Integrated Instruction Set Randomization and Control Reconfiguration for Securing Cyber-Physical Systems

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Motivation

- CPS are vulnerable to code injection attacks through software vulnerabilities
- Zero day exploits make it important to consider multiple levels of defense mechanisms
- System crashing can have devastating effects on safety critical CPS
- Performance overhead can lead to real time constraint violations

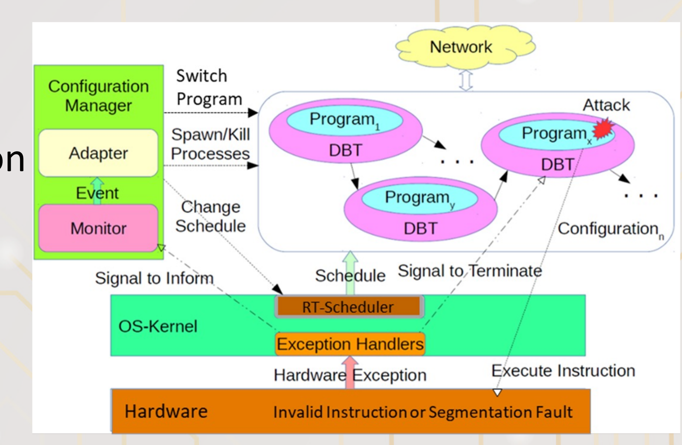
Problem Formulation

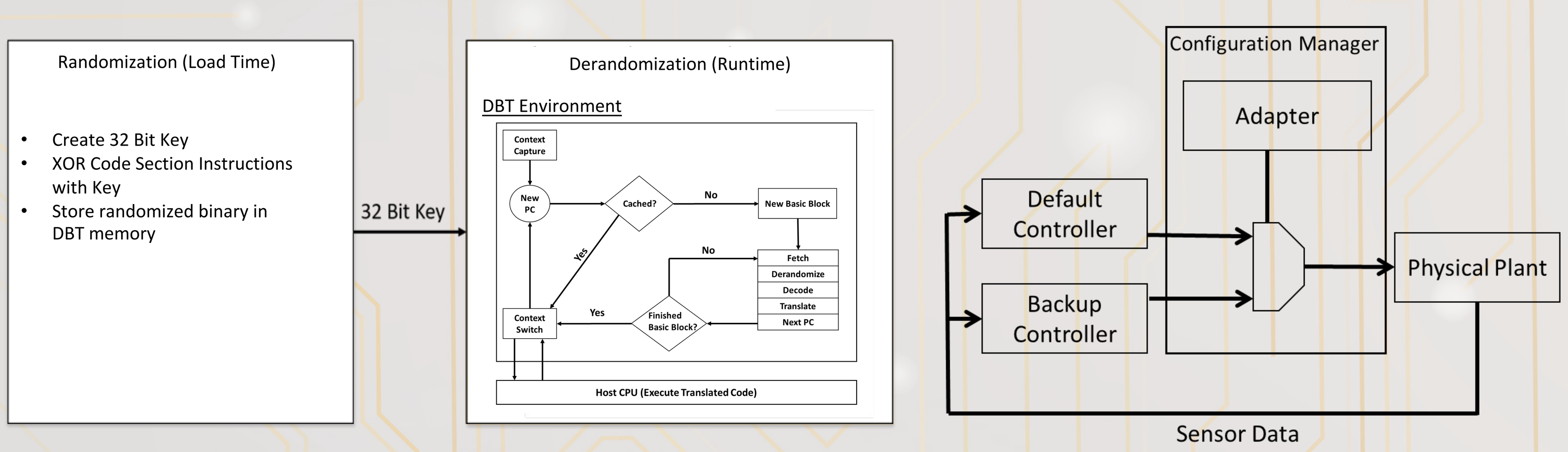
- Remote hijacking of vehicles can occur through code injection attacks
- Instruction set randomization (ISR) has been proven to be effective against code injection attacks, but leads to system crashing
- Reconfiguration is necessary to maintain safe CPS operation

Hypothesis: We can integrate ISR with control reconfiguration to detect and recover from attacks fast enough to maintain safe and stable CPS behavior

Approach

- Control Software ISR
  - Machine code encoded with 32 bit key
- Runtime Derandomization
  - Code is executed through dynamic binary translation layer (DBT)
  - Context switch between DBT and host CPU
  - Derandomization after instructions fetched in DBT pipeline
- Detection
  - Signal handler for invalid instruction exception
- Recovery
  - Switch to non-compromised controller





Experimental Setup

Hardware Testbed

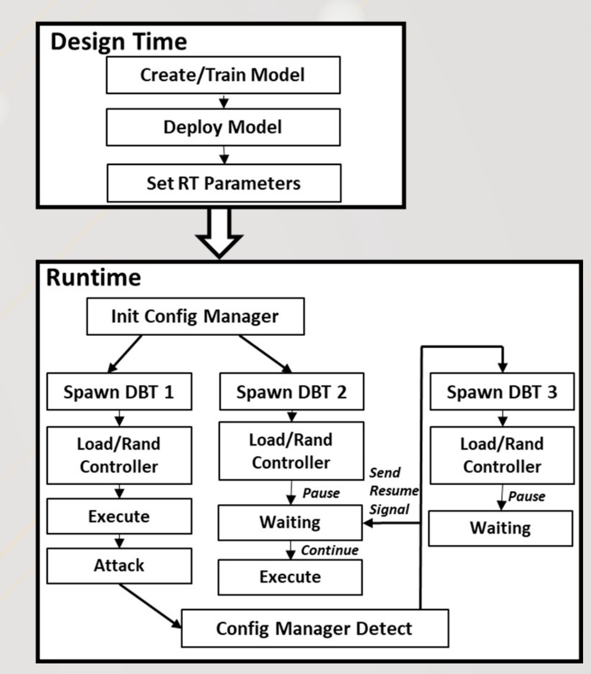
- ECU Cluster – 2 Beaglebone Black
- Controller Board – NVIDIA Jetson TK1
- Two Network Interfaces
  - Ethernet
  - CAN Bus

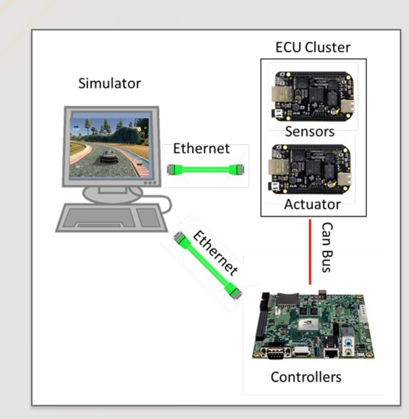
Software Environment

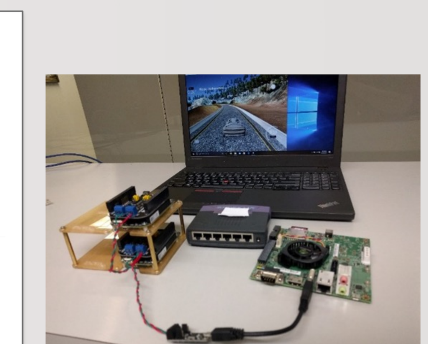
- OS – Linux4Tegra 21.5
- DBT Environment – MAMBO
- Communication
  - ZMQ – Ethernet
  - SocketCAN – Can Bus

Simulation Environment

- Udacity Simulator – Open source autonomous vehicle simulator (Physical Domain)
- Sensors and Actuators – Beaglebone Black
- Vehicle Controllers – NVIDIA Jetson
- MTD Framework – Encapsulates vulnerable controllers on NVIDIA Jetson





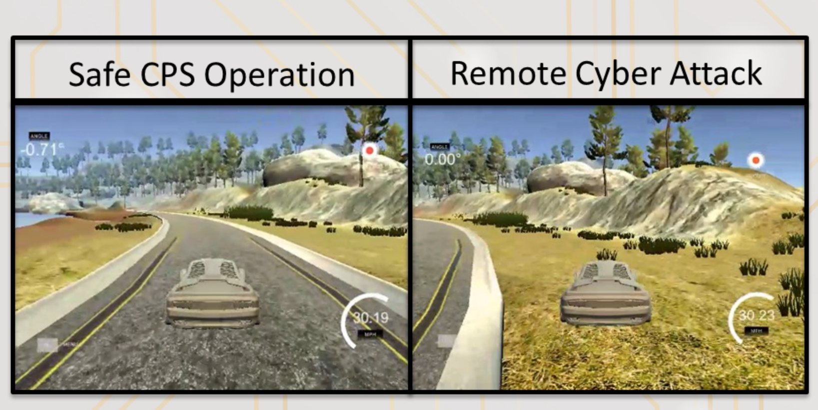


Autonomous Vehicle Case Study

Sensors
- Camera
- GPS
- Gyroscope

Actuators
- Steering
- Throttle

Controllers
- Convolutional Neural Network
  - 9 layers
  - Input: Camera Images
  - Output: Steering

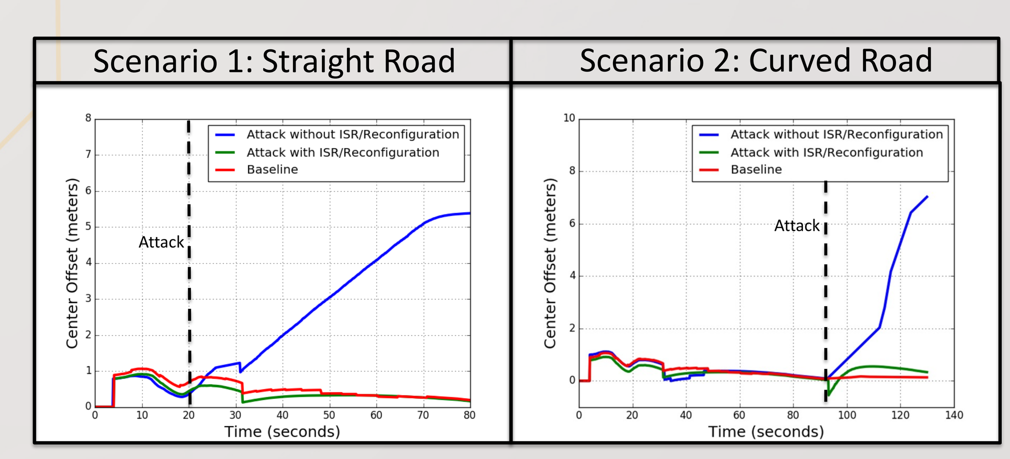


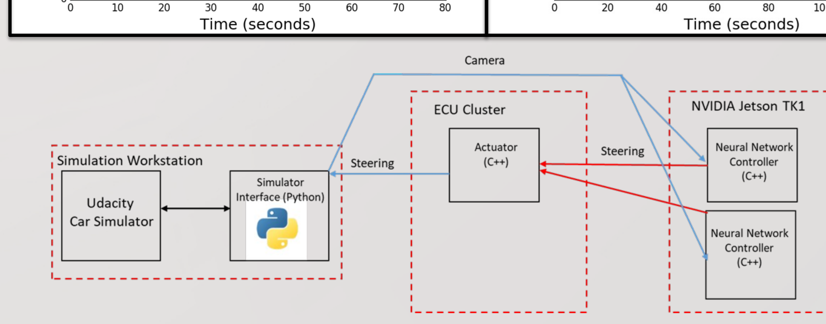
Case Study Results

Vulnerability
- Buffer overflow vulnerability in NN controller camera input processing function

Attack Process
- Spoof malicious camera packet to exploit buffer overflow in NN controller
- Divert control flow and execute malicious instruction payload
- Drive vehicle off of the road at maximum speed

Defense Mechanism
- ISR – Results in invalid instruction exception
- Recover to backup NN controller



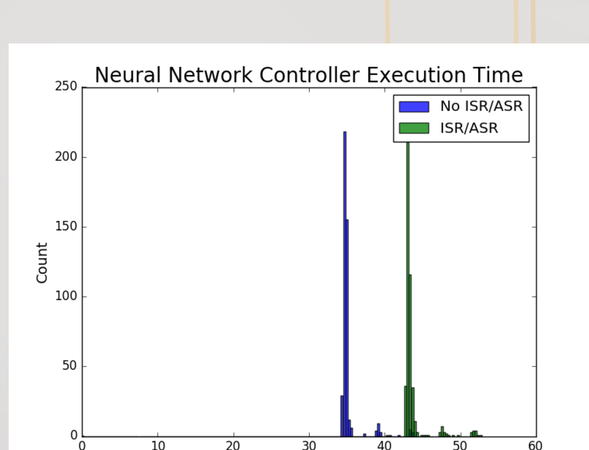


Performance Overhead

Experiment Setup
- 1000 iterations of controller under varying inputs

Measured Time Difference
- Sensor input received -> controller output computed

Neural Network Controller
- Sampling Period – 100 ms
- Worse Case Execution Times
  - No ISR Framework – 41.74 ms
  - ISR Framework – 54.32 ms
- Average Execution Times
  - No ISR Framework – 38.5 ms
  - ISR Framework – 42.9 ms

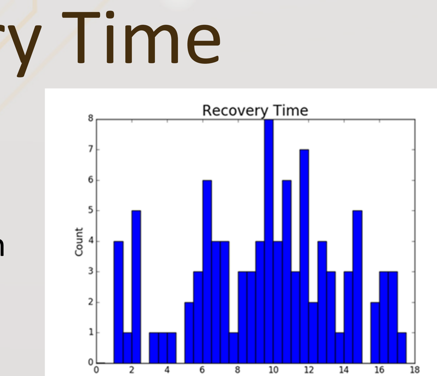


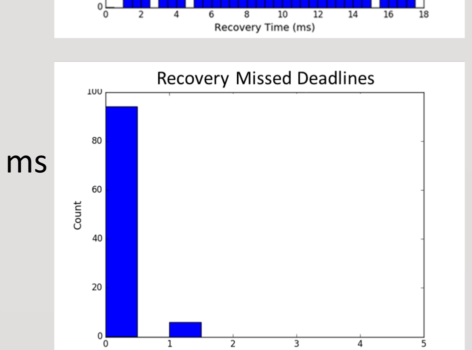
Recovery Time

Experiment Setup
- 100 experiments with ISR/Reconfiguration resulting in controller recovery

Measured Time Difference
- Attack detection -> backup controller resumes execution

Neural Network Controller
- Average Recovery Time – 10.21 ms





Future Work

- Implementing diverse controllers
- Exploration of address space and data space randomization
- Integration of dynamic reconfiguration

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