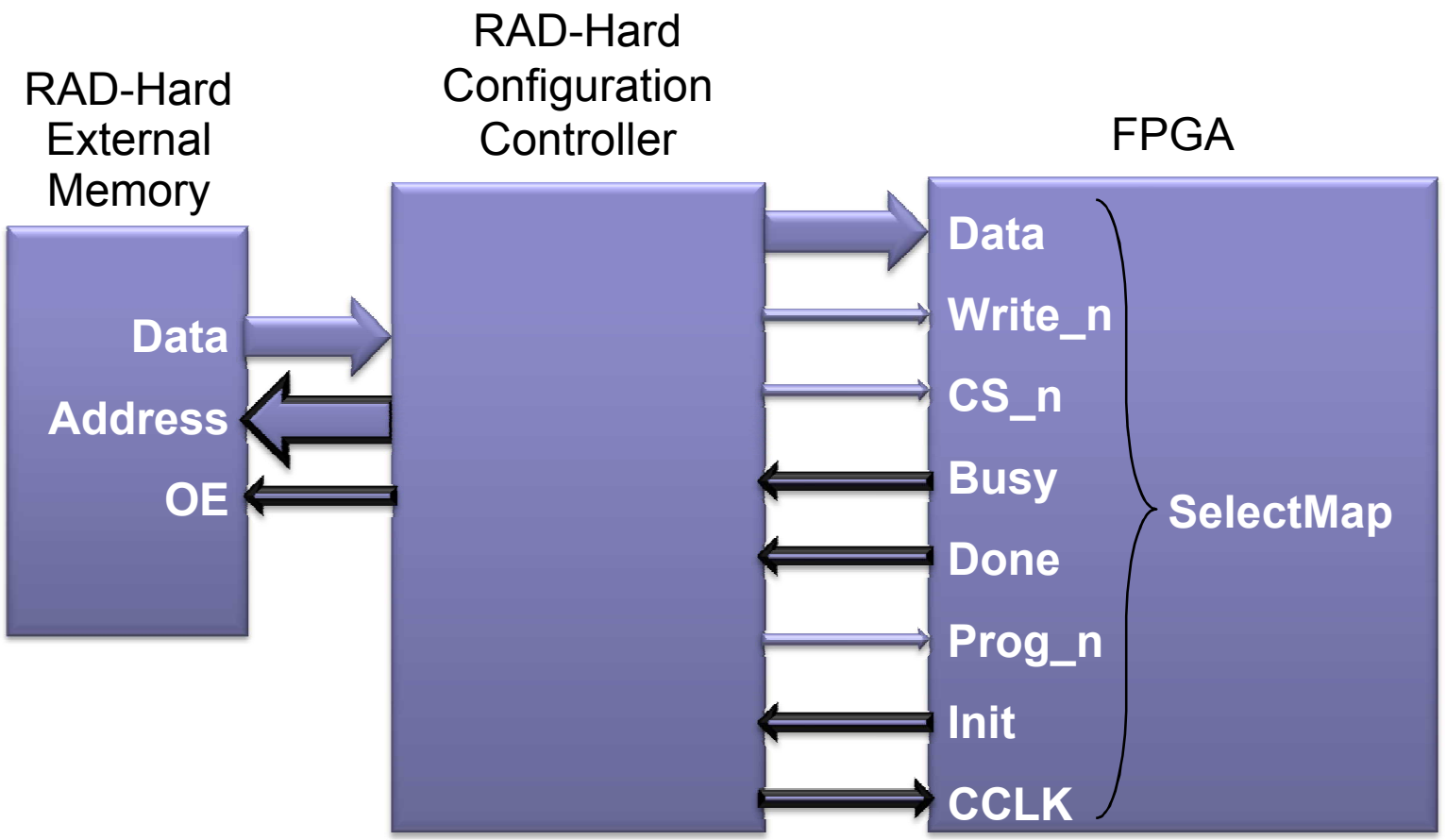
BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

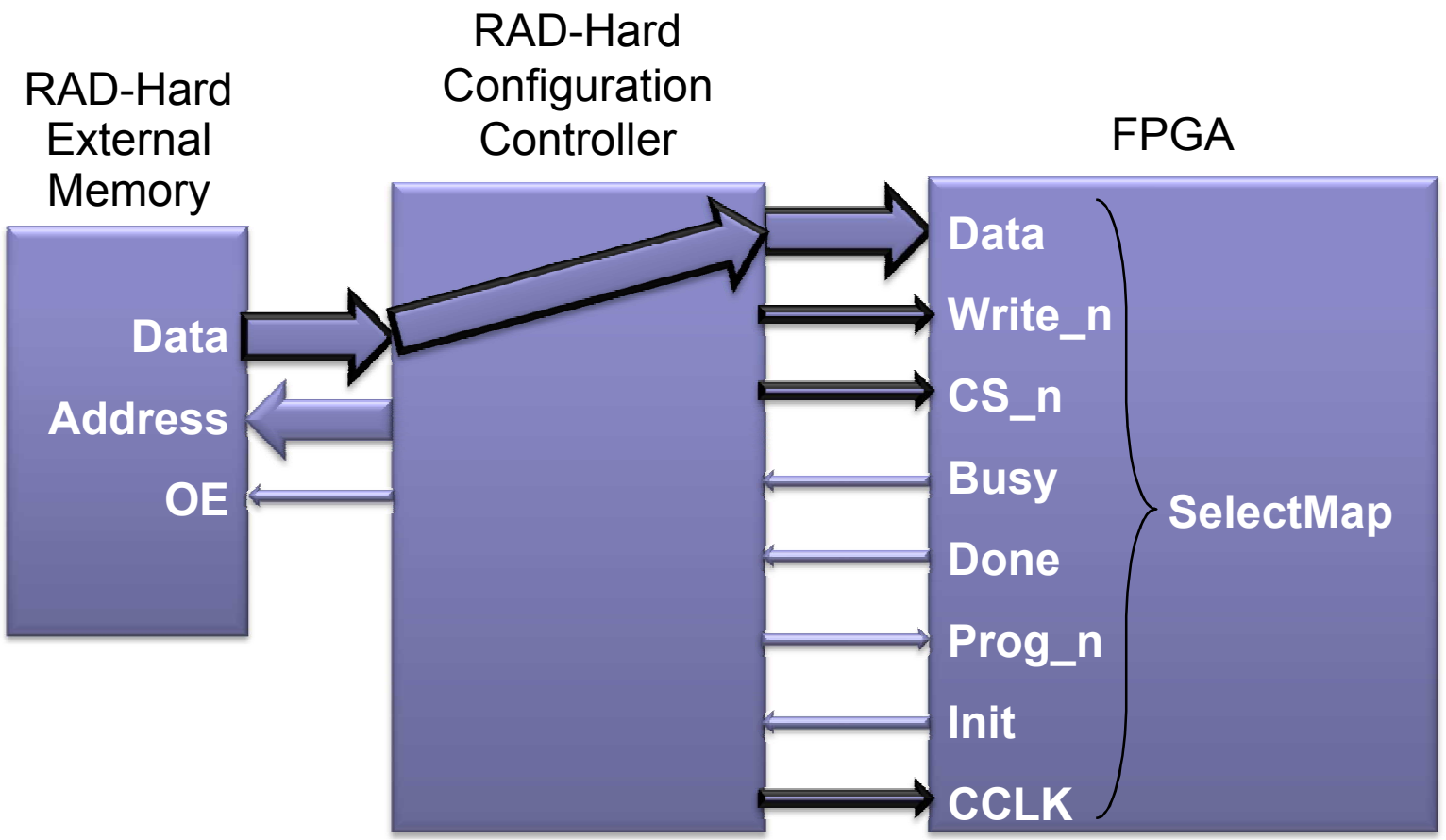
Traditional Scrubbing Process



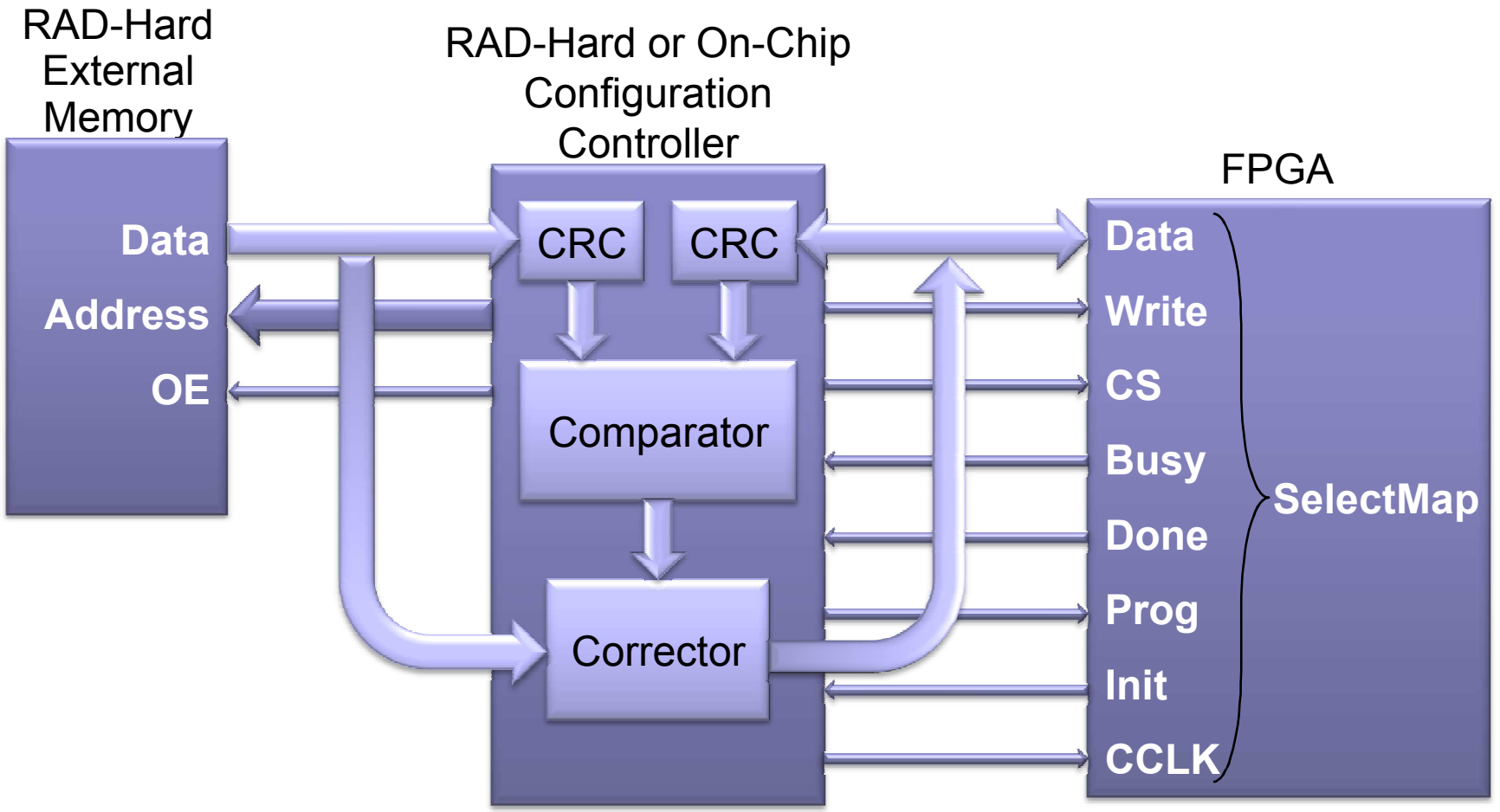
Traditional Scrubbing Process



Traditional Scrubbing Process

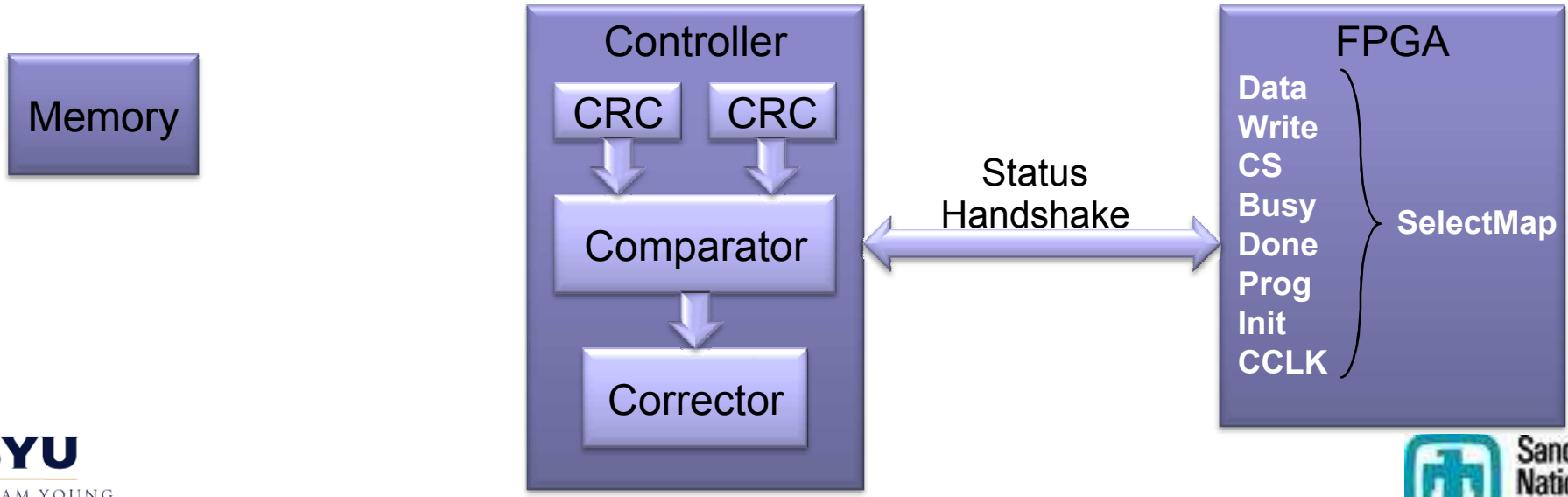


Readback w/ Compare Architecture



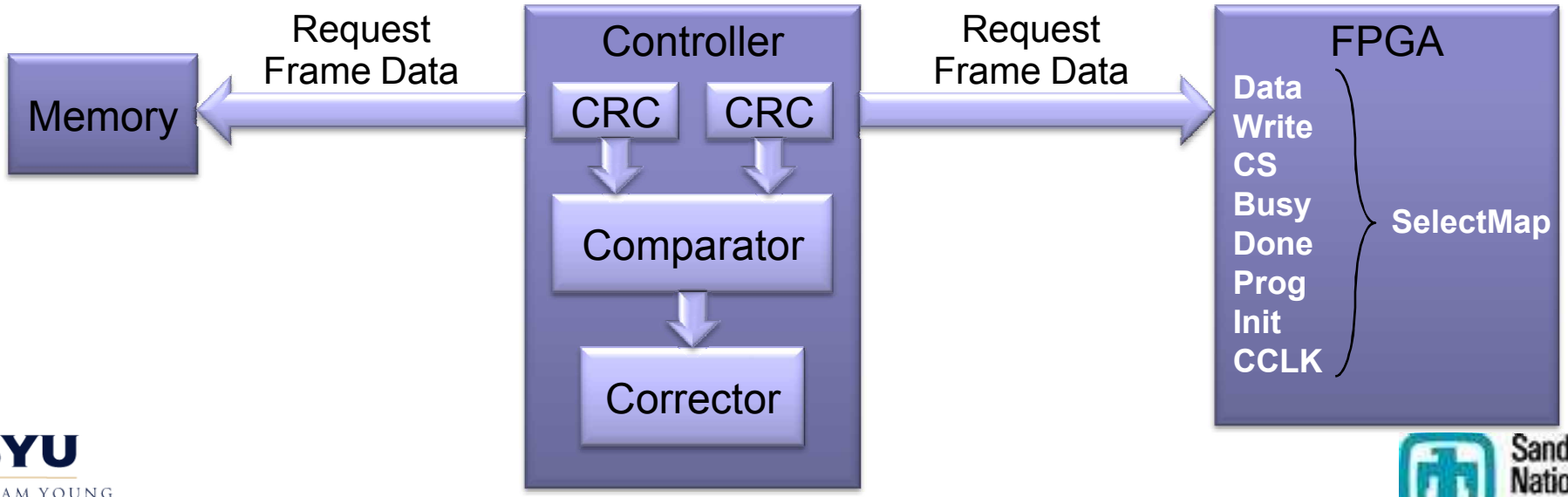
Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.



Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.

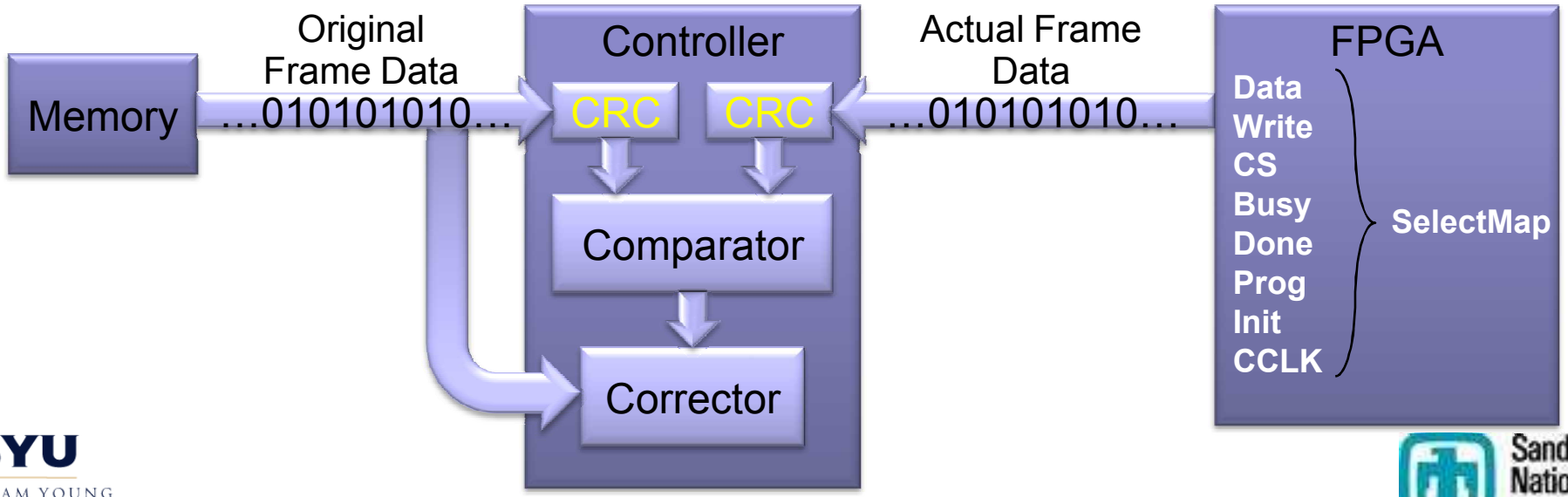


BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

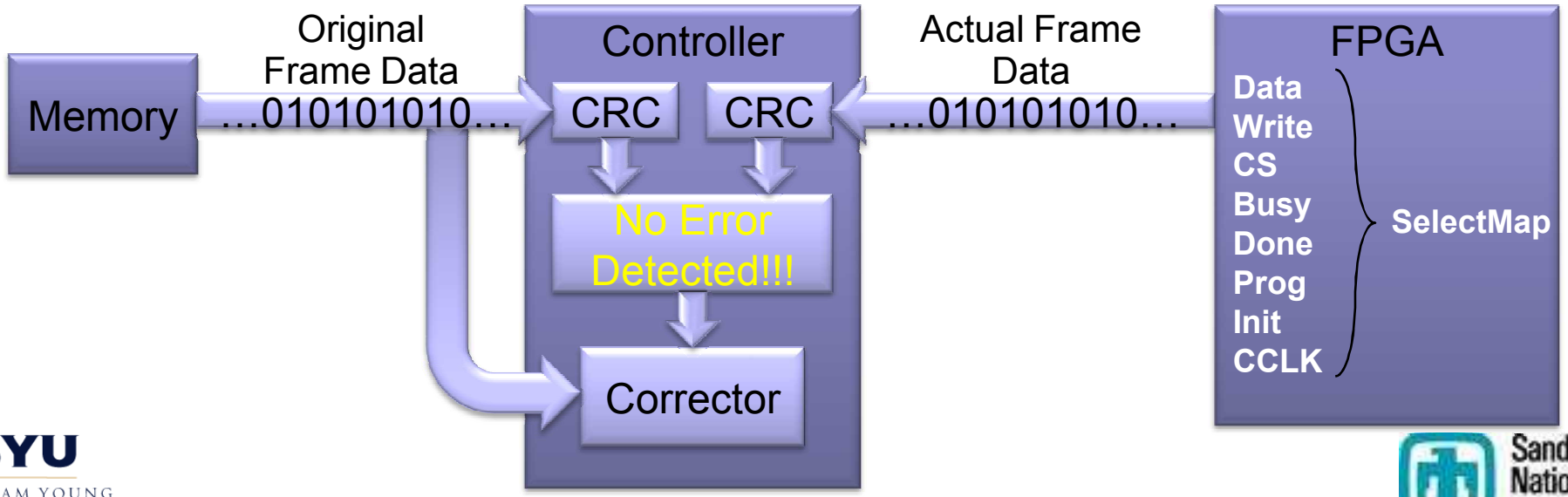
Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.
  - Compute CRC value on frames (optional).



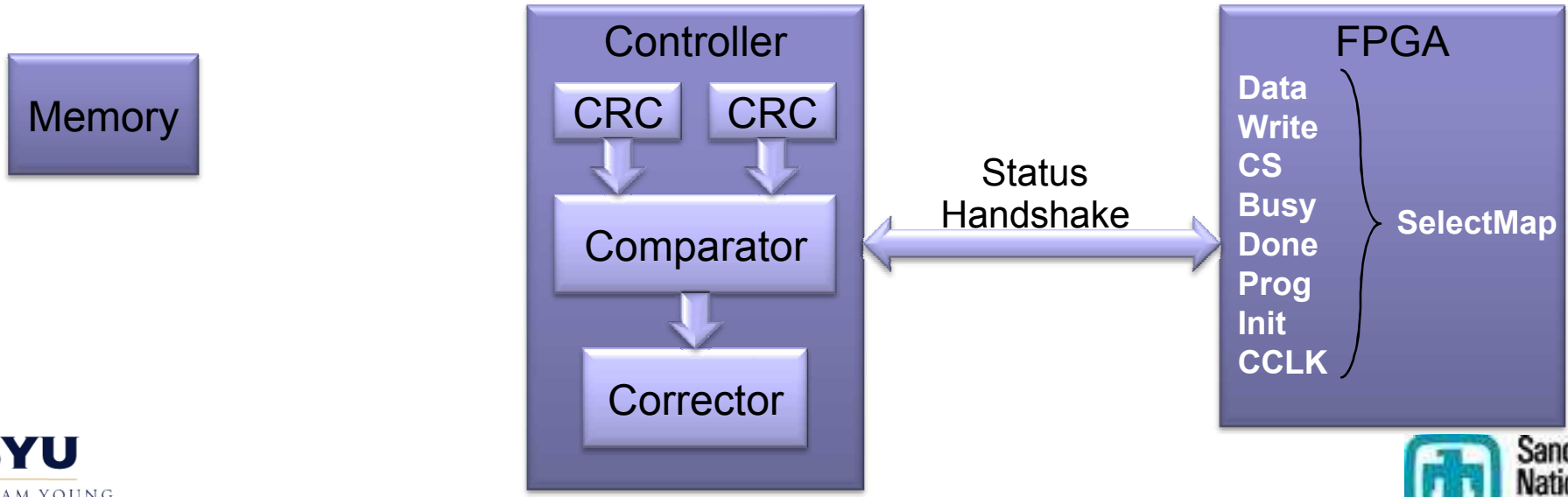
Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.
  - Compute CRC value on frames (optional).
  - Compare frames or CRC values to detect errors.



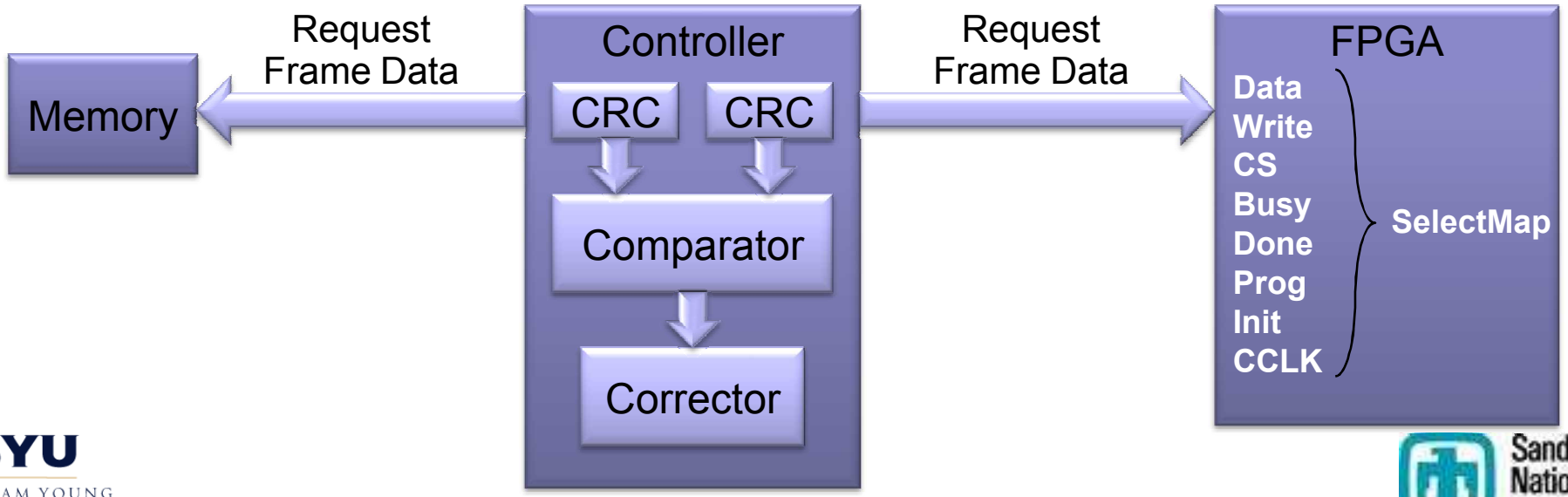
Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.



Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.

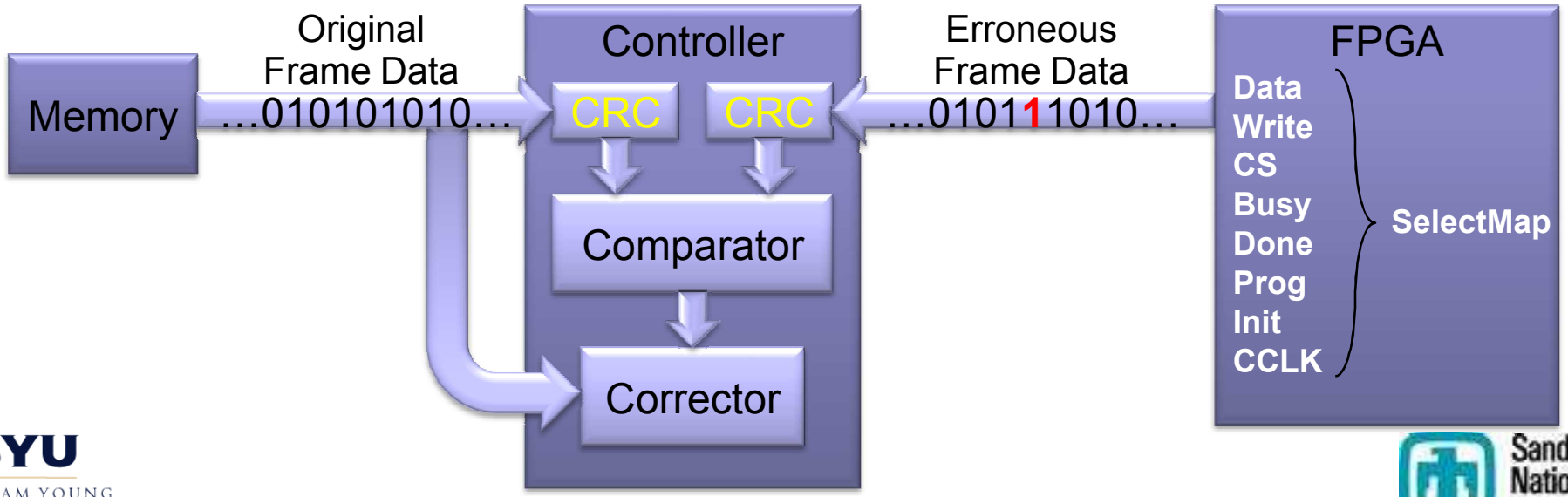


BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.
  - Compute CRC value on frames (optional).

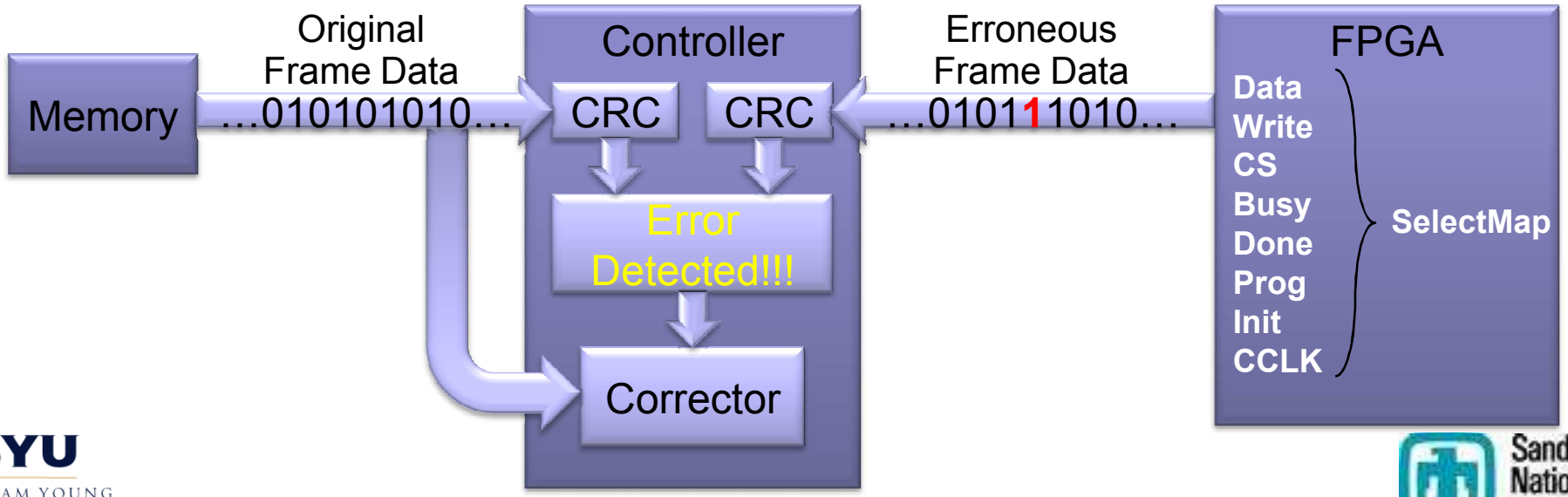


BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

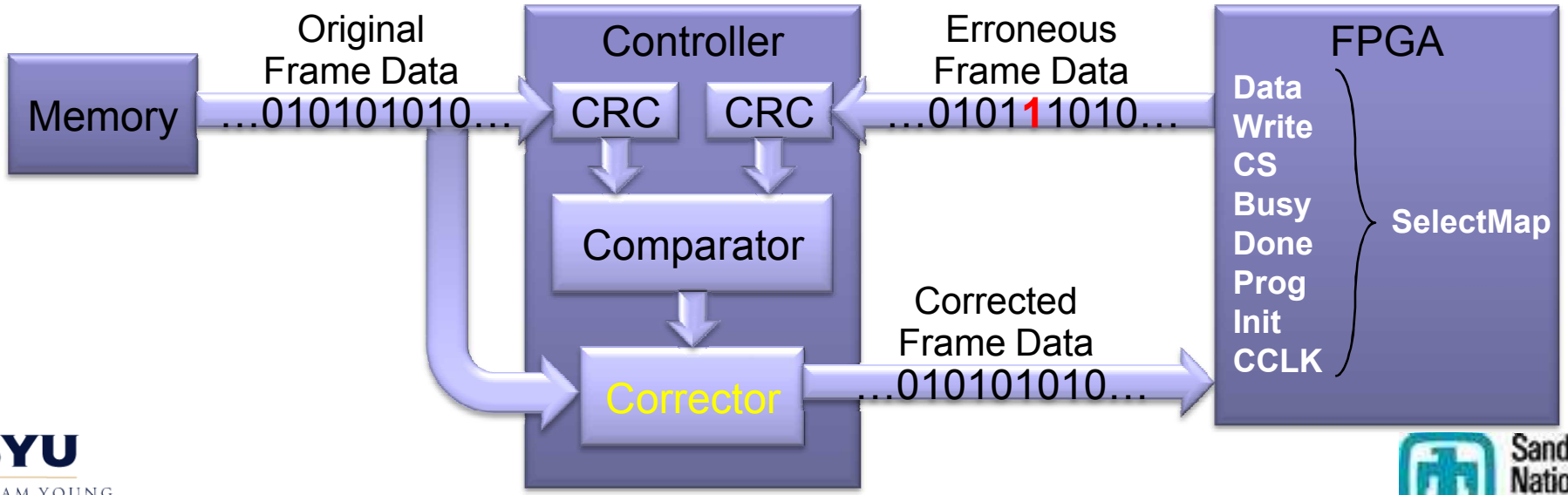
Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.
  - Compute CRC value on frames (optional).
  - Compare frames or CRC values to detect errors.



Readback w/ Compare

- Read-back Scrubbing Process
  - Check status of controller and SelectMap.
  - Read one frame from memory and FPGA.
  - Compute CRC value on frames (optional).
  - Compare frames or CRC values to detect errors.
  - Correct error or write original frame to FPGA through SelectMap.

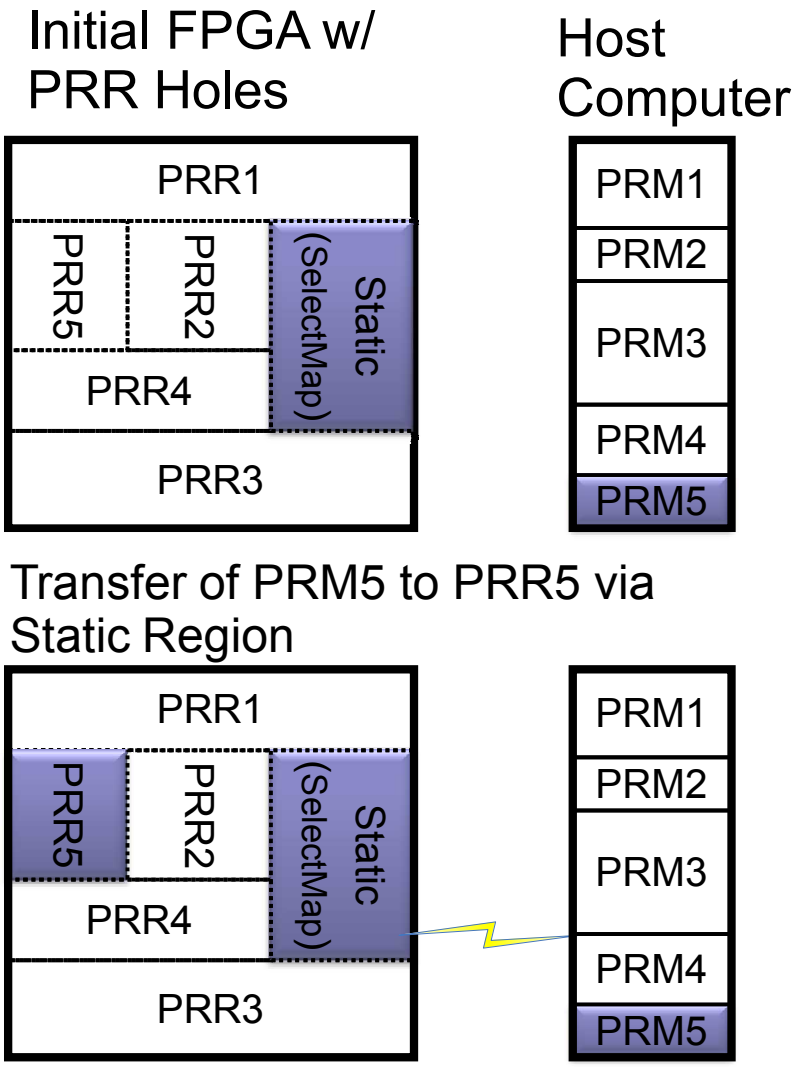


BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

Partial Reconfiguration (PR)

- Smaller initial footprint = faster boot-up
- Generic initial footprint = multiple device boot-ups
- "On-the-Fly" Reconfiguration
  - Design Updates
  - Component Swapping
  - Requires complete access to configuration memory.
- Divide Design
  - Static Region - All system critical components
  - Partial Regions - All non-critical components
- Partial Logic
  - Transmit via COM
  - Stored locally off-chip



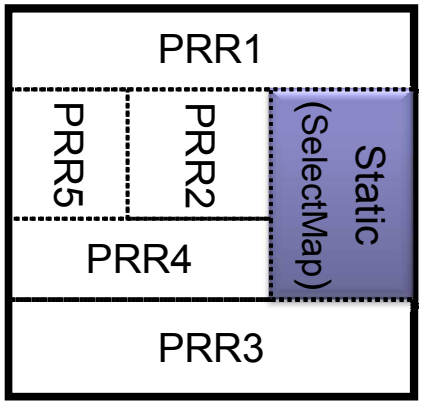
BYU BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

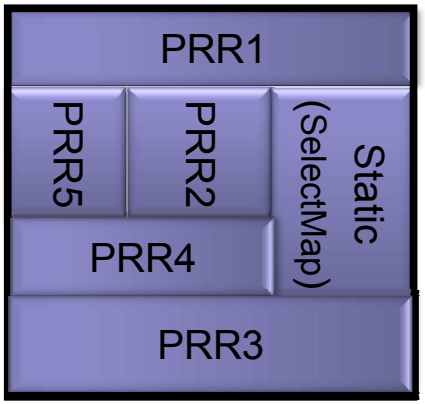
Partial Reconfiguration (PR)

- Virtual Hardware
  - Emulate large hardware resource by ‘paging’ circuits
- Multiplex hardware at run-time
  - Change hardware based on run-time conditions
- Run-time customization
  - Modify design based on user specific constants
- This work: Incremental configuration
  - Stage 1: Static reconfiguration using rad-hard memory
  - Stage 2: Dynamic reconfiguration over a network

Static Design



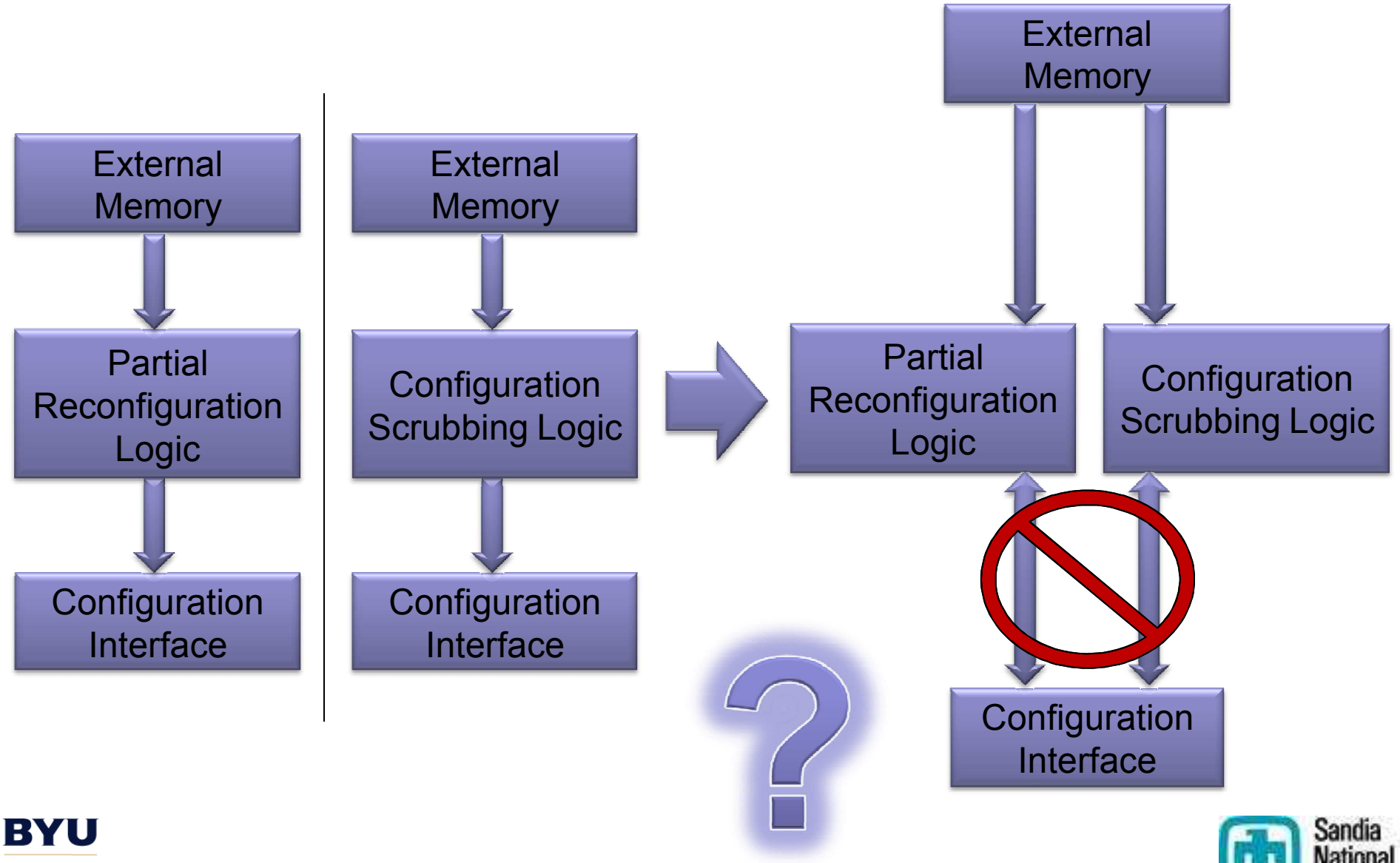
Dynamic Design



BYU
BRIGHAM YOUNG UNIVERSITY

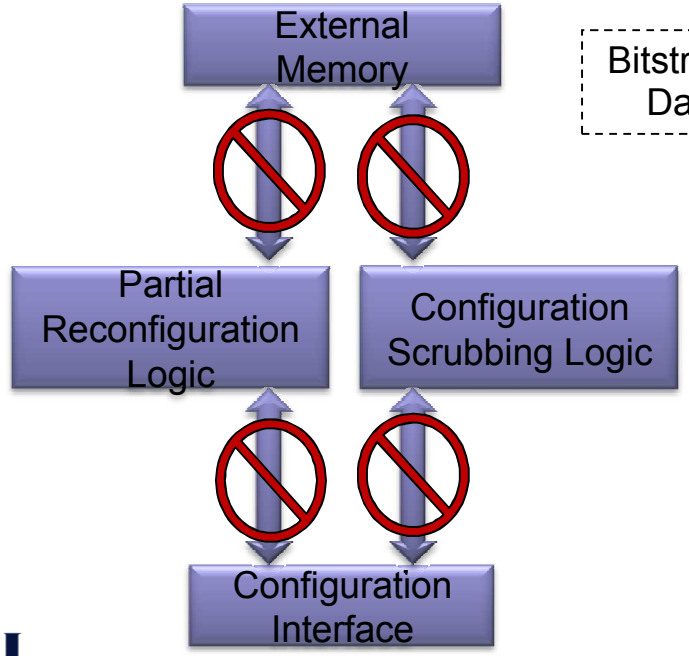
Sandia National Laboratories

PR vs. Configuration Scrubbing

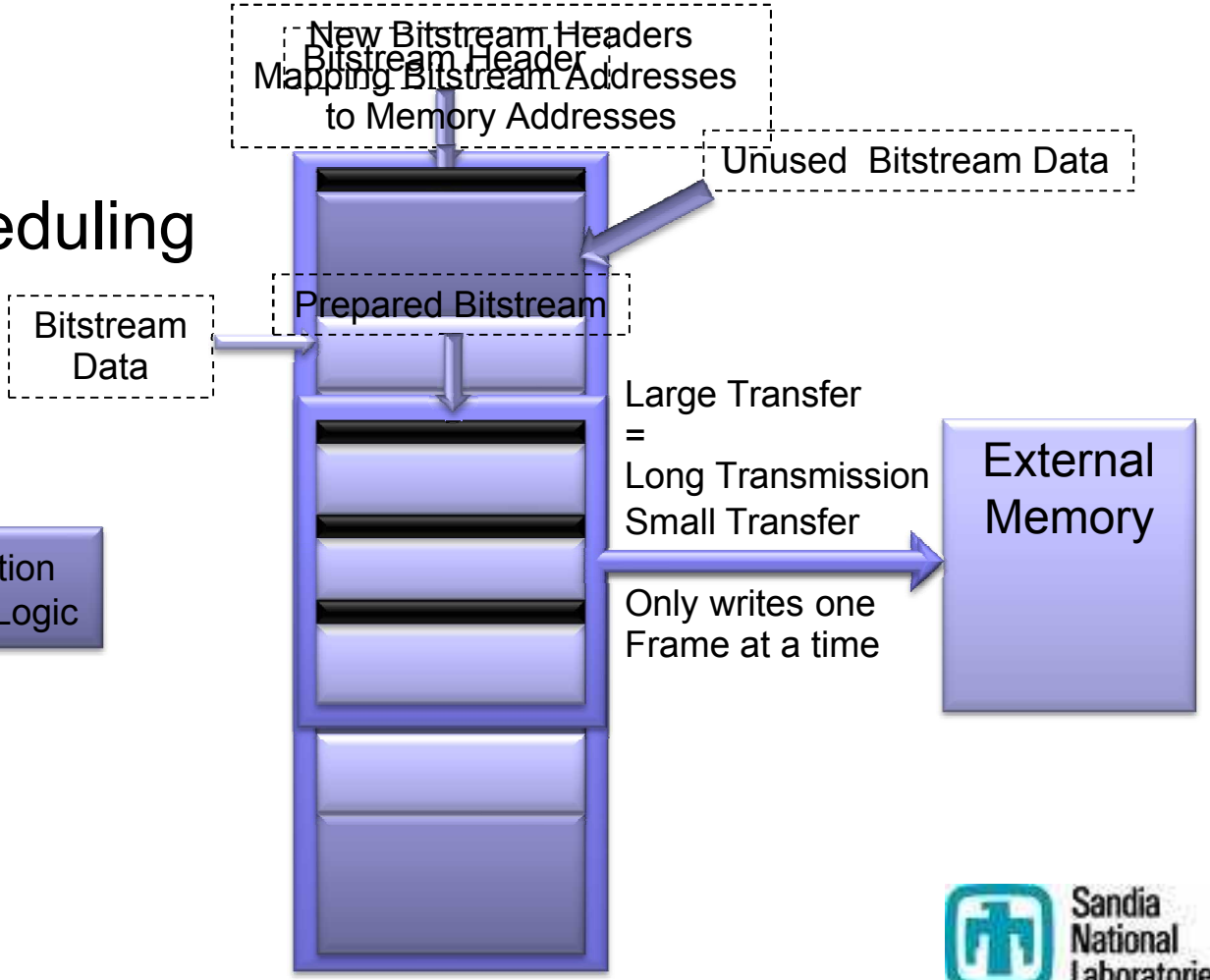


PR & Configuration Scrubbing Challenges

- Resource Scheduling
  - A. Configuration Scheduling
  - B. Memory Scheduling



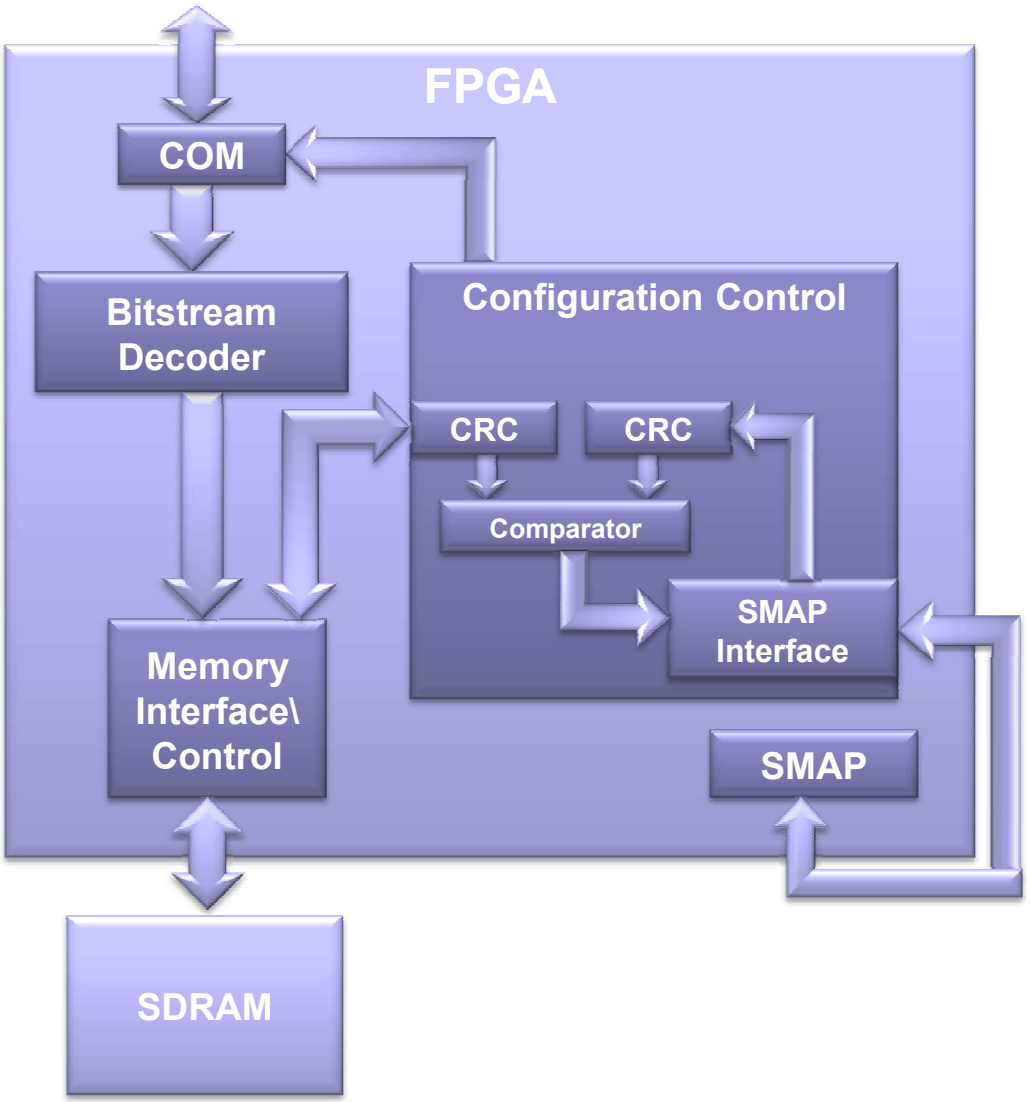
- Bitstream Preparation



BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

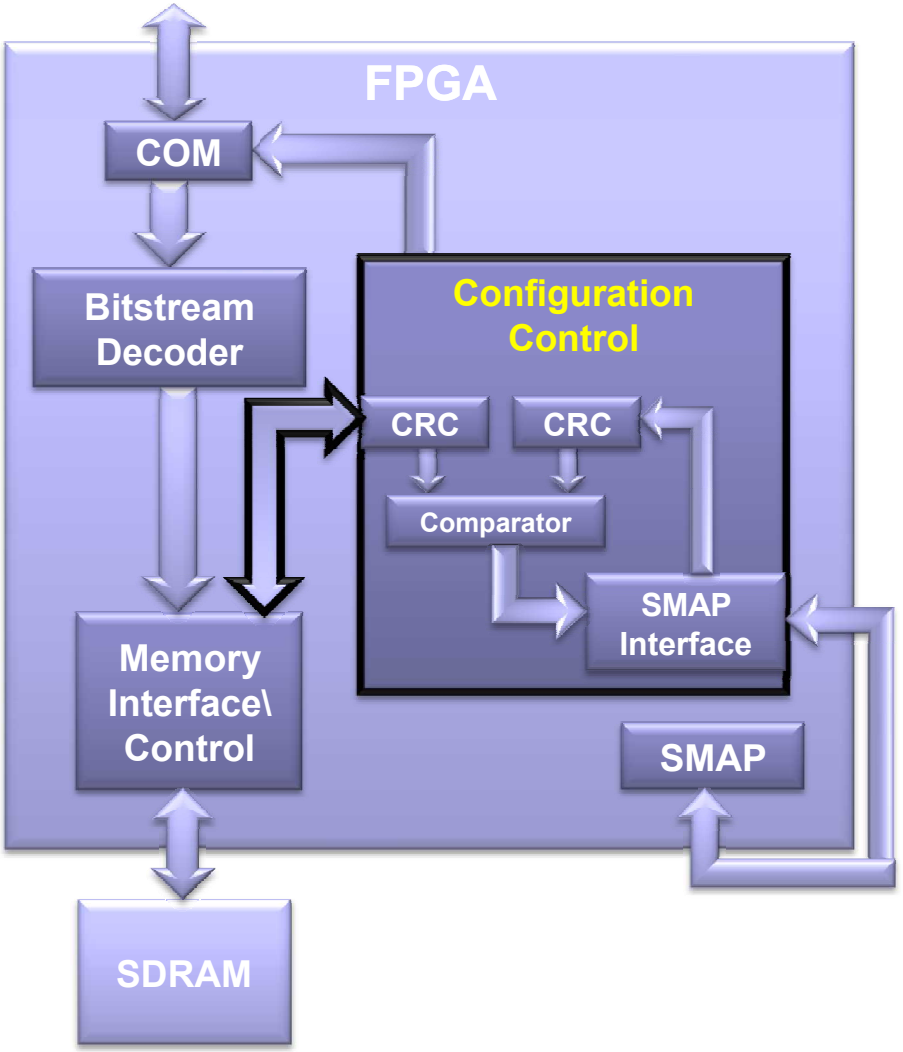


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Configuration Scrubbing
  - Configuration Control requests access to memory arbiter.

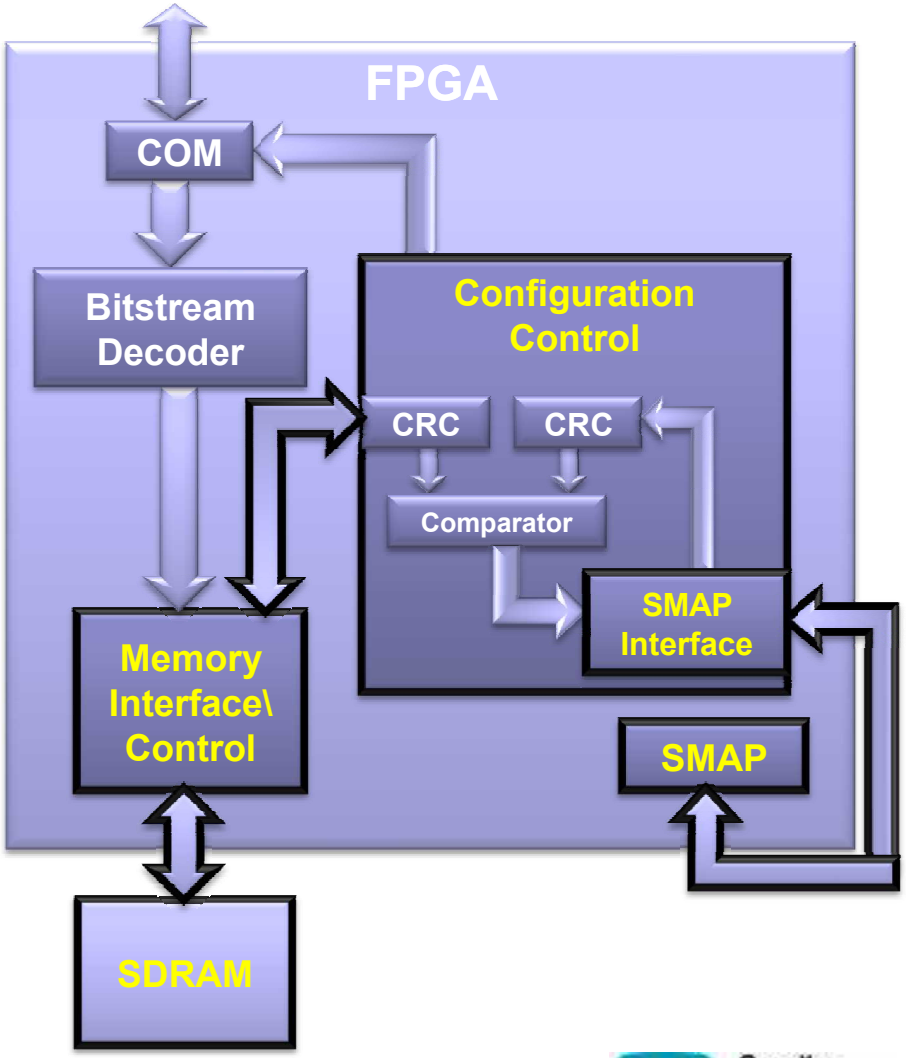


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Configuration Scrubbing
  - Configuration Control requests access to memory arbiter.
  - Configuration Control requests/reads a frame from both SMAP and SDRAM memory arbiter.

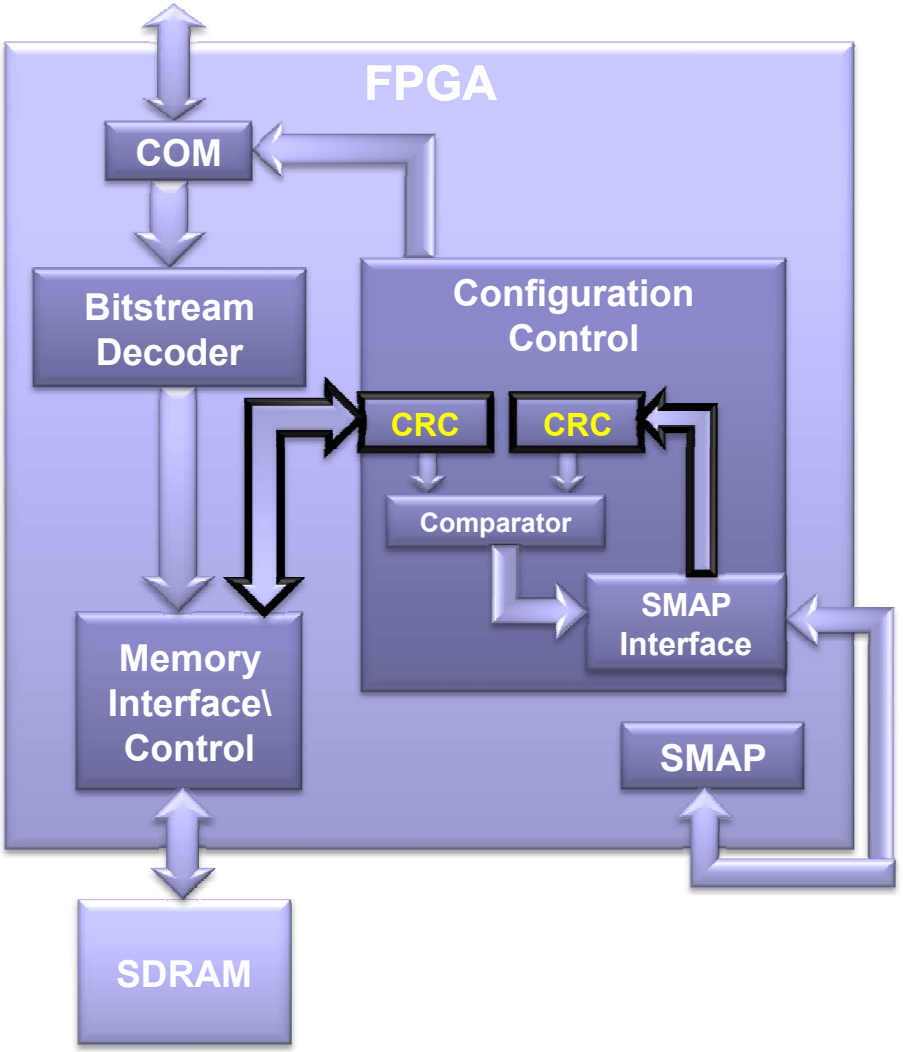


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Configuration Scrubbing
  - Configuration Control requests access to memory arbiter.
  - Configuration Control requests/reads a frame from both SMAP and SDRAM memory arbiter.
  - CRC values are computed

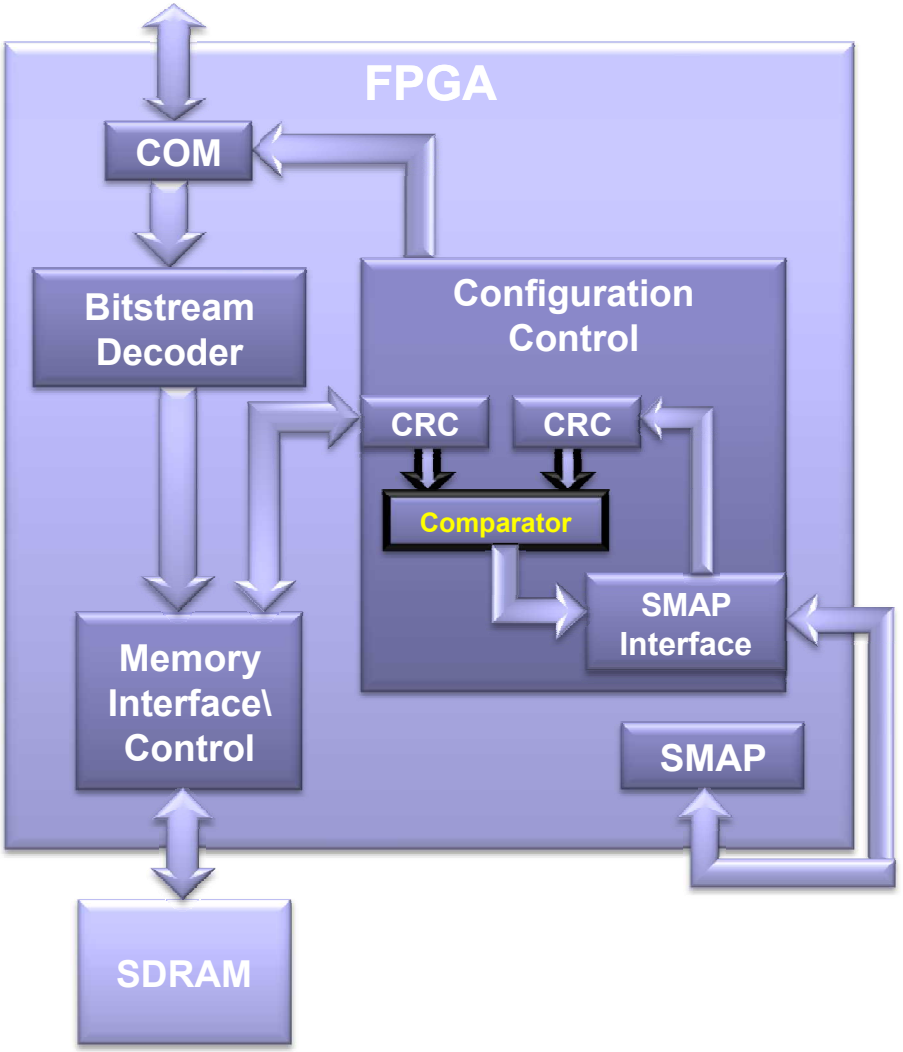


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

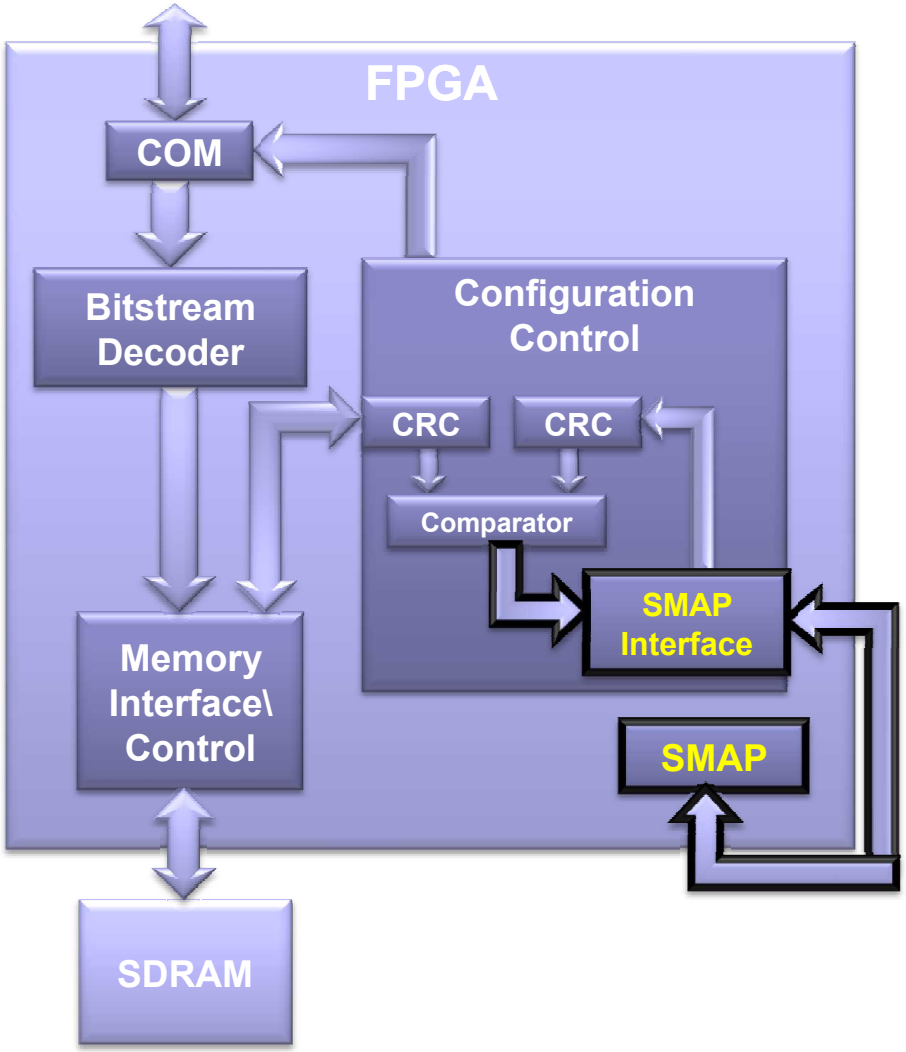
PR via Configuration Scrubbing Architecture

- Configuration Scrubbing
  - Configuration Control requests access to memory arbiter.
  - Configuration Control requests/reads a frame from both SMAP and SDRAM memory arbiter.
  - CRC values are computed
  - CRC values are compared to detect errors.



PR via Configuration Scrubbing Architecture

- Configuration Scrubbing
  - Configuration Control requests access to memory arbiter.
  - Configuration Control requests/reads a frame from both SMAP and SDRAM memory arbiter.
  - CRC values are computed
  - CRC values are compared to detect errors.
  - If error detected, SDRAM version of frame written to SMAP.

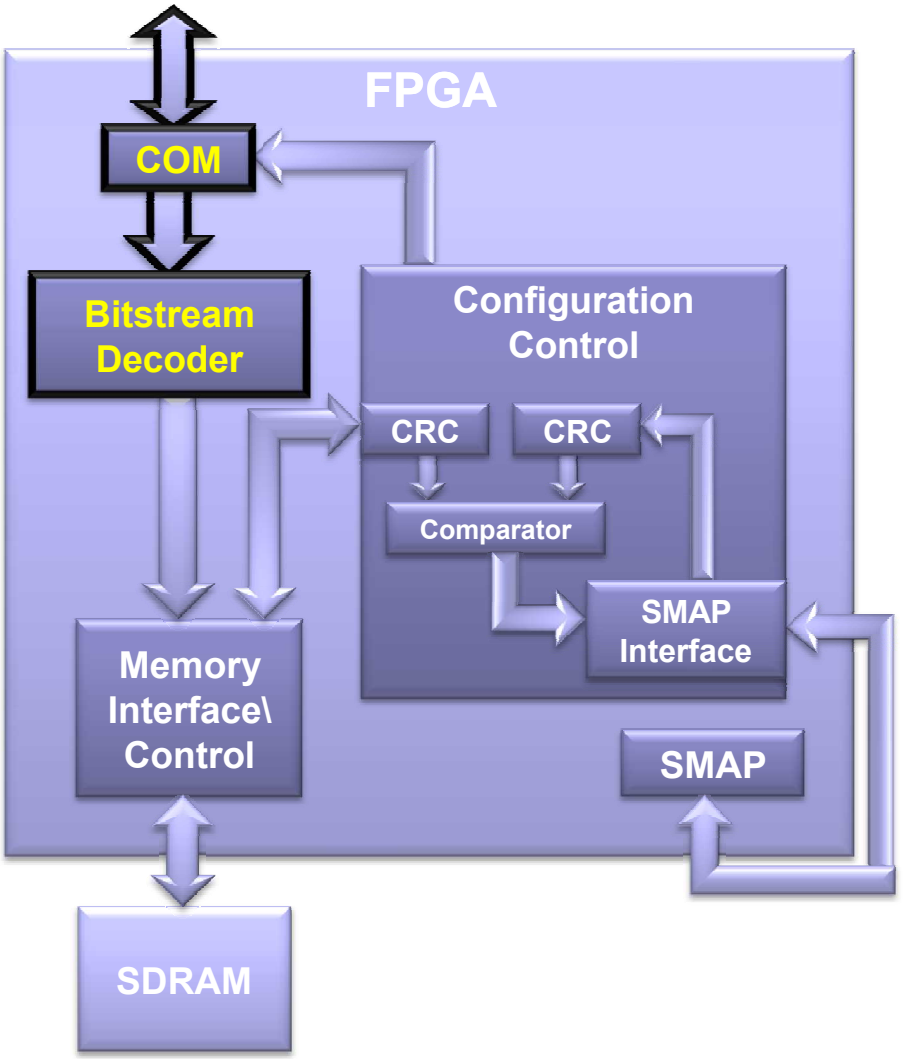


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Partial Reconfiguration
  - COM receives encoded bitstream and decodes bitstream using decoder.

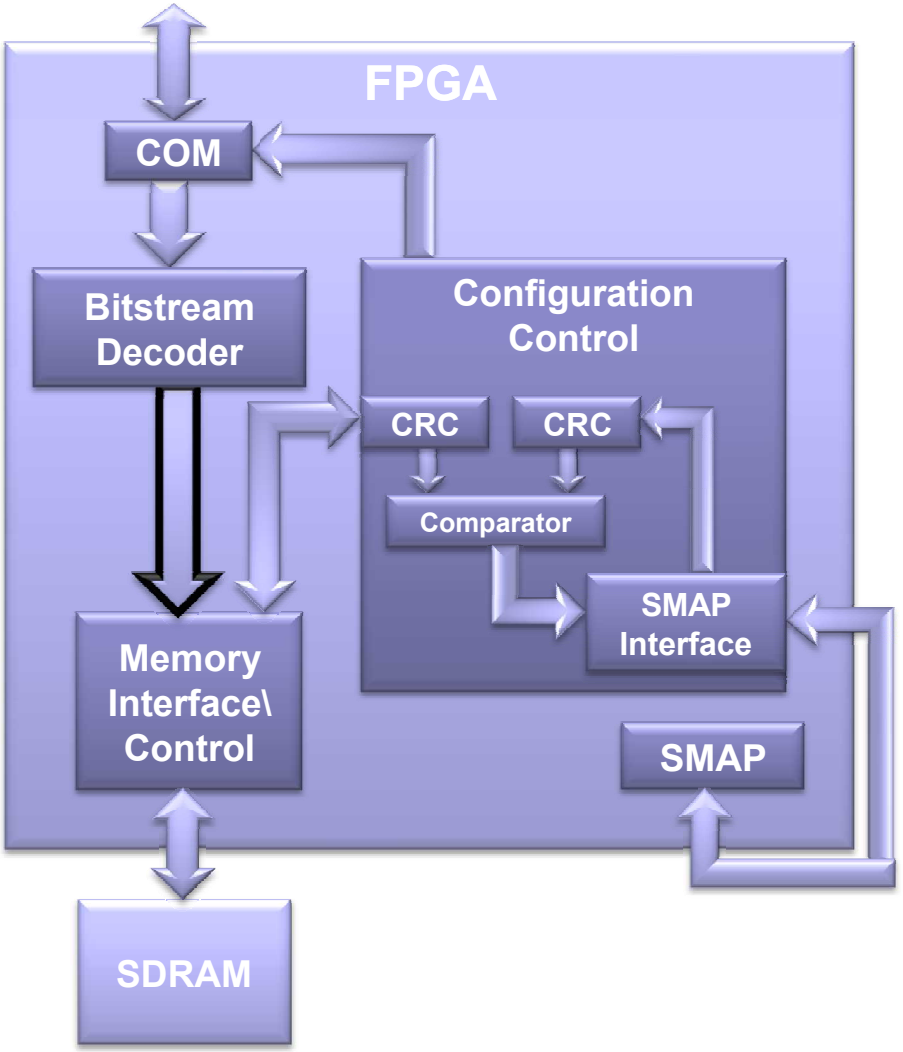


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Partial Reconfiguration
  - COM receives encoded bitstream and decodes bitstream using decoder.
  - COM Control requests access to memory arbiter.

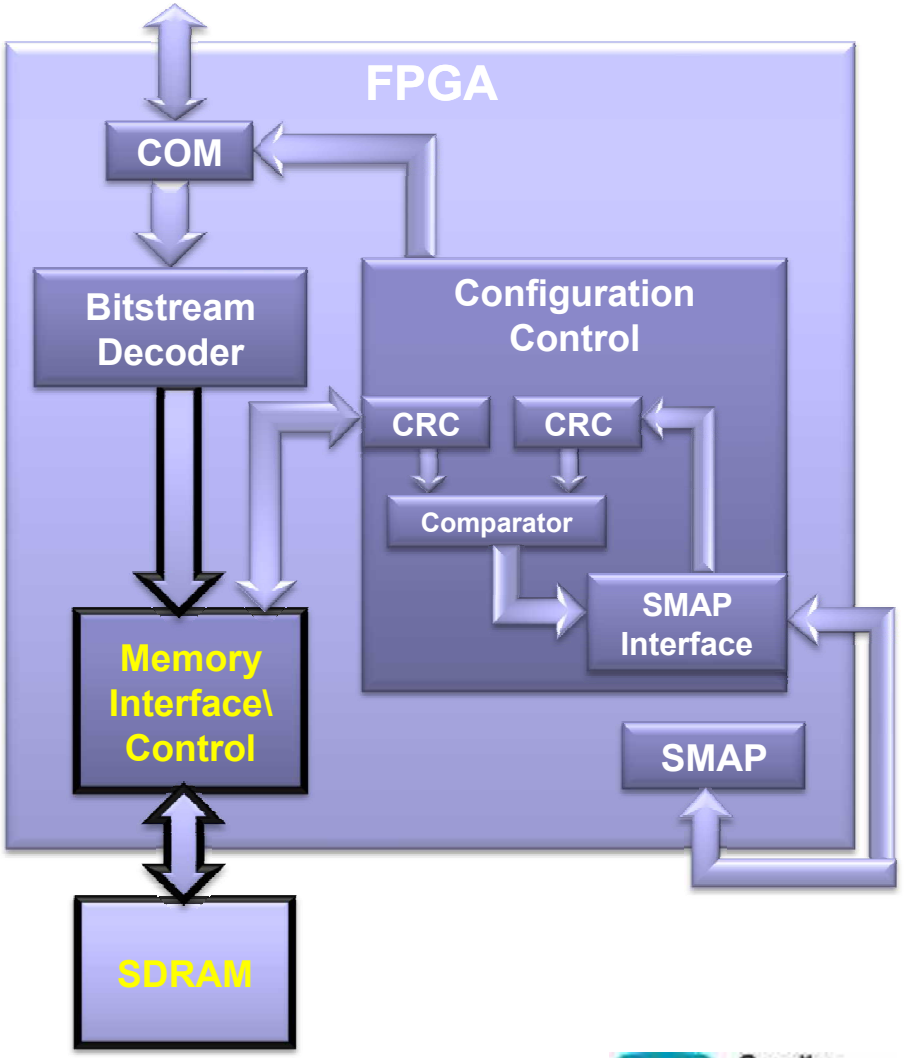


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

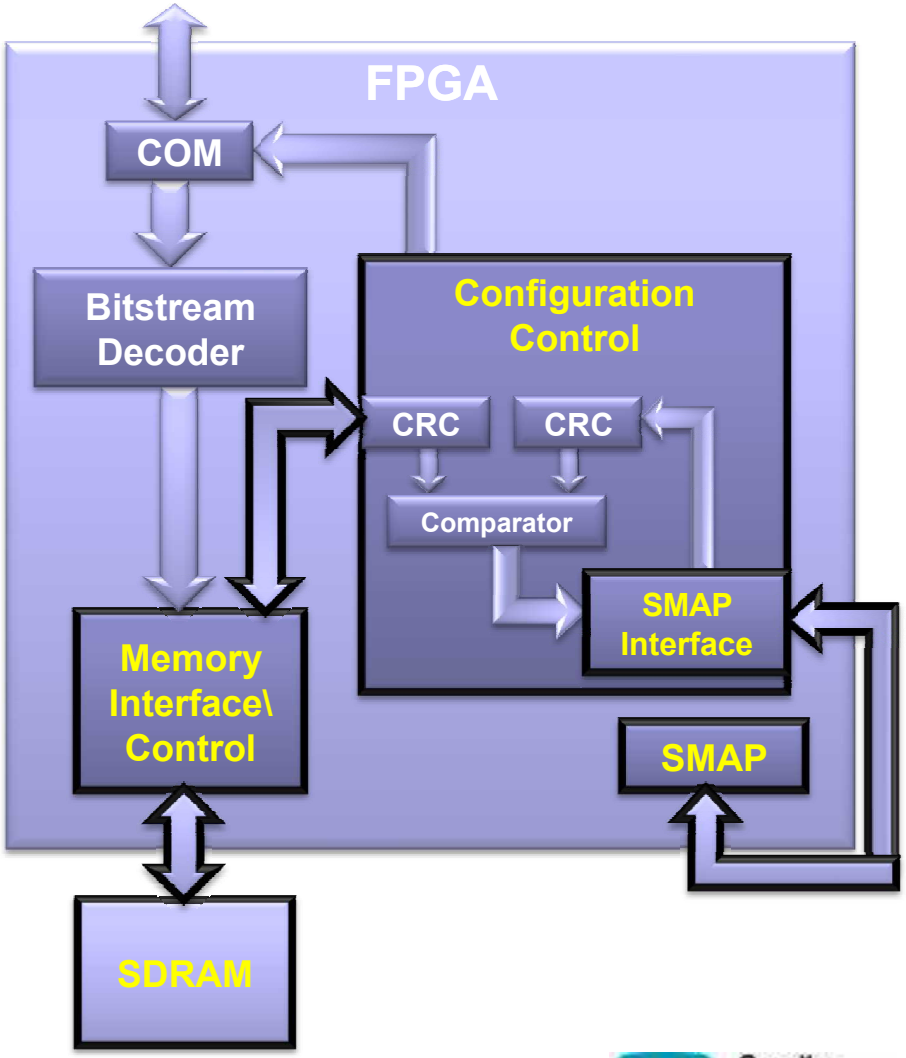
PR via Configuration Scrubbing Architecture

- Partial Reconfiguration
  - COM receives encoded bitstream and decodes bitstream using decoder.
  - COM Control requests access to memory arbiter.
  - COM Control transfers bitstream to memory arbiter for storage into SDRAM one frame at a time.



PR via Configuration Scrubbing Architecture

- Partial Reconfiguration
  - COM receives encoded bitstream and decodes bitstream using decoder.
  - COM Control requests access to memory arbiter.
  - COM Control transfers bitstream to memory arbiter for storage into SDRAM one frame at a time.
  - Configuration Controller requests/reads a frame from both SMAP and SDRAM.

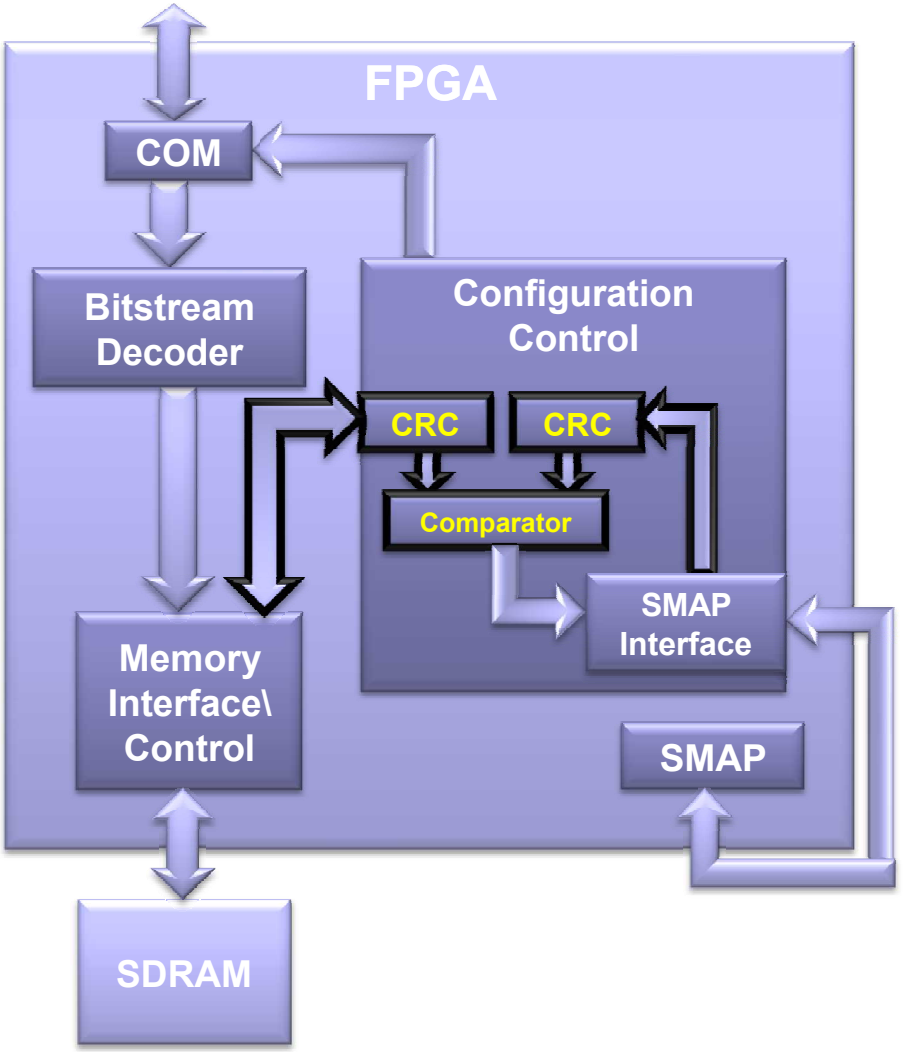


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Partial Reconfiguration
  - COM receives encoded bitstream and decodes bitstream using decoder.
  - COM Control requests access to memory arbiter.
  - COM Control transfers bitstream to memory arbiter for storage into SDRAM one frame at a time.
  - Configuration Controller requests/reads a frame from both SMAP and SDRAM.
  - Configuration Controller identifies difference between memory and SMAP.

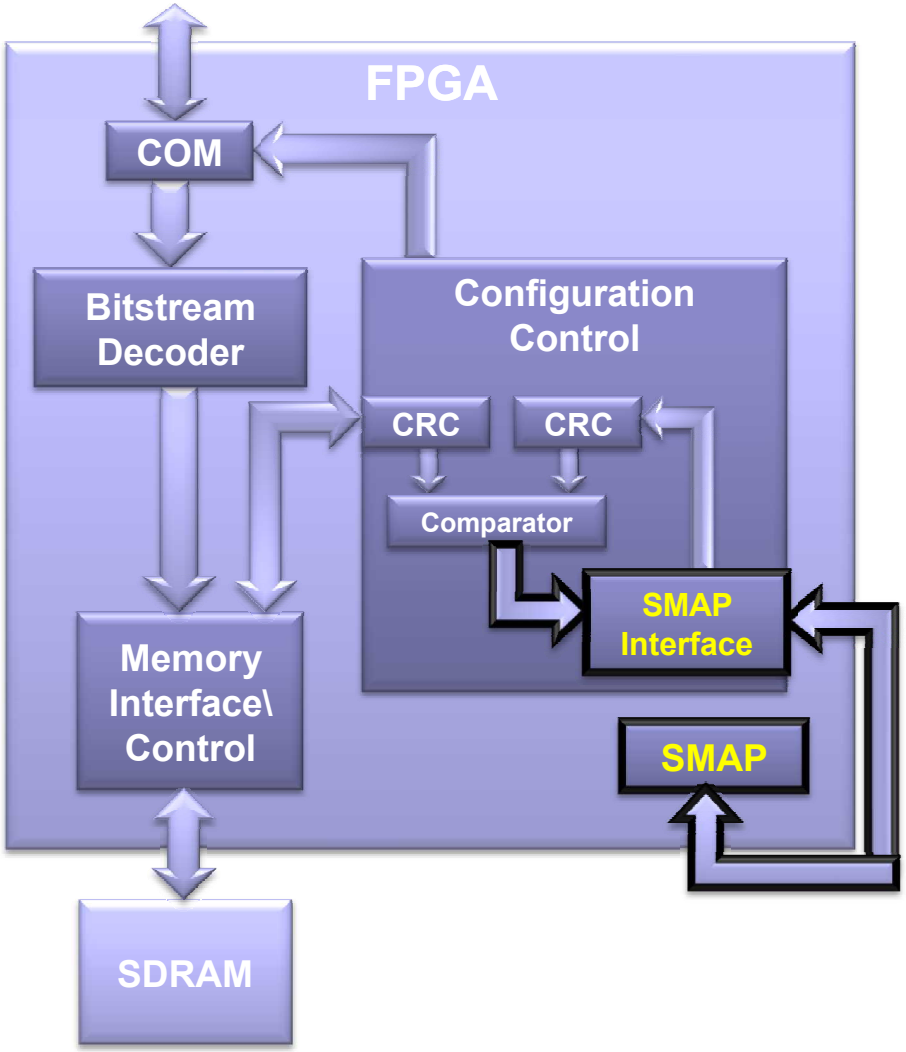


BYU
BRIGHAM YOUNG UNIVERSITY

Sandia National Laboratories

PR via Configuration Scrubbing Architecture

- Partial Reconfiguration
  - COM receives encoded bitstream and decodes bitstream using decoder.
  - COM Control requests access to memory arbiter.
  - COM Control transfers bitstream to memory arbiter for storage into SDRAM one frame at a time.
  - Configuration Controller requests/reads a frame from both SMAP and SDRAM.
  - Configuration Controller identifies difference between memory and SMAP.
  - Configuration Controller writes new logic over old logic performing Partial Reconfiguration.



BYU
BRIGHAM YOUNG UNIVERSITY

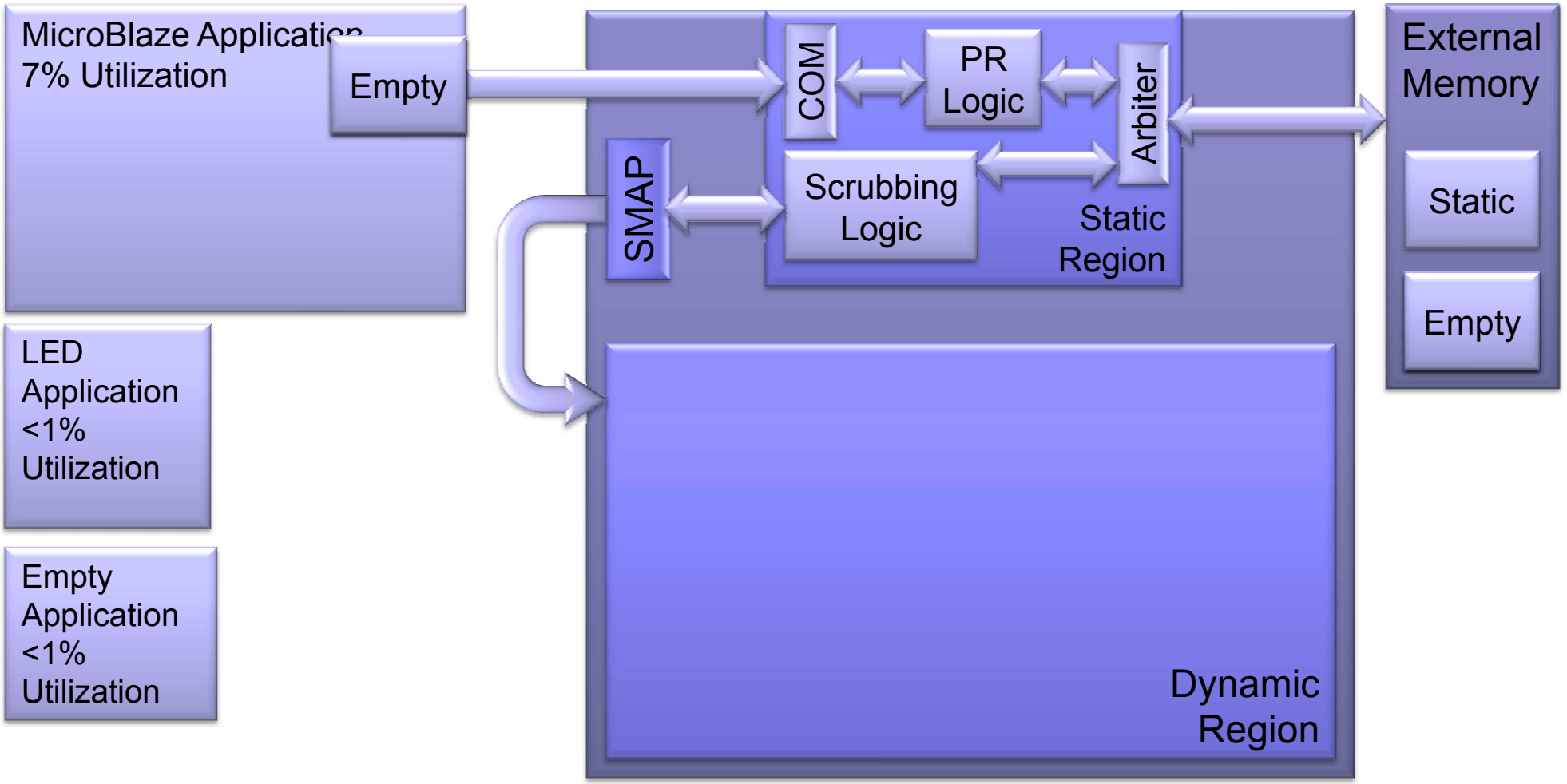
Sandia National Laboratories

Benefits and Limitations

- Benefits
  - Reconfigurable Space Applications
    - Upgradeable
    - Component Swapping
  - Time
    - Reduced Boot-up
    - Reduced Upload
  - Cost
    - Reduced RAD-HARD Cost
- Basically all the benefits of PR and Configuration Scrubbing.

- Limitations
  - Idea
    - Reduced reliability by stopping scrubber.
  - Implementation
    - Single-port SDRAM
      - Needs dual-port
      - Preferably non-volatile
    - UART
    - Physical Wire Loop

Experiment


MicroBlaze Application
7% Utilization
Empty
LED
Application
<1%
Utilization
Empty
Application
<1%
Utilization
COM
PR
Logic
Arbiter
SMAP
Scrubbing
Logic
Static
Region
External
Memory
Static
Empty
Dynamic
Region

Test Designs

- Static
  - Provides COM, PR, and Configuration Scrubbing Capabilities
  - ≈ 20%
- Dynamic Partials
  - Empty
    - Turns lights on when reset button is pressed.
    - Small < 1% of FPGA
  - LED
    - Performs Binary Counter displayed on LEDs
    - Small < 1% of FPGA
  - MicroBlaze
    - Displays Screensaver to OLED
    - ≈ 7% Logic and 44% BRAMs

Results

FPGA	Total # of Frames	Frame Scrub Rate w/out Errors	Frame Scrub Rate w/Errors	Device Scrub Rate w/out Errors	Device Scrub Rate w/ Errors
Virtex-4 LX-25	4764	19.3 us	36.6 us	92 ms	174.6 ms

<2x Penalty with scrubbing

Design	Actual Reconfiguration Time(s)	Theoretical Reconfiguration Time (ms)	# of Frames
Full Bitstream	237 s	174.6 ms	4764
Empty	22 s	10.0 ms	272
LED	22 s	10.7 ms	292
MicroBlaze	57 s	42.3 ms	1155

Actual Reconfiguration Time is limited by BAUD Rate

BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories

Summary

- Partial Reconfiguration via Configuration Scrubbing
  - Demonstrated effectiveness of technique.
  - Minimal degradation to scrubbing circuitry.
  - Allows for greater flexibility in space applications.
- Future
  - Comparisons to current scrubbing-only results.
  - BRAM one-time scrubbing
  - Selective scrubbing w/ partial reconfiguration and memory management.

Questions?

BYU
BRIGHAM YOUNG
UNIVERSITY

Sandia
National
Laboratories