National Aeronautics and
Space Administration

Testing a Neural Network Accelerator on a High-Altitude Balloon

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Ethan Barnes / NASA Intern (2018)

Introduction - Speakers

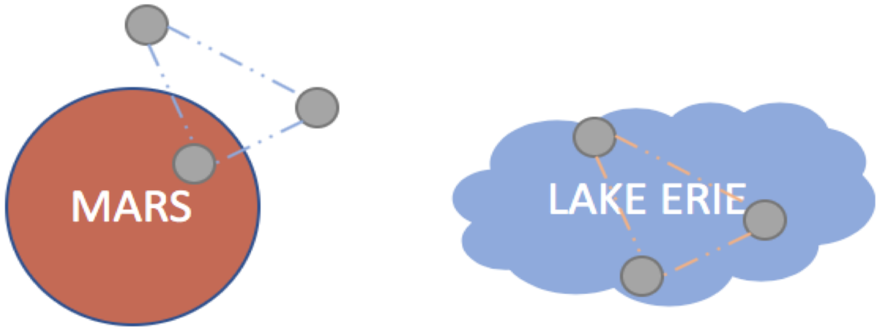
- Gilbert Clark
  - NASA Glenn Research Center
  - Cleveland, OH
- Ethan Barnes
  - Student intern in summer of 2018
  - Firmware lead for flight systems

Agenda

- Introduction and Motivation
  - Applied engineering project for students
  - Improve Technology Readiness Level (TRL) for on-board processing
- Flight Experiment Design
  - Balloon communications payload
  - Processor, hardware, software, etc.
- Experiment Results
  - Experiment was generally successful
- Moving Forward
  - Using platform as basis for future experiments

An Internet of Things … in Space

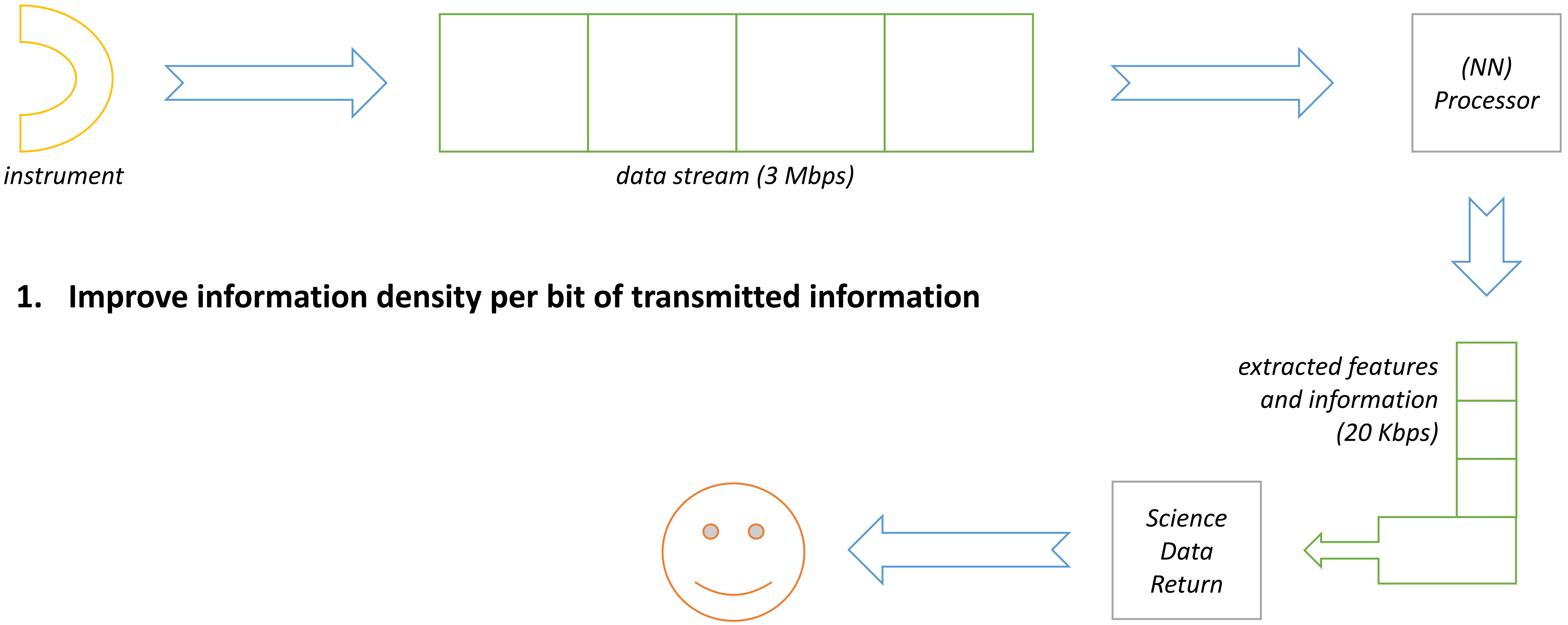
- There are commonalities between space and ground sensors
  - Step 1: take an instrument
    - IoT: temperature sensor in refrigerator
    - Space: expensive telescope
  - Step 2: mix it with a processor, storage buffer, and an RF (or optical!) link
    - IoT: LTE, 900 MHz ISM, 433 MHz ISM, etc.
    - Space: Optical, Ka-band, S-band, UHF, etc.
  - Step 3: place instrument and push gathered data to remote destination
    - IoT: often a cloud (e.g. Amazon, Google, Azure, etc.)
    - Space: ground-based processing elements
  - Step 4: SCIENCE HAPPENS!
    - IoT: assurance that food won't spoil
    - Space: assurance that new frontiers have been explored



An Internet of Things … in Space (cont.)

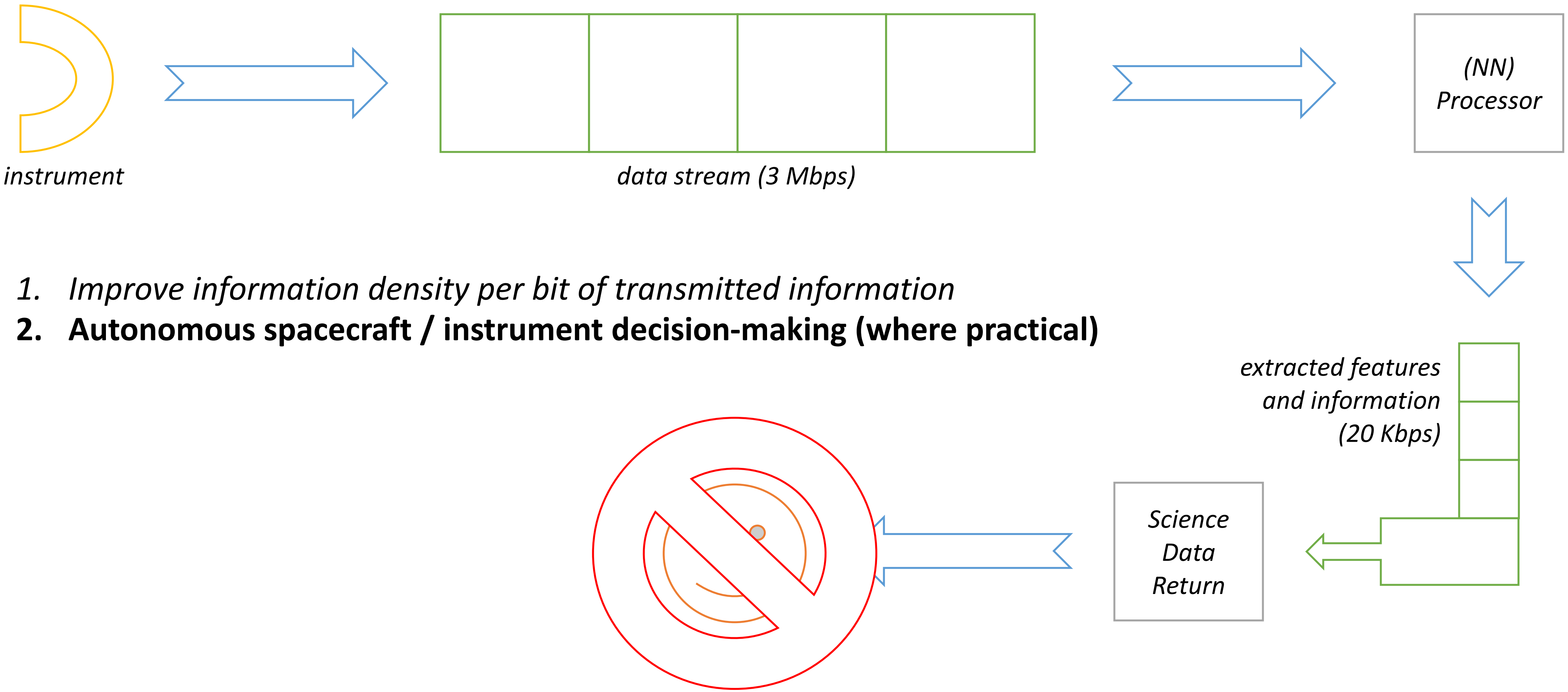
- Many common research areas, too!
  - Routing through sensor networks
    - Relatively new area in ***space*** communications
      - One reason: inter-satellite links are ***hard*** to get right
      - Spectrum has been historically dedicated to specific missions
    - Existing relays ***don't route***
      - No packet processing capability – operate entirely at RF layer
  - Edge computing
    - "On-Board Processing" (OBP) for the space-centric folks
    - Instead of returning ***all*** data, pre-process data to extract features and just return those
      - Substantially reduces amount of bandwidth required to collect data
- This talk – focusing on OBP elements
  - Other aspects are under active research / development as well, though!

On-Board Processing (objectives)



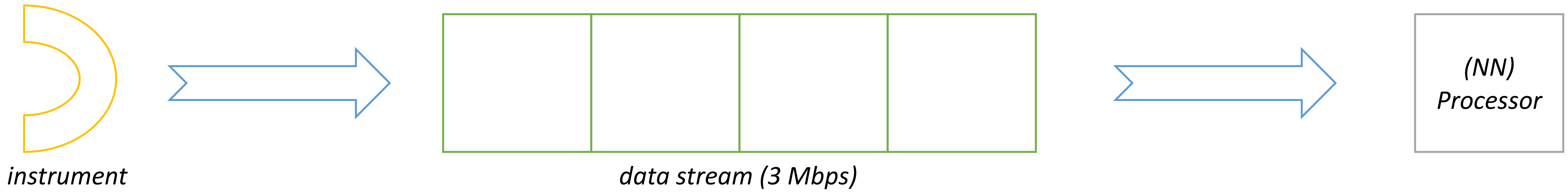
1. Improve information density per bit of transmitted information

On-Board Processing (objectives)

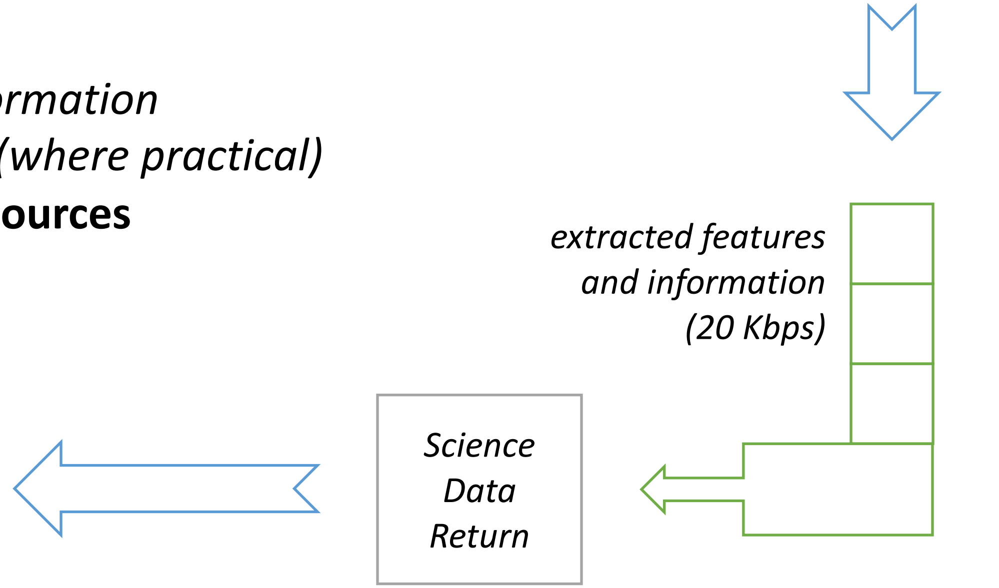


1. *Improve information density per bit of transmitted information*
2. **Autonomous spacecraft / instrument decision-making (where practical)**

On-Board Processing (objectives)



1. *Improve information density per bit of transmitted information*
2. *Autonomous spacecraft / instrument decision-making (where practical)*
3. **Optimize global efficiency of SCaN's networks and resources**



On-Board Processing

- Objective: become familiar with approaches to on-board processing
  - Learn how hardware can be applied toward this task
  - Enumerate different approaches to on-board processing
  - Hardware should minimize Size, Weight, and Power (SWaP)
- Opportunity: high-altitude balloon flight
  - Seven students split across two different internship programs
- Show that commercial off-the shelf (COTS) component may be used …
  - … to execute AI tasks directly in near-space …
  - … at a low SWaP cost

On-Board Processing (cont)

- Experiment primarily focused on development of a platform
  - Put together a functional intelligent communication system …
  - … within SWaP constraints of balloon
    - 4 lb. upper limit on weight
    - Styrofoam container approximately 1’ x 1’ x 1’
- ***Sanity check / risk mitigation*** for future development efforts
  - Likely that future missions will use different hardware
- Offers an excellent ***applied*** engineering opportunity for students
  - ” BUT IT ALL WORKED SO WELL IN THE SIMULATION! ARGH!”

Processing Elements

- Two aspects of development
  - Communications system
  - On-board Processor
- Informal trade studies completed for both aspects
- Selections were
  - Communications: ARM microcontroller + 902 MHz ISM-band radio
  - OBP: Raspberry Pi Zero + Myriad 2 MA2450
    - Packaged in unified “Google AIY Vision Kit”
  - Following charts offer a brief overview of why the second selection was made
    - If there’s interest in ARMs / radios reviewed, feel free to get in touch

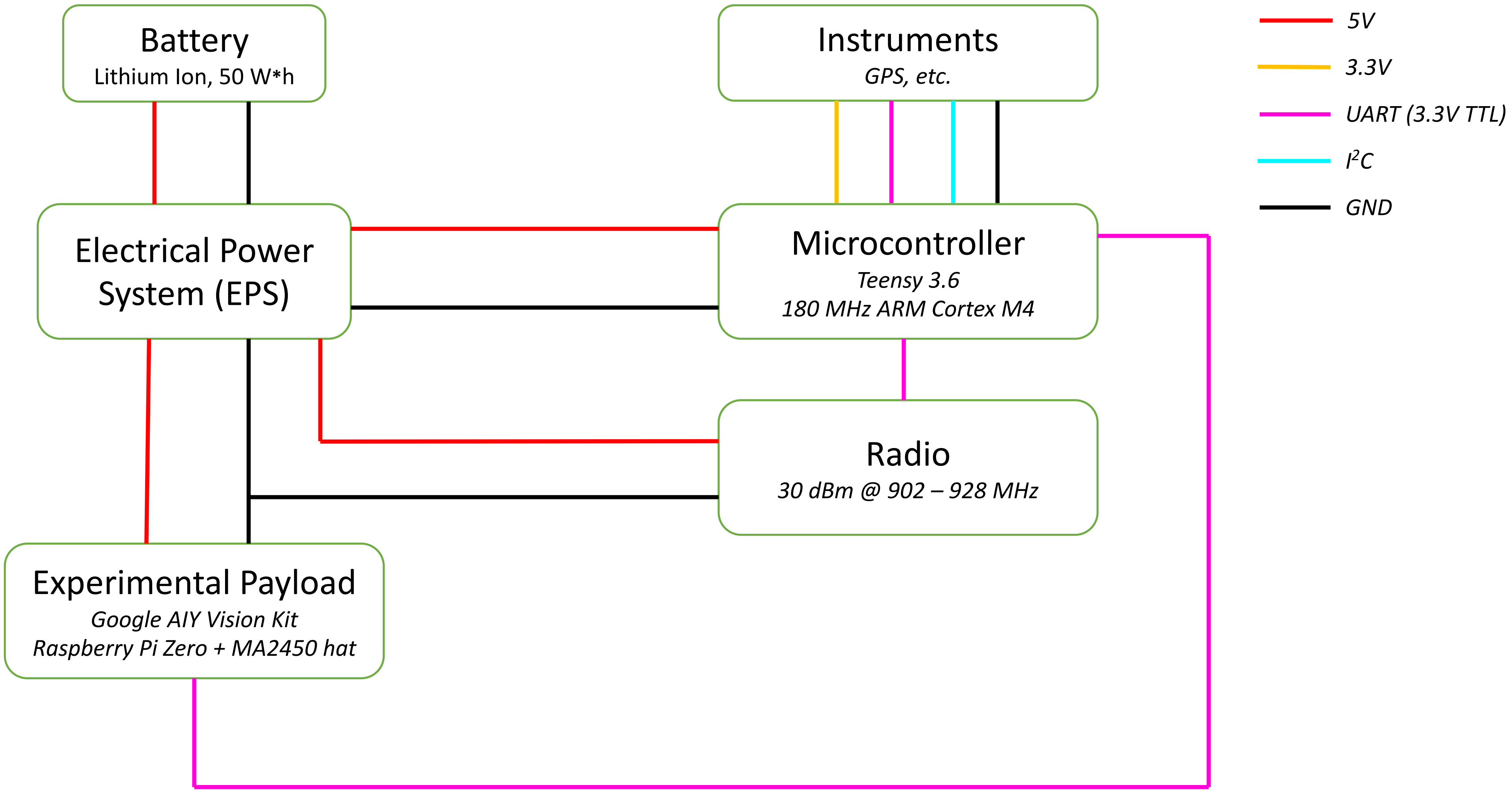
OBP Evaluation

- Looking for an on-board processing system that was:
  - Simple to set up and work with
    - Students would have limited time available
  - Low-cost
    - Some risk of damage or loss associated with a balloon flight
  - Low SWaP
    - Batteries are heavy and the payload was weight-constrained, so less power is better
  - Capable of supporting work in intelligent systems research …
    - … at a level that students would likely be able to contribute to
- Based on requirements, looking for system with AI / ML emphasis

OBP Experiment

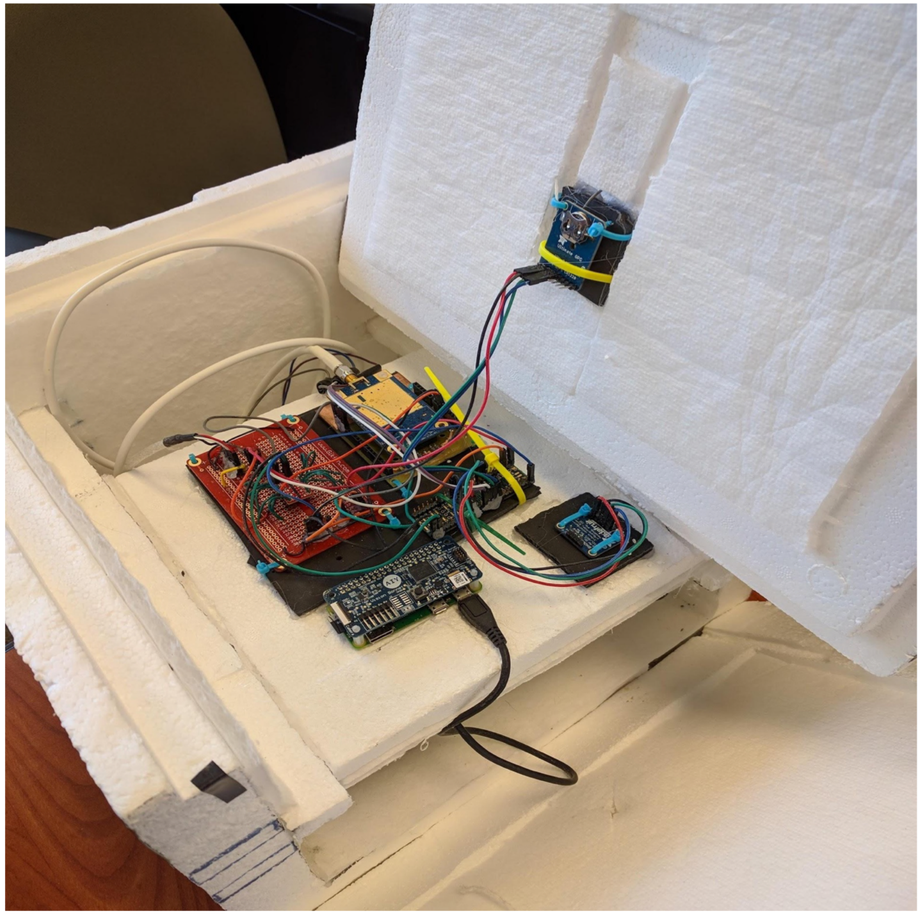
- Selected Google AIY Vision Kit
  - Includes 1 GHz ARM SoC (Raspberry Pi Zero)
  - Designed for hobbyists and students
  - Hardware acceleration for (very specific types) of neural networks
  - Power consumption within acceptable parameters
  - No requirement for USB support on OBP
- Overview of combined platform is provided on next slide
  - Will let Ethan take over from here to discuss the work performed
  - Also will be discussing experimental results and where the platform might go

Platform Integration and Design



Platform Integration and Design (cont.)

Ground System
Raspberry Pi 3



Flight System
Diagram on Previous Slide

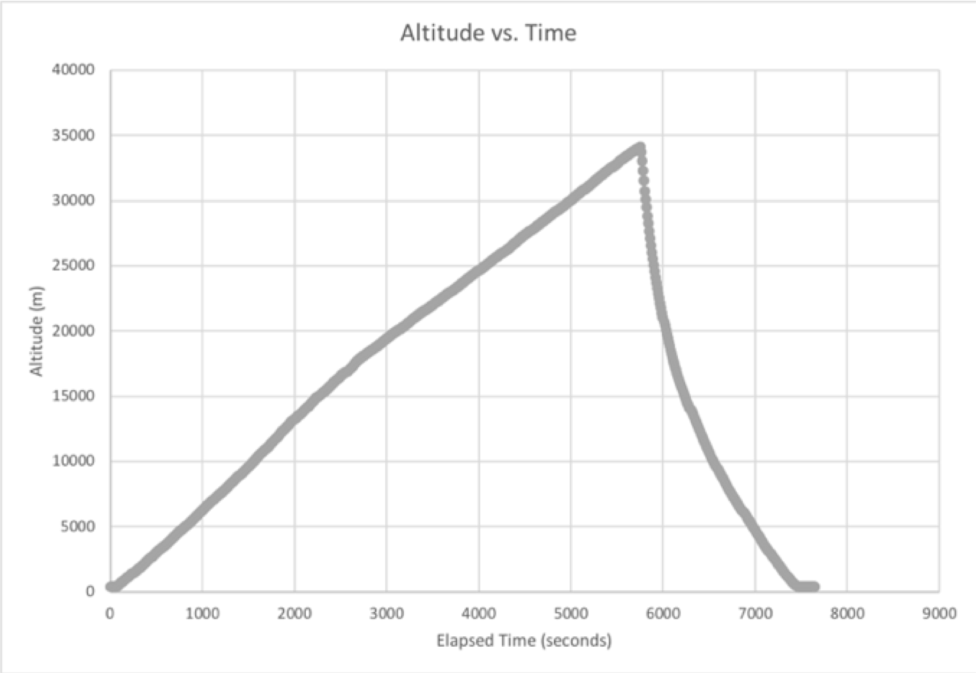
Ground System

- Raspberry Pi 3 running ground software
  - Recorded telemetry frames and instrumentation frames received from flight
  - Flight system sent three different frame types
    - Telemetry was sent once per 2.5 seconds
    - Instrumentation was sent once every second
    - Payload data was sent once every 1.5 seconds
- Attached to 900 MHz radio via USB to serial converter
  - Communicated with radio directly via custom format
- Ran a small 802.11 access point and web server
  - Allowed people to join the AP and monitor the balloon’s progress
  - Could view telemetry data and location data in real time

Experimental Design

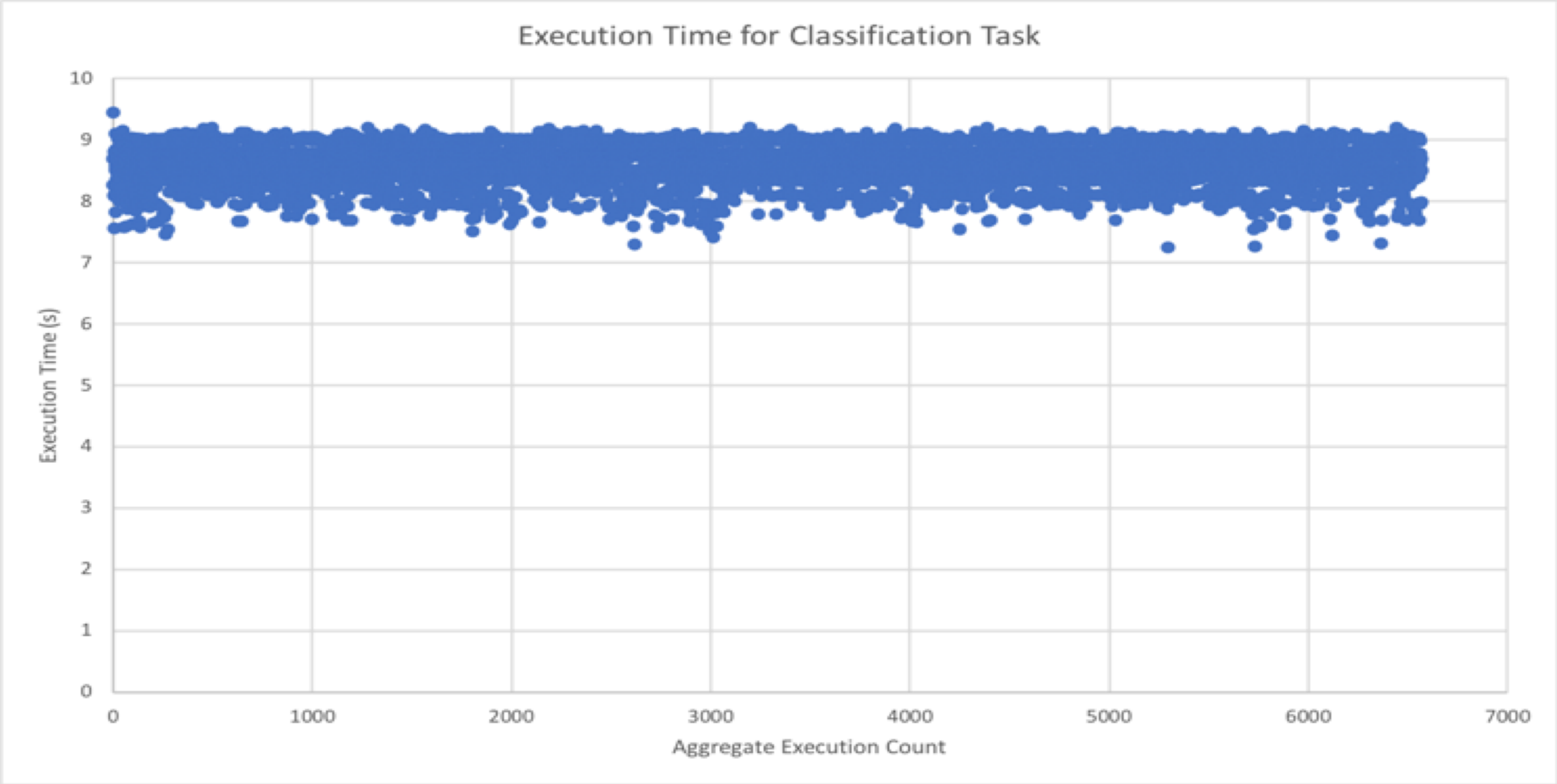
- Ensure hardware performs properly at altitude
  - Repeatedly run a test on known input and check that:
    - Results are consistent across executions,
    - Timing is consistent across executions, and
    - No errors are encountered
- Execute a compute-intensive image classification routine
  - Attempts to determine an object's general "type"
    - e.g. "guitar", "hat", "kitty", etc.
- Repeat for as many executions as can be performed …
  - … until the balloon is recovered or the battery dies
- Use 900 MHz radio system for downlink of telemetry data
  - Also to instrument channel and evaluate loss, etc.

Flight Results



The balloon was in the air for 135 minutes, and reached a maximum altitude of 112,000 feet.

Experiment Results



Conclusions

- The communications package worked as expected
  - Coverage was maintained for a large portion of the flight
  - Vegetation was a significant issue for the system as designed
    - Future work – replace with a different type of antenna system
- The Vision Kit performed as expected during the flight
  - There was no obvious difference in execution timing between runs
  - Large variance may be due to e.g. variations in SD card write latency
    - Other applications running at the same time that the experiment was!
- The platform could be used to support future work in this area
  - A low-cost means to test AI / ML techniques on a platform in near-space

Future Work

- This experiment was only to demonstrate viability
  - Show that the hardware and configuration generally work
- Moving forward, we would need to adapt a custom neural network
  - Porting to run on the hardware takes some effort …
    - … but still ***seems*** possible for a student to tackle in a summer
  - Possibilities include link parameter tuning, data route selection, etc.
- Alternatively, could repeat experiment with different hardware
  - Google's Coral TPU chipset is one possibility along these lines
  - The MicroZED might be another (FPGA-based) option
- Notably, future work could be based on this platform
  - Largely general-purpose: could be adapted to serve in many capacities

Acknowledgment + Questions

- Thanks to a very large number of folks from GRC for their help!
  - Pulled a functional flight project together in just under 12 weeks
  - Many individuals lent their time and expertise to help make this possible …
- Thanks to all of you for listening!
- Contact information is included on the paper
  - Please feel free to get in touch for further conversation …

- **Are there any questions?**