Quantifying Degradations of Convolutional Neural Networks in Space Environments

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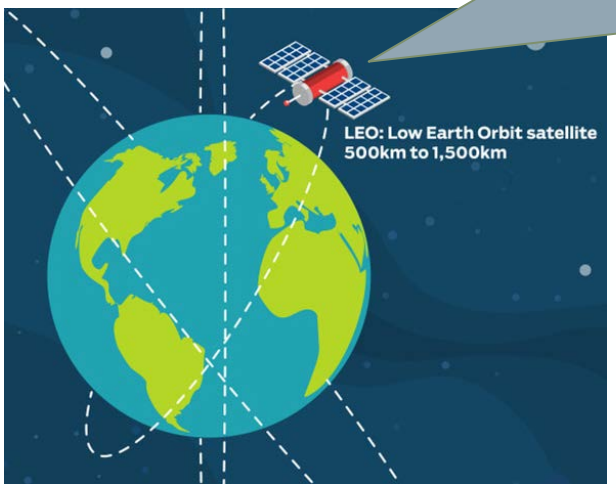
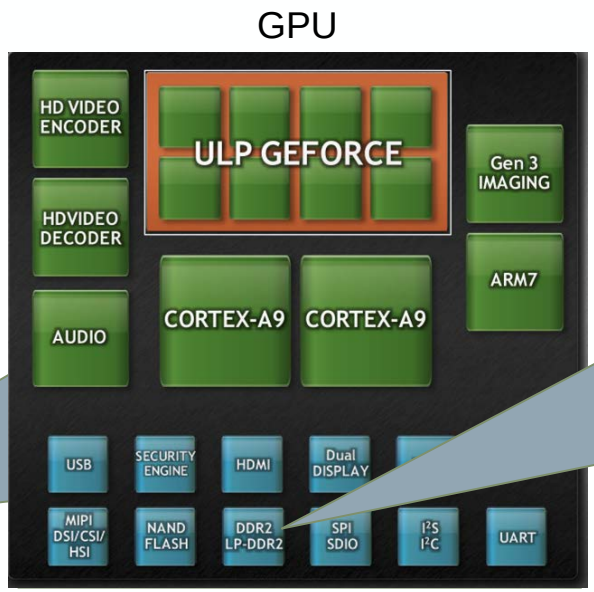
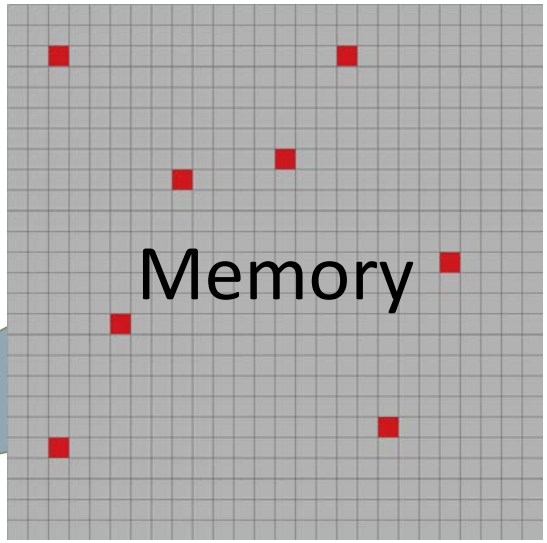
Single Event Upsets

- Electrically charged cosmic rays colliding with memory hardware can cause random binary bits to flip, changing the value of that number.



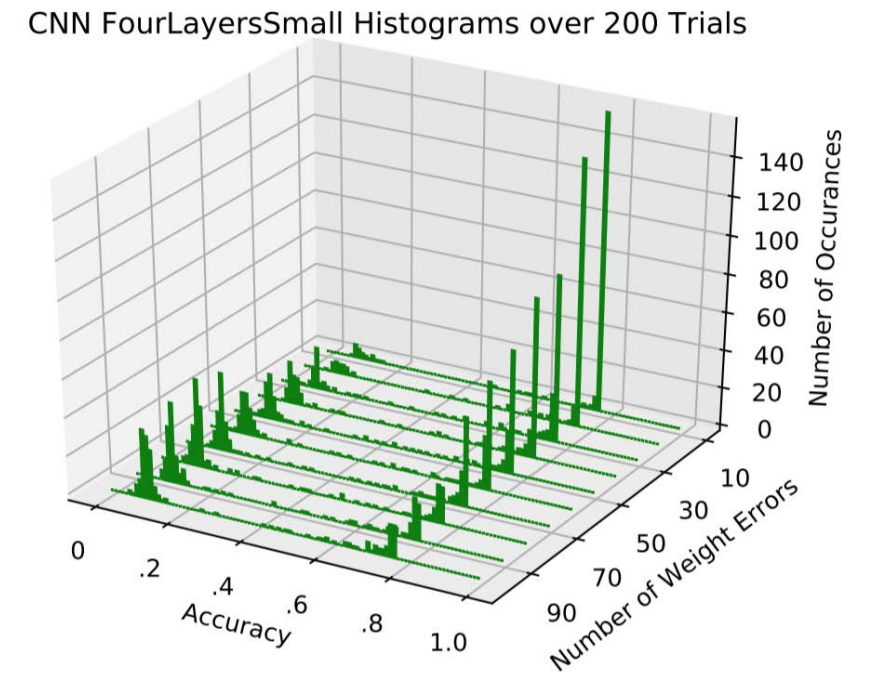




= single event upset

- The likelihood of an SEU occurring increases in higher radiation environments

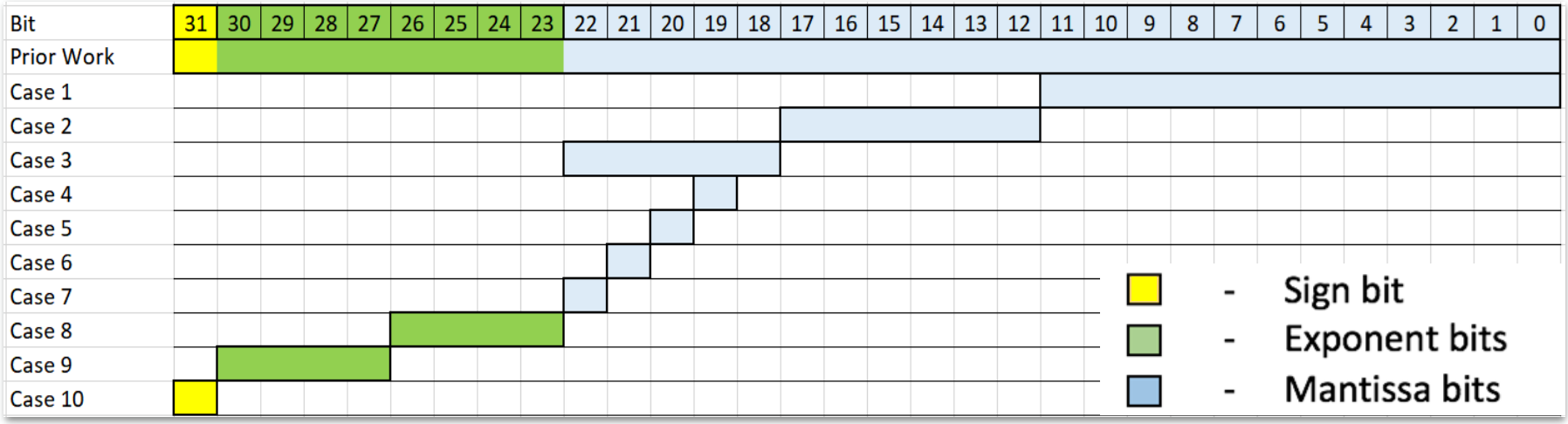
Building off of Arechiga's work



- Randomly flipped a bit within a percentage of weights in a CNN
  - Simulated space environment where radiation can cause Single Event Upsets (SEUs)
- Accuracy of errored CNNs exhibited bimodal behavior, rather than linear degradation as expected

A.P. Arechiga and A.J. Michaels. "The effect of weight errors on neural networks." IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC) pp. 190-196, Jan. 2018.

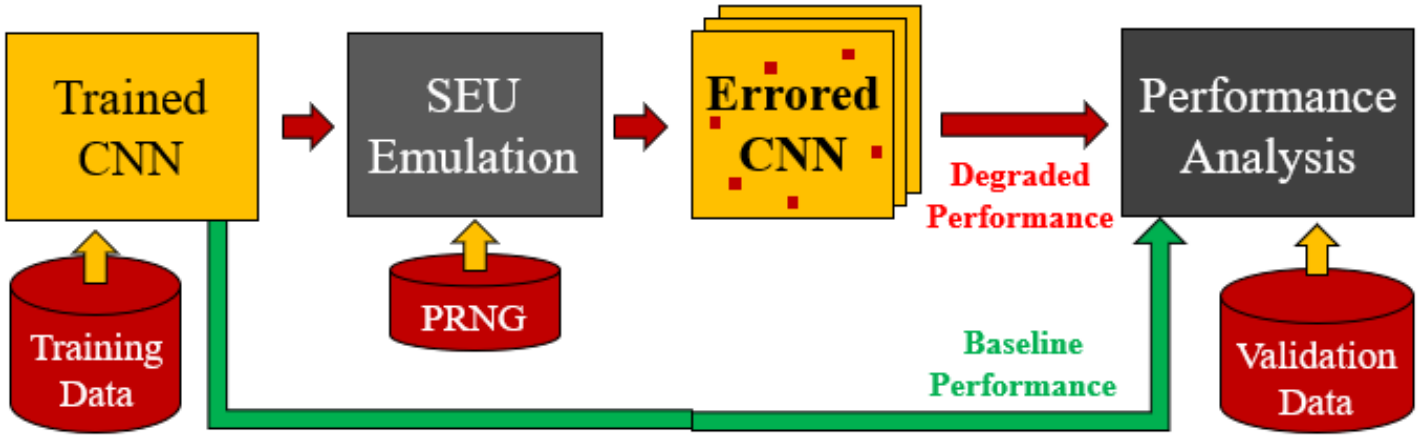
Purpose



- To further investigate this bimodal behavior, we defined ten distinct targeted SEU scenarios within an IEEE 32-bit word
- In each case, random weights or biases were chosen without preference within the target range

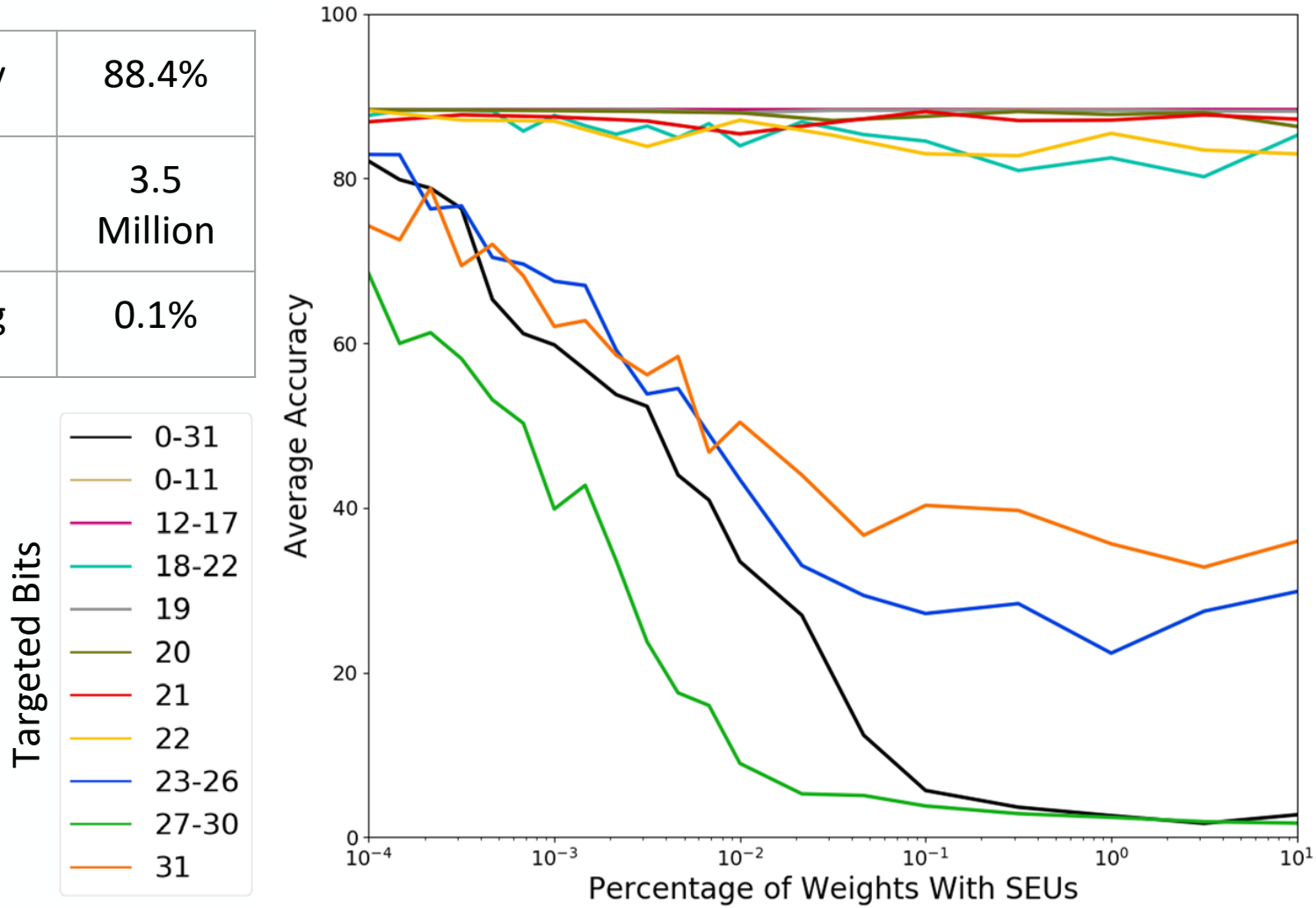
Experimental Outline

- 20 different percentages of weights altered for each case ranging from 10^-10 to 10% increasing in a logarithmic fashion by a magnitude of 10 and from 0.01-0.1% increasing linearly by 0.01%.
- 100 trials for each percentage starting with unaltered pretrained weights each trial
- CNN will perform classification on a validation set of data with the altered weights and the accuracy will be compared to the base accuracy



Performance Degradation: MobileNetV2

Baseline Accuracy	88.4%
Number of parameters	3.5 Million
Random Guessing	0.1%



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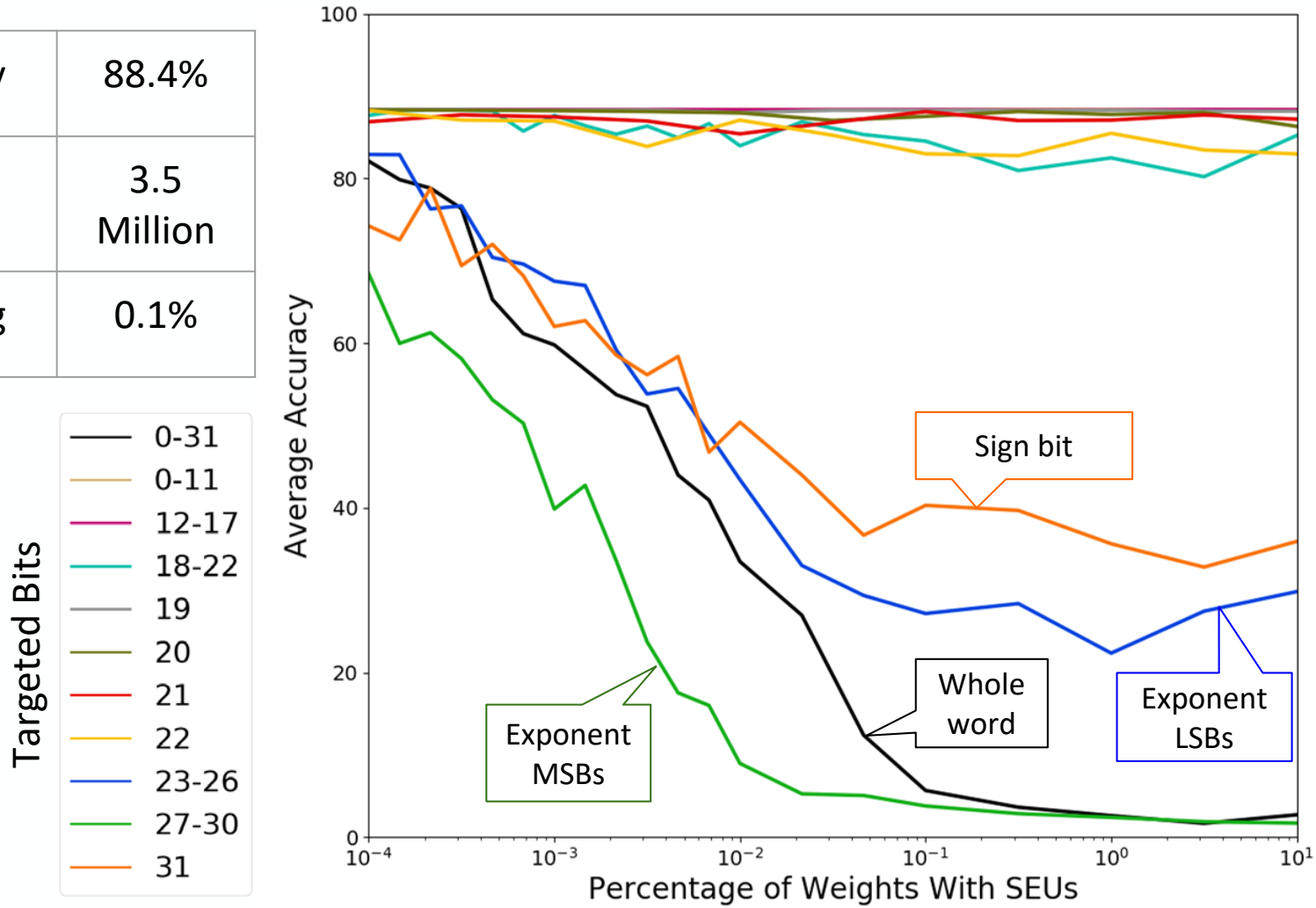
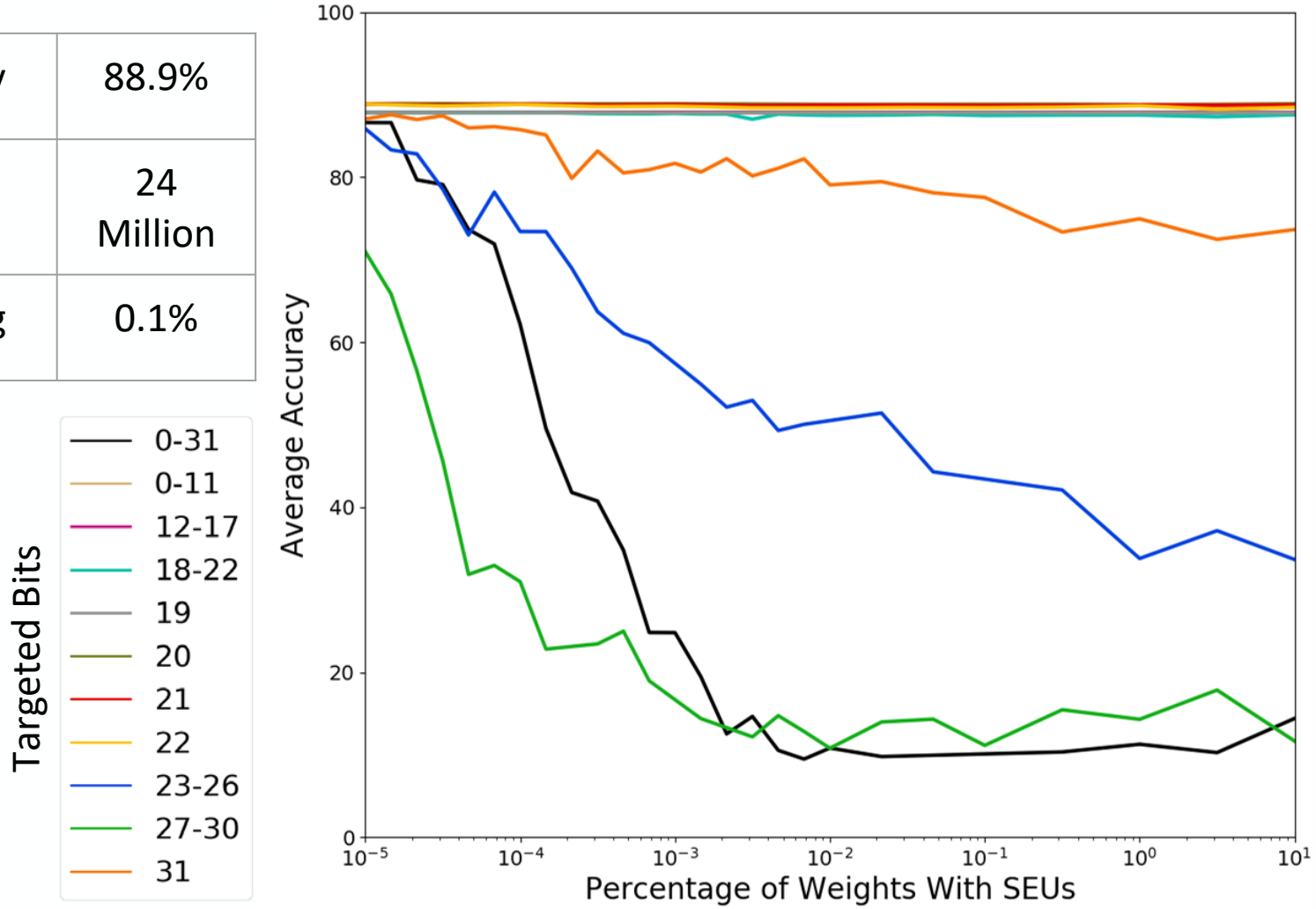


Performance Degradation: InceptionV3

Baseline Accuracy	88.9%
Number of parameters	24 Million
Random Guessing	0.1%



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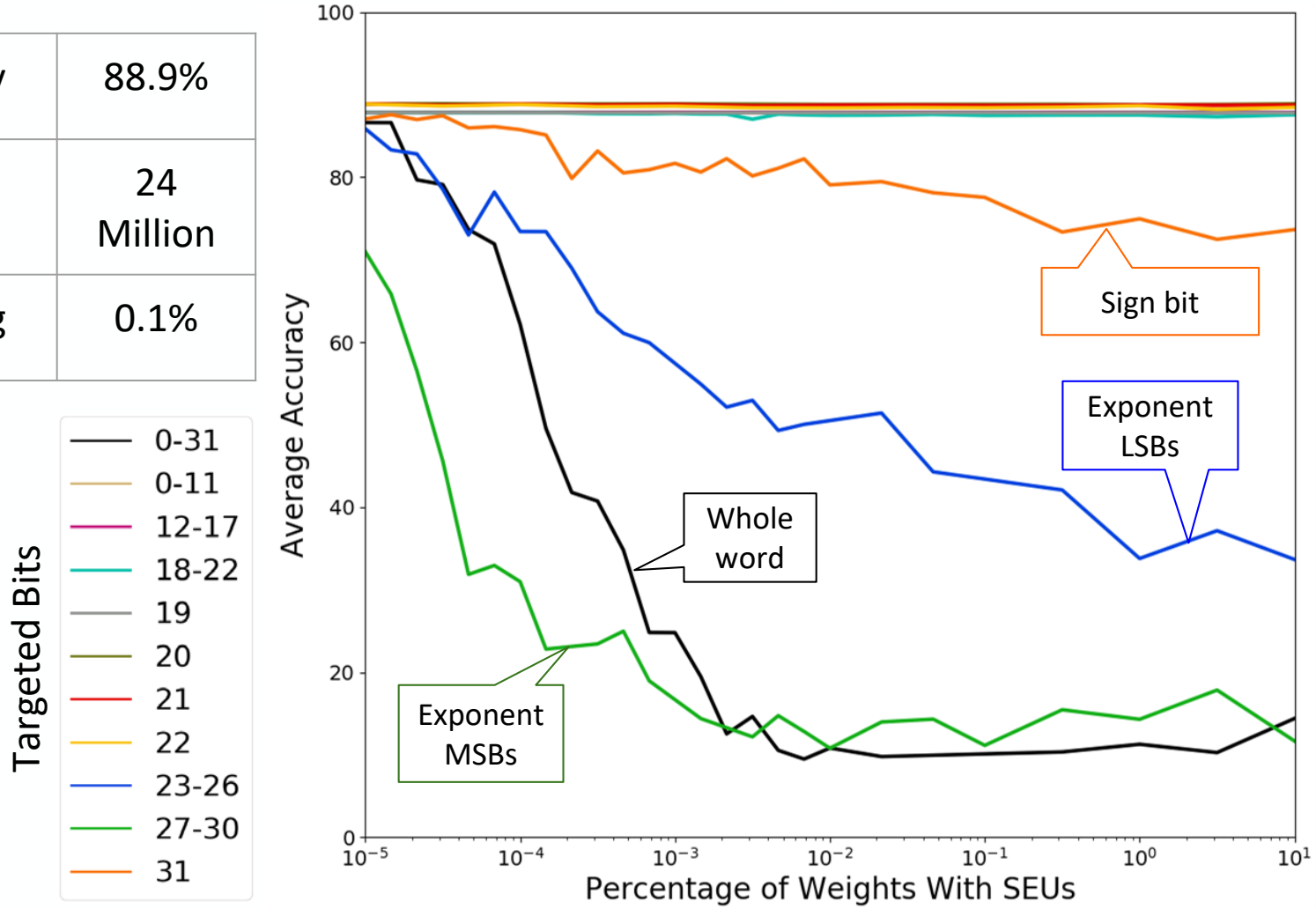
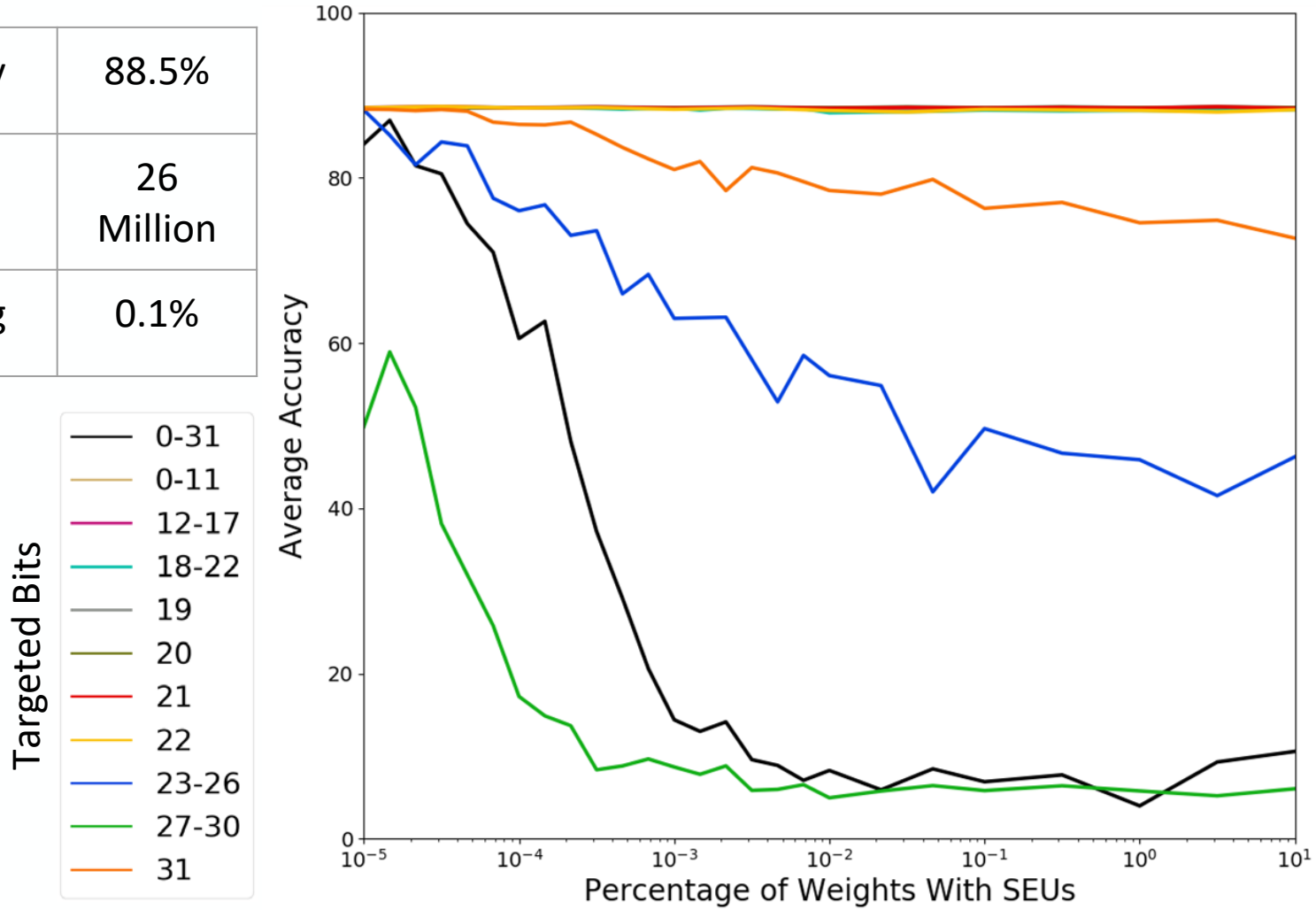


Performance Degradation: ResNet50

Baseline Accuracy	88.5%
Number of parameters	26 Million
Random Guessing	0.1%



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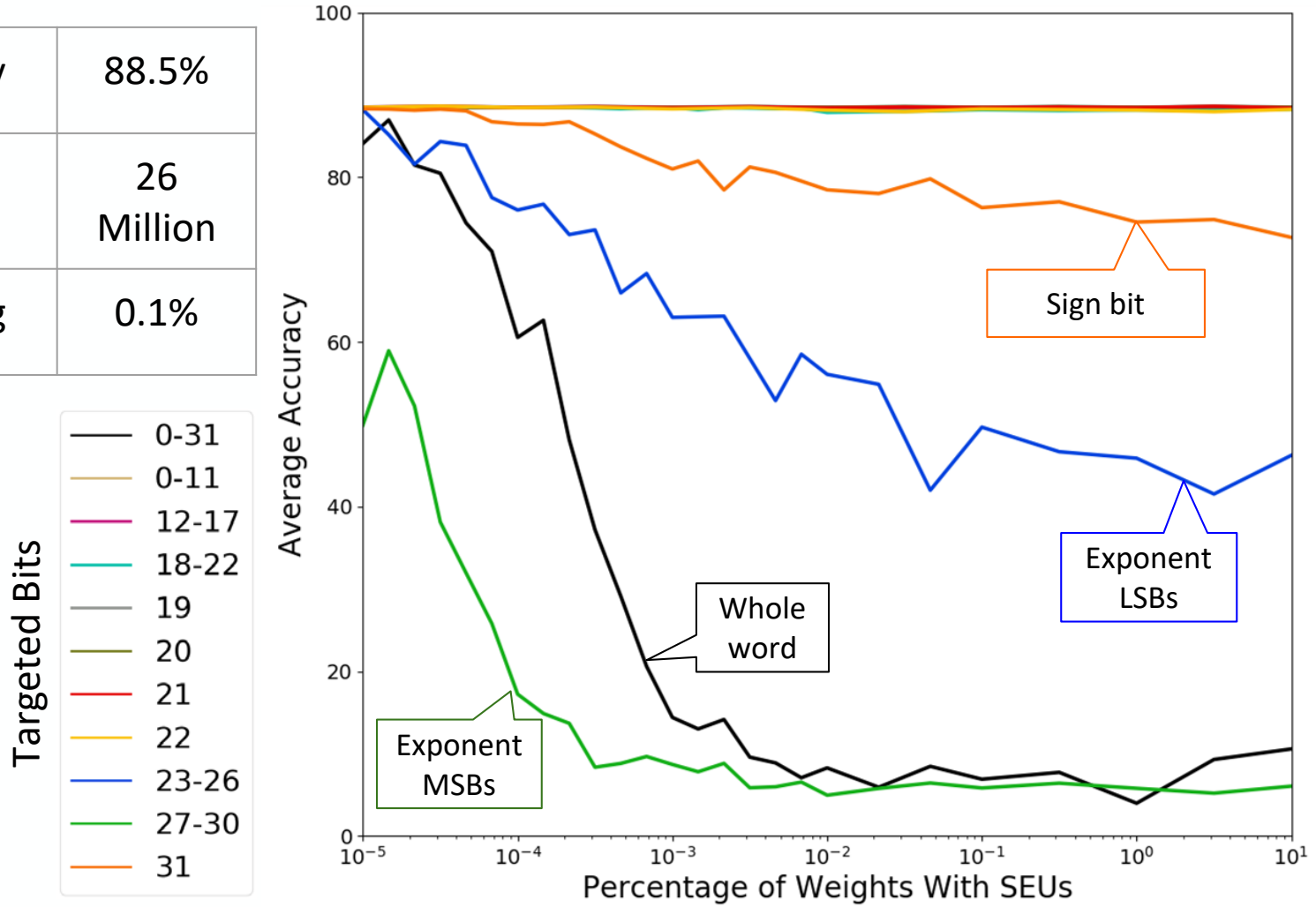
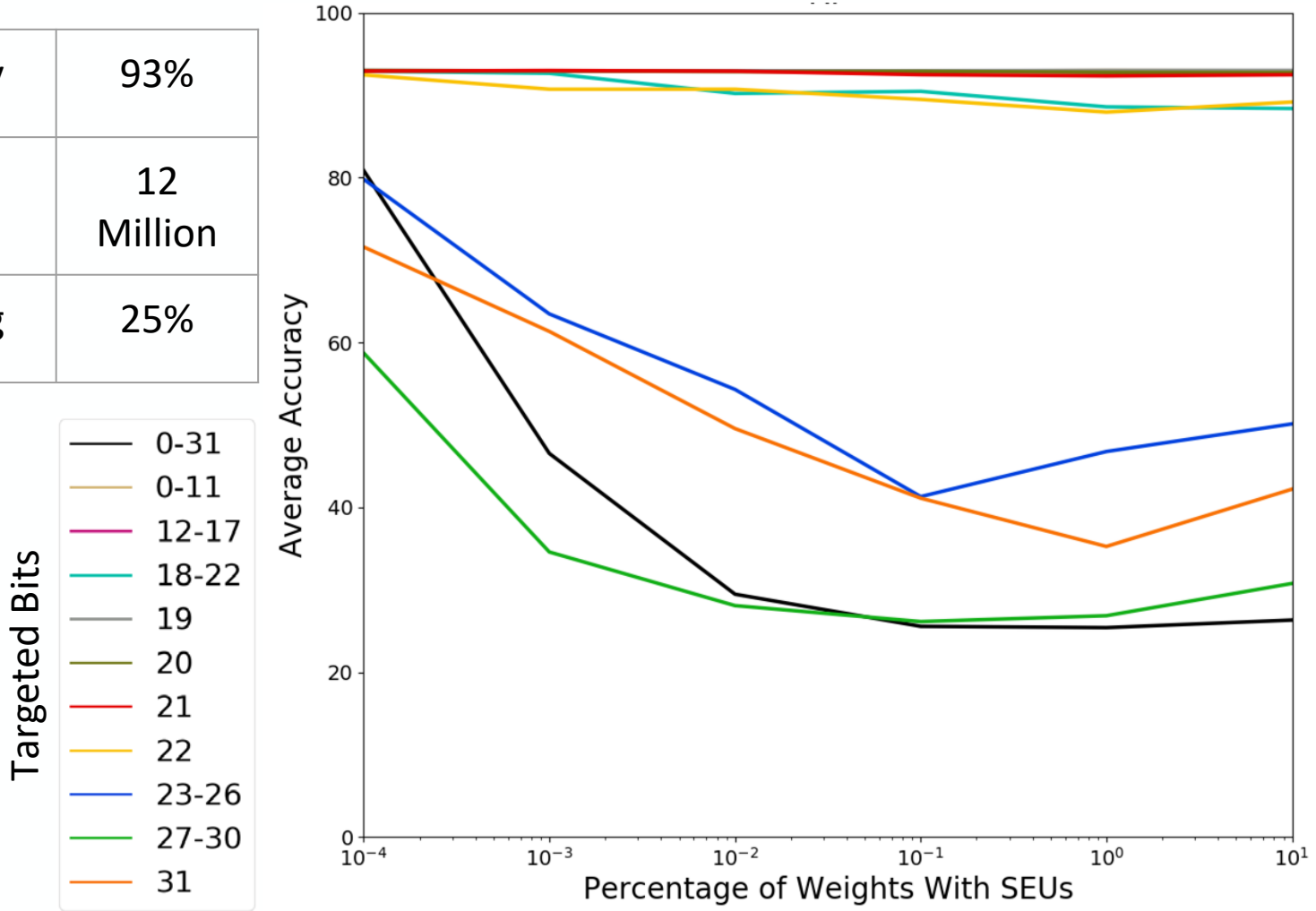


Performance Degradation: Custom RF

Baseline Accuracy	93%
Number of parameters	12 Million
Random Guessing	25%

Classifies radio signals as
- QPSK
- BPSK
- QAM16
- QAM64



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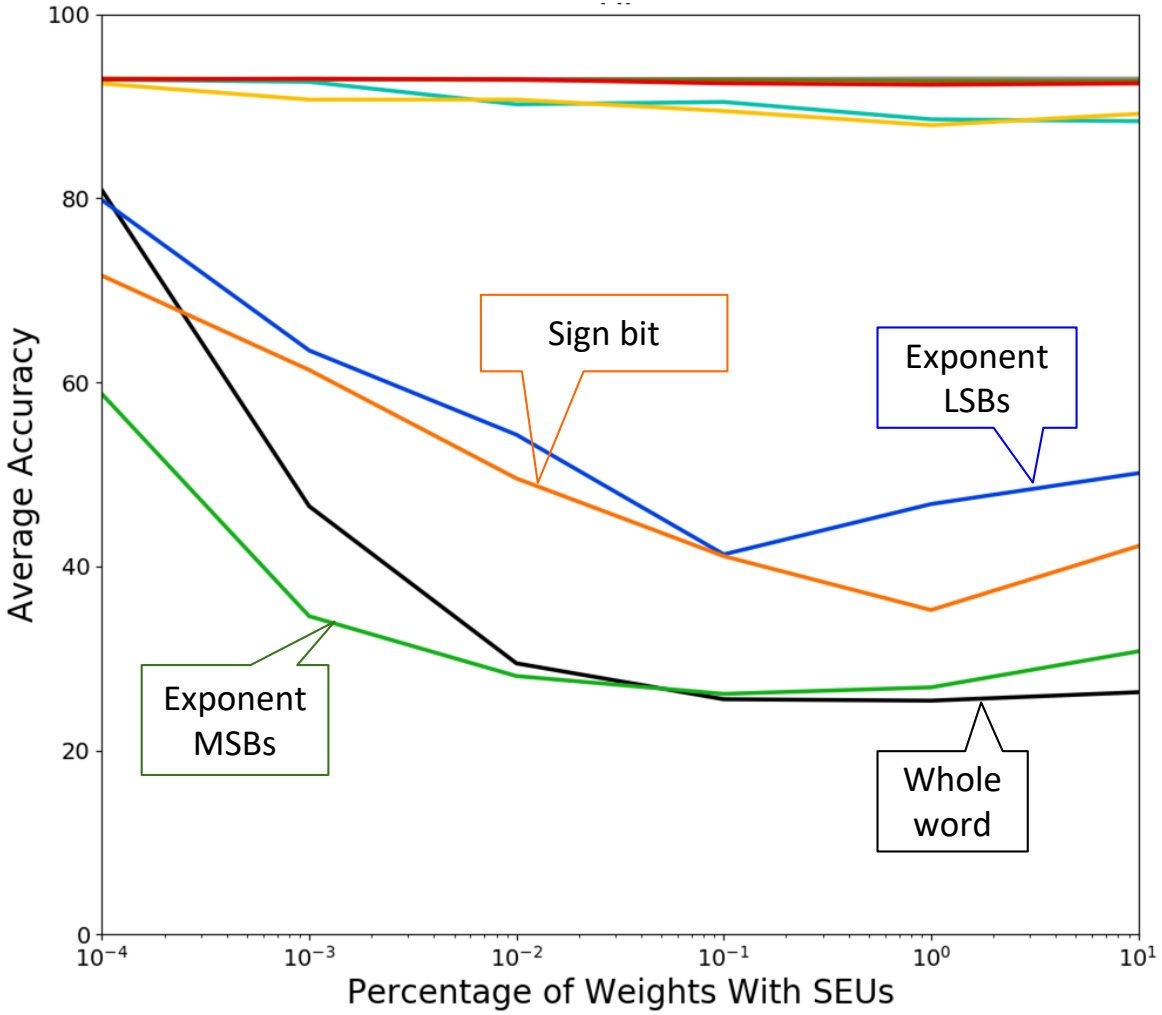
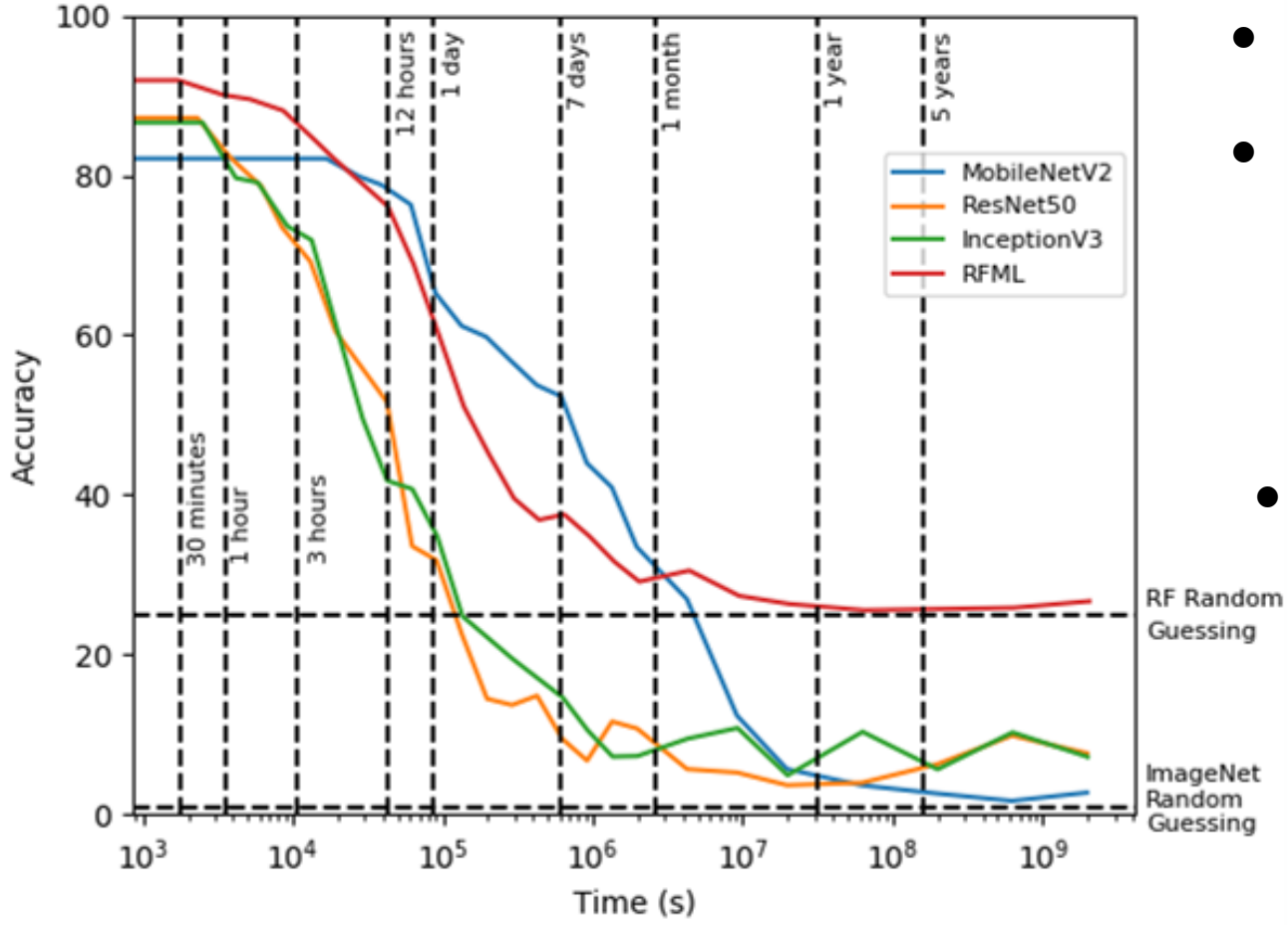


Results

- Targeted SEUs in bits 23-31 (sign bit, exponent bits) were the greatest contributor to the degradation of the entire neural net. SEUs induced in the 18 LSBs of the mantissa had little to no effect on CNN accuracy
  - LSBs may be used to protect the memory stored in the MSBs
- Targeted SEUs in the sign bit did not contribute as much to the degradation as the other MSBs
  - Suggests that many values are relatively close to 0, so a sign change does not significantly change the value of these weights

Environmental Analysis

CNN Longevity in Low Earth Orbit



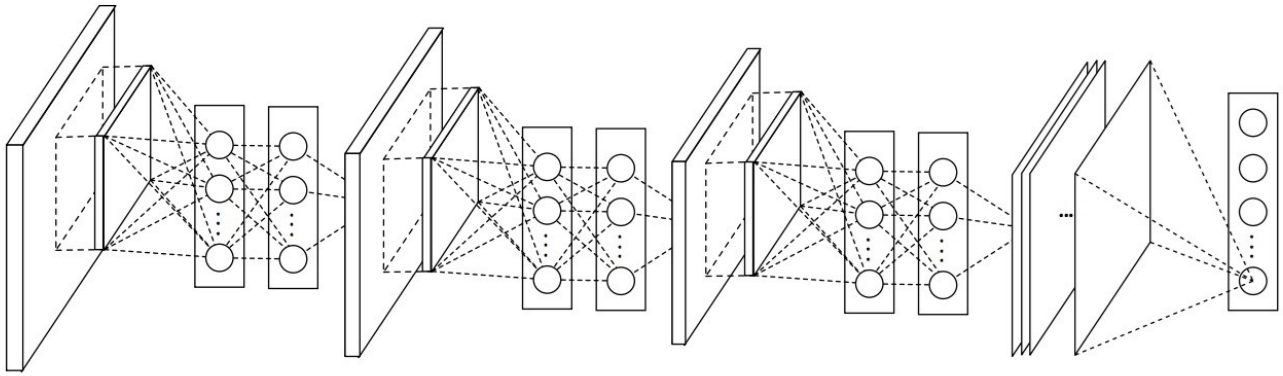
- Other environments may be viewed as a re-scaled x-axis.
- Time to reach 80% ("unstable") accuracy:
  - Earth: 13.2 years
  - LEO: 20 hours
  - Moon: 176 days
  - Mars: 1.5 seconds
- **In most environments, there is enough time to implement error detection or correction algorithms**

Future Work

Architectural Analysis

Target certain layers in neural net architectures and comparing accuracies

- CNN Kernels
- LSTM Cells
- RNN Recurrent Layers
- Importance of layer depth

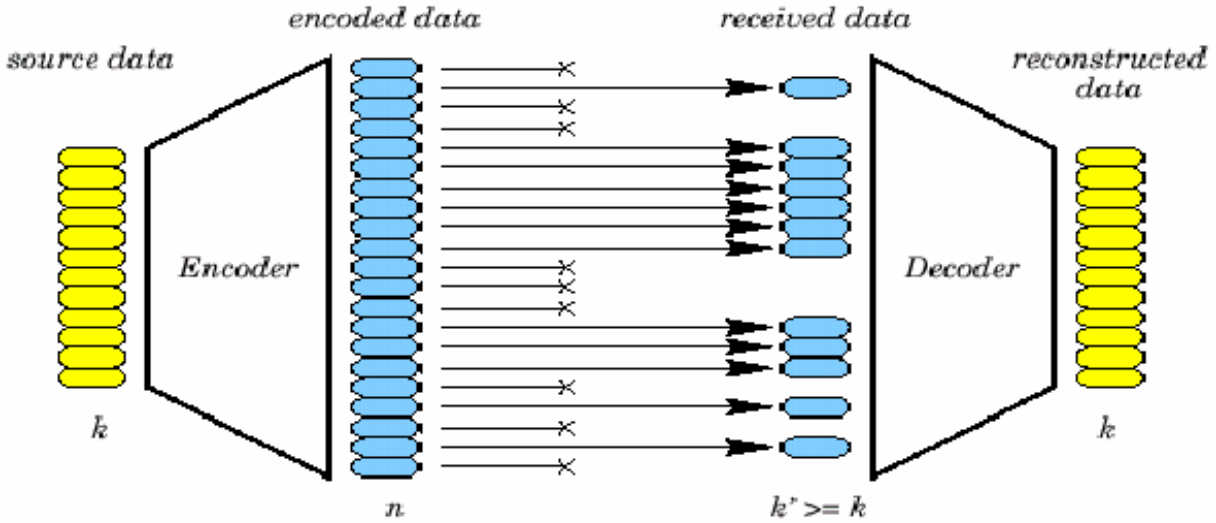


Future Work (continued)

Forward Error Correction

Use less significant bits to protect the more significant bits within weights by implementing known FEC methods

- Triple Mode Redundancy (TMR)
- Cyclic Redundancy Check (CRC)
- Parity Check
- Hamming Code
- Reed Solomon
- Floating Point to Fixed Point Conversion



Questions?