Co-Simulation of an Avionics Device

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Background: QEMU

- Processor emulator that allows execution of programs for specified board/processor
- Allows us to simulate a and ARM Cortex A9 for a Zynq-7000 FPGA SoC platform
- Can run embedded Linux or bare metal programs
  - We are using Buildroot to compile and assemble an Embedded Linux Boot Image and File System

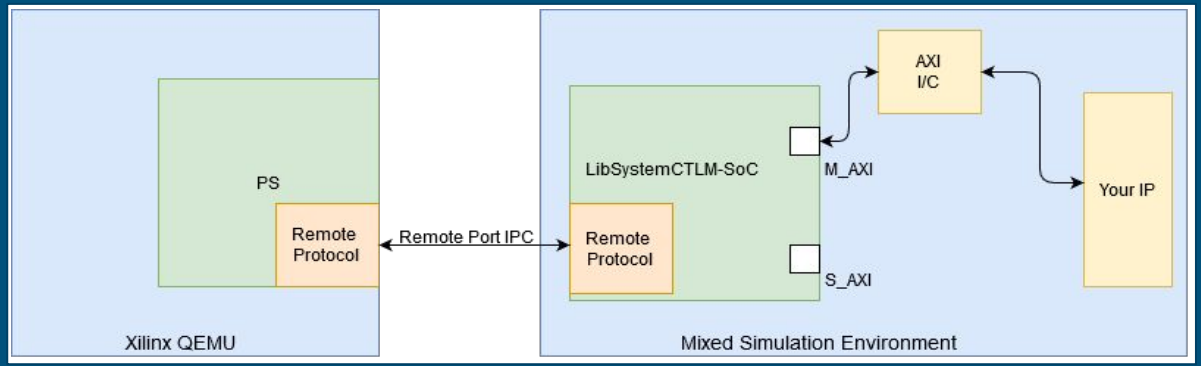
```
[test@donizetti ~]$ qemu-arm ./ls --color /
bin   etc   lib64       mnt   root  srv             system-upgrade-root  var
boot  home  lost+found  opt   run   sys             tmp
dev   lib   media       proc  sbin  system-upgrade  usr
[test@donizetti ~]$ uname -a
Linux donizetti 4.6.7-300.fc24.x86_64 #1 SMP Wed Aug 17 18:48:43 UTC 2016 x86_64
 x86_64 x86_64 GNU/Linux
[test@donizetti ~]$ file ./ls
./ls: ELF 32-bit LSB executable, ARM, EABI5 version 1 (SYSV), dynamically linked
, interpreter /lib/ld-linux-armhf.so.3, for GNU/Linux 3.0.0, stripped
[test@donizetti ~]$
```

Background: SystemC-TLM

- Hardware modeling language that uses plain C/C++ syntax to model hardware systems
- Allows complete simulation of Memory Mapped hardware, AXI systems, and more
- *Libsystemctlm-soc*: Xilinx SystemC library that provides an interface between a SystemC modeling environment and a Zynq-7000, Zynq Ultrascale+, and Versal ACAP computation platforms

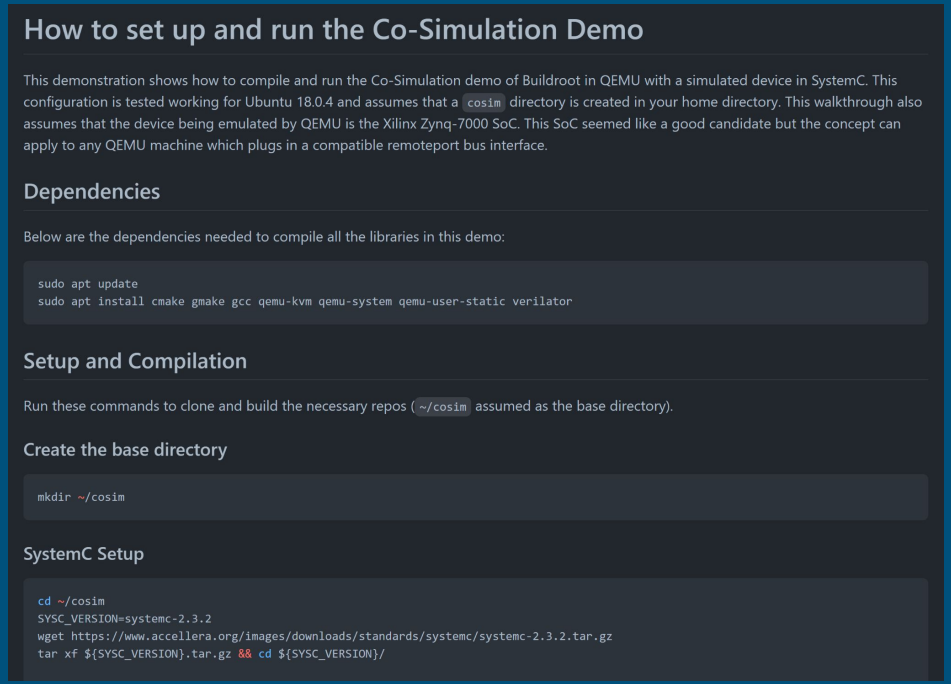
Hardware/Software Co-Simulation

- Simulate the processor your code is running on (Embedded ARM Cortex-A9)
  - Processor emulator (QEMU)
  - Buildroot Linux
- Simulate the hardware interactions and mock all calls made
  - Hardware implementation (SystemC)
  - Hardware transaction modeling (TLM)
- Connect the two simulated environments (FPGA PS-PL connection)
  - Xilinx Remote Port



Problem Statement

- Steep learning curve for beginners
  - Few documented example projects
  - Lacking basic documentation
- Desire for additional flexibility
  - Once the simulation has been setup, difficult to manipulate data “Generated” by simulated hardware
  - Desire to “feed” data into the system from an external source
  - Processing System (QEMU) being none the wiser, assumes it is a real device



How to set up and run the Co-Simulation Demo

This demonstration shows how to compile and run the Co-Simulation demo of Buildroot in QEMU with a simulated device in SystemC. This configuration is tested working for Ubuntu 18.0.4 and assumes that a `cosim` directory is created in your home directory. This walkthrough also assumes that the device being emulated by QEMU is the Xilinx Zynq-7000 SoC. This SoC seemed like a good candidate but the concept can apply to any QEMU machine which plugs in a compatible remoteport bus interface.

Dependencies

Below are the dependencies needed to compile all the libraries in this demo:

```
sudo apt update
sudo apt install cmake gmake gcc qemu-kvm qemu-system qemu-user-static verilator
```

Setup and Compilation

Run these commands to clone and build the necessary repos (`~/cosim` assumed as the base directory).

Create the base directory

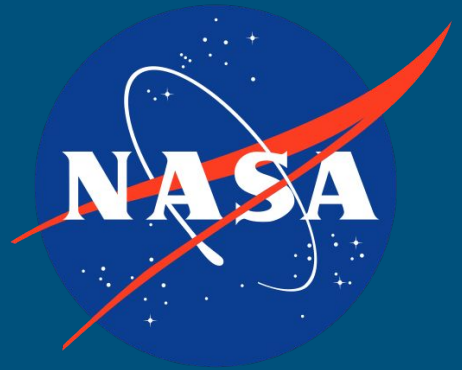
```
mkdir ~/cosim
```

SystemC Setup

```
cd ~/cosim
SYSC_VERSION=systemc-2.3.2
wget https://www.accellera.org/images/downloads/standards/systemc/systemc-2.3.2.tar.gz
tar xf ${SYSC_VERSION}.tar.gz && cd ${SYSC_VERSION}/
```

Intended Users

- Corporations who simultaneously develop hardware/software solutions
  - Aerospace, Defense, Industrial Automation, Automotive
- Users looking to extensively test hardware and software independently of one another
- People interested in applying Co-Simulation to their own project who are stymied by the barrier of entry



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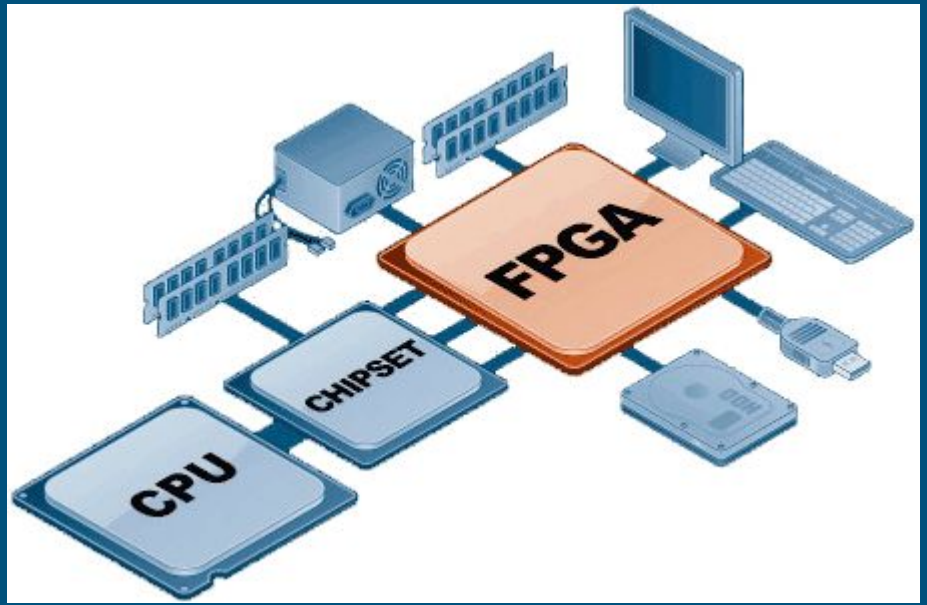
Use Case Example

- You are a software engineer developing a hardware driver to control a new temperature sensor
  - Interfacing with it over an I^2C interface
  - You have the technical documentation
  - You have v0.1 of the driver written
  - Now What?
- How can you test your driver code in a simulated environment before a engineering sample of the sensor has been produced?

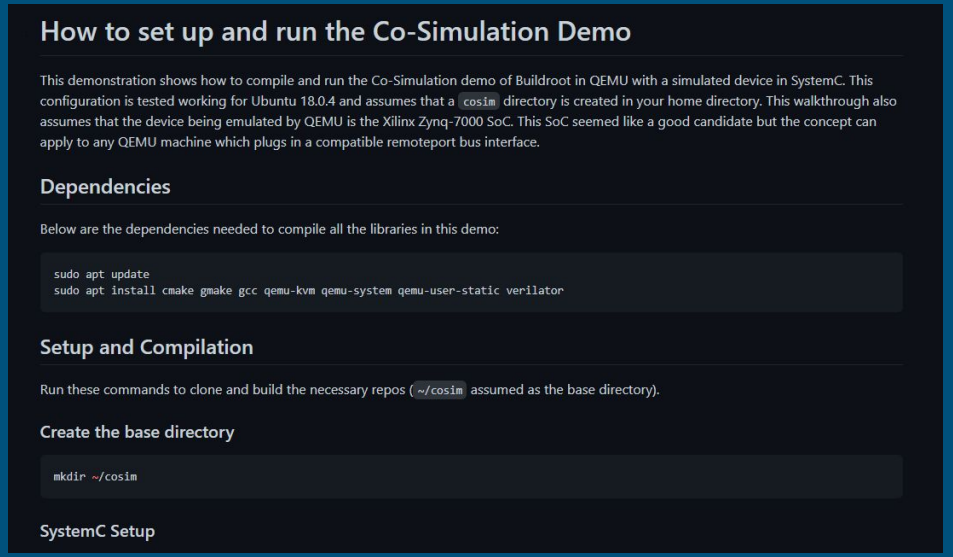


Functional Requirements/Deliverables

- Documentation
  - Document an initial environment setup walkthrough → PR has been submitted, being revised
  - Create an additional demo to for a more complex system → PPM demo working, publishing soon
- External Data Source/Modeling Tool
  - Model an I^2C Bus in SystemC and corresponding test application → Initial research completed
  - Drive a simulated IMU device over I^2C with static data → Initial research completed
  - Develop Remote port custom communication tunnel for external data source tool → Test application with decoded packets working
  - Demonstrate an off-the-shelf Linux IMU driver running on QEMU, working with modeled hardware → IMU and driver selected, test application in development

Non-Functional Requirements

- Author supplemental documentation for Xilinx technologies utilized
- Contribute all to centralized (Xilinx Confluence or otherwise) documentation body
- Documentation describing in full our I^2C/Remote Port implementation resources utilized
- Implement additional examples with other protocols in our custom SystemC device server
- Support multiple device simulation simultaneously in the SystemC device server



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SystemC Setup

Hardware/Software/Technology Platforms used

QEMU: Machine emulator. In this project, simulates a Zynq-7000 processor.

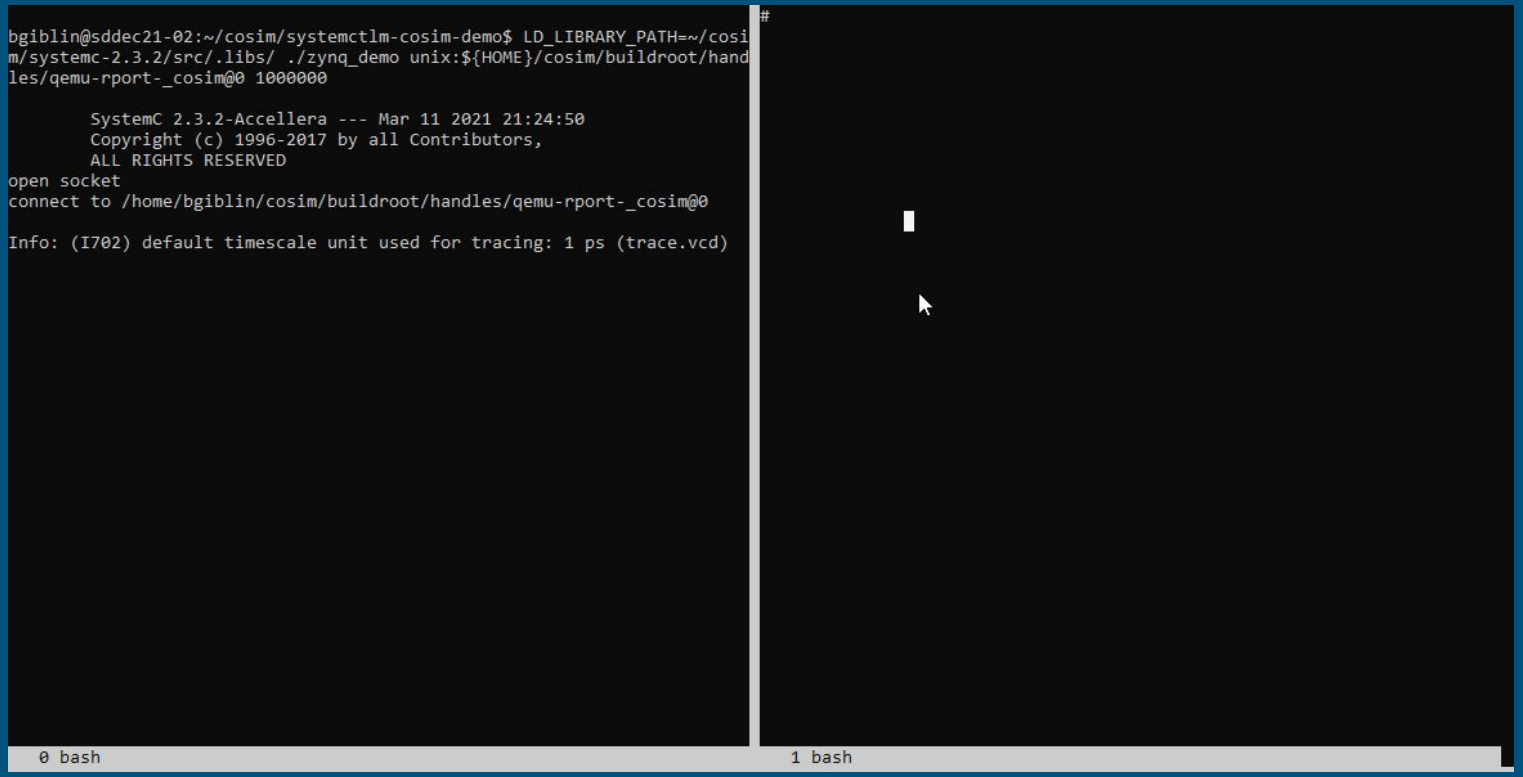
SystemC: C++ classes used for event driven simulation, used in tandem with QEMU to provide co-simulation.

LibRemotePort: Socket-work in C++ that allows systems to connect over Unit sockets, used for Host system → SystemC communication

Server: Ubuntu 18.0.4 Server

Project Management: Github - Version Control, Trello - Task management, and Discord - Collaboration

Co-Sim System Clock Demo



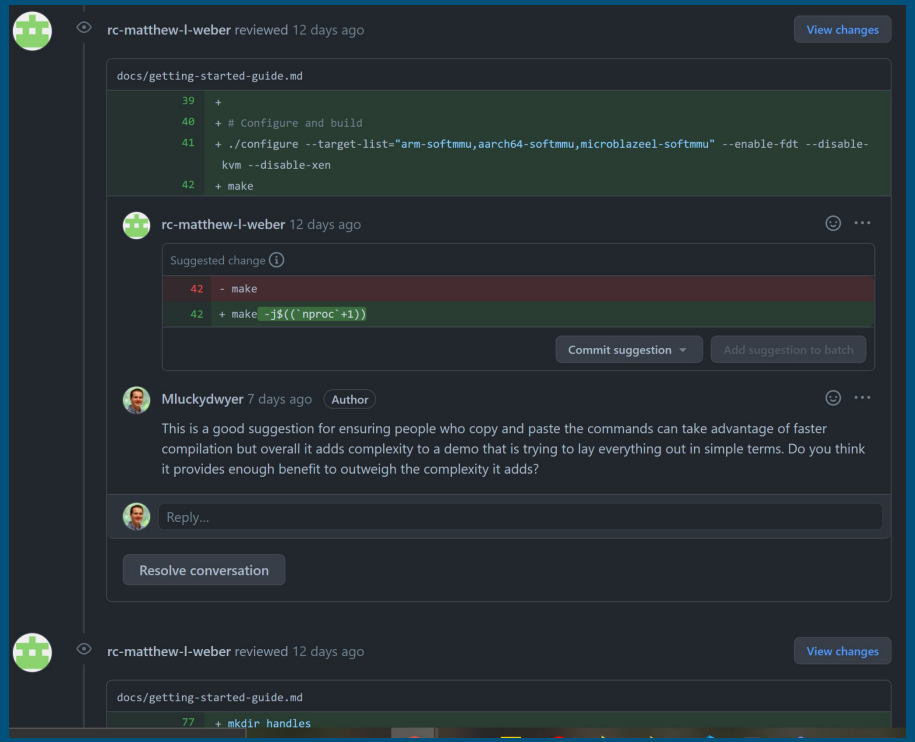
PPM State Machine Demo

```
void PPM_Receiver::gen_ppm()
{

  const int FRAME_TIME = 20000; // 20000 uS
  const int CH_NUM = 6; // just use one channel, 0 to 15

  const int frame[] = {1500, 800, 1000, 1250, 2000, 1750};

  const sc_time rx_period(FRAME_TIME, SC_US);


  SC_REPORT_INFO("PPM_IN", "Beginning State machine\n");

  while (reg_ctrl == 0x0); // Wait for enable signal

  // endless loop
  while (true) {

    // capture simulation time at the start of the transmission period loop
    sc_time rx_period_start = sc_time_stamp();

    for (int i=0; i < CH_NUM; i++) {
      reg_ch_n[i] = frame[i];
      wait(sc_time(frame[i], SC_US));
    }
    reg_count++;

    sc_time rx_period_consumed = sc_time_stamp() - rx_period_start;

    if (rx_period_consumed > rx_period)
      SC_REPORT_WARNING("PPM", "Channels to Long!\n");
    // otherwise, wait out the remaining part of the period
    else
      wait(rx_period - rx_period_consumed);

  }
}
```

```
en=4
Channel 0: 0x000005DC        Info: PPM_IN: Reading Count
Channel 1: 0x00000320
Channel 2: 0x000003E8
Channel 3: 0x000004E2        Info: PPM_IN: Reading Count
Channel 4: 0x000007D0
Channel 5: 0x000006D6
Channel 0: 0x000005DC        Info: PPM_IN: Reading Count
Channel 1: 0x00000320
Channel 2: 0x000003E8
Channel 3: 0x000004E2        Info: PPM_IN: Reading Count
Channel 4: 0x000007D0
Channel 5: 0x000006D6
```

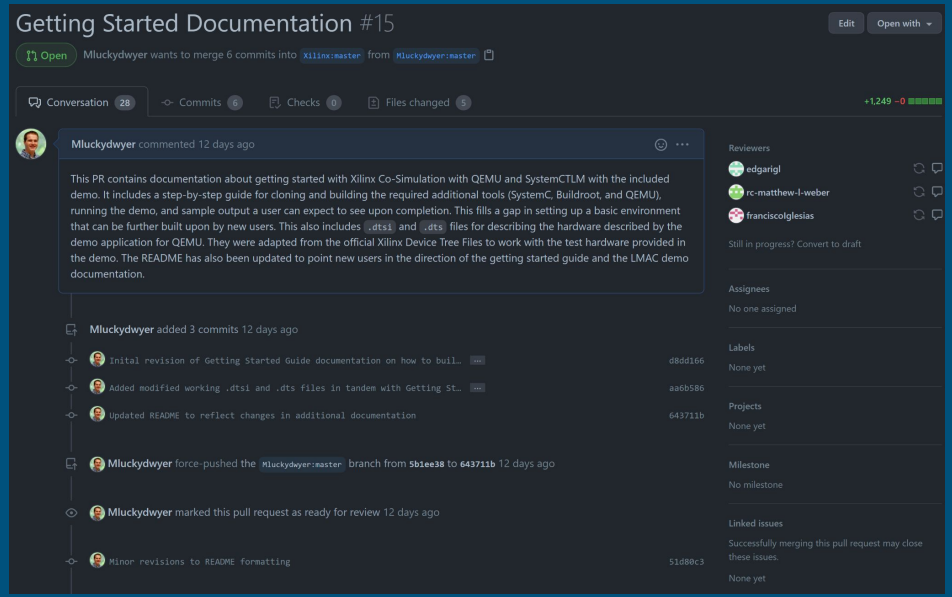
Detailed Design - Documentation

- Generate Documentation that describes how to setup and build existing Demos
- Explain how to modify existing Demos to extend the hardware/software capability
- In depth documentation on new functionality that describes use cases, setup, and modification
- Receive feedback from development community and iterate



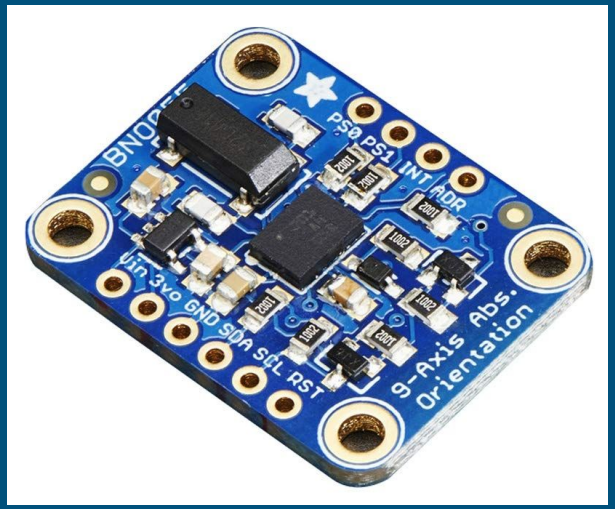
Documentation Status

- We have reached out to Xilinx Co-Sim Repository Maintainers and have established communication
- Submitted Pull Request for a running a “getting started demo”
- Have been iterating over the pull request to complete suggestions made my maintainers
- Contributes towards our fulfillment of improved end-user documentation deliverable



Detailed Design - I²C IMU Implementation

- Write a state machine in SystemC to model an I²C bus
- Identify a real IMU with a Linux driver that we will use as our test device
- Model backend value registers of IMU using SystemC + remote interconnect to host to allow host to control IMU data values
- Demonstrate and document a working mixed simulation consisting of
  - QEMU, running Buildroot Embedded Linux with IMU Kernel Module and front end test application
  - SystemC modeling an I²C bus with one or more devices attached
  - Host system modifying SystemC parameters on the fly to vary IMU data



I^2C IMU Implementation Status: SystemC

- Built and tested state machined consisting of a Pulse Position Modulation encoder / decoder
- Executed a bare metal driver & runner program developed independently as a course project, demonstrating Mixed Simulation functioning with no software changes needed
- Remote Port Protocol Identification and Research
  - Identified Xilinx SystemC SoC Remote Port library as a candidate for SystemC to Host communications
  - Have established a one directional handshake between SystemC and host program, verifying read/write connectivity between the two

Test Plan

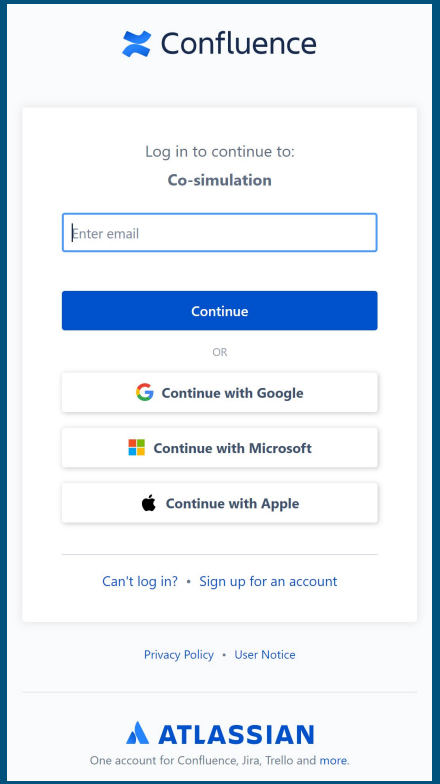
- Documentation will be tested by ensuring it conforms to all standards set forth by repository maintainers
- Documentation will also be tested by Collins Intern teams that attempt to follow our demos and work on tangential projects
- All commits will pass code review by repository maintainers, ensuring that we meet the standards outlined by each repository

Test Plan

- Each module will be unit tested to the fullest extent possible
- Integration testing will be conducted in stages with known working system states
- Each of the modules, along with the full demonstration of our working system, will be documented to ensure quality of testing.

Constraints & Considerations

- Open-source community sentiment to our proposed additions
  - Welcoming and positive from our numerous interactions
  - Generous suggestions and critiques
- Unfamiliarity with simulating technologies
  - Internal team documentation for basic demo progressions
  - Team requirement to complete basic demos
- Minimal documentation for Xilinx implementations
  - Reaching out to experts in development community
  - Reverse engineering implementation source
  - Evaluating responses from compliant implementations



Future Milestones

- Further document internal tooling and technologies used
- Develop external Python/C++ tool for external data sourcing
  - Document multiple use cases
  - Document implementation for future development
- Implement additional sensors/protocols in SystemC device server
- IMU graphical interface demonstration

Thank You For Listening!

Questions?

Current Project Status

Completed:

- Outreach to open-source community was successful
- Initial Documentation for a co-simulation demo in a pull request to main repository
- Application involving LibRemotePort configuration is working (?)

Our work may be given to interns at Collin’s Aerospace to use/work on over the summer.

Prototype Implementations

- Implemented basic remote port application
  - Still reverse engineering protocol
  - Documentation and consistent operation still in progress
- PPM demo working as intended
  - Documentation needed
  - Cleanup and publication needed
- Documentation
  - Basic walkthrough 3rd revision completed
  - Needs to be pushed for additional feedback
- IMU Driver
  - Still being compiled into the Buildroot kernel

Problem Statement

The existing co-simulation environment provided by Xilinx, which utilizes a SystemC TLM and QEMU, lacks sufficient documentation for a newer user to learn and use it. It also has opportunities for an expanded interface to allow more robust testing

Task Contributions of Each Member (Each person fill out)

Matt: Open-Source Community contact, demo documentation, remote-port/communication protocol architecture, administrative documentation

Braedon: PPM SystemC state machine / demo, IMU kernel module compilation, Threading demo build, version control configuration

Cody: Initial demo set-up, documentation for original demo, technology research, IMU research/set-up

Spencer: Website updating, IMU research