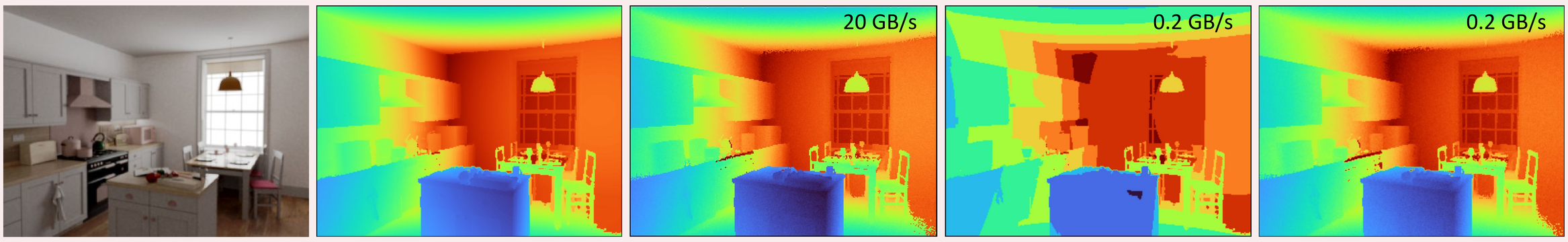
P09

Count-Free Histograms with Race Logic for Single-Photon LiDAR

Atul Ingle, David Maier
Department of Computer Science, Portland State University
https://computational.camera/EDPHi/

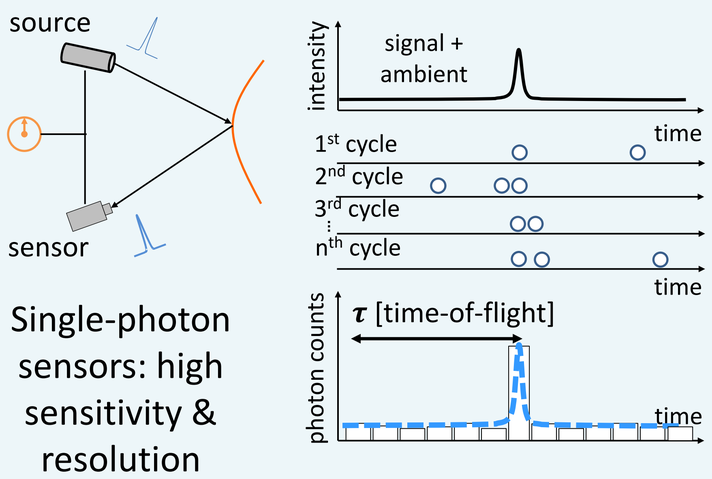
Portland State UNIVERSITY

Single-Photon LiDAR at 100x Lower Bandwidth



Equi-depth photon histograms: 100x lower bandwidth while maintaining distance resolution

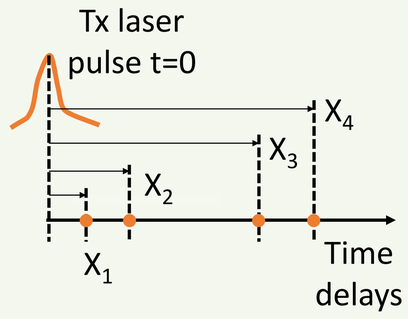
Single-Photon LiDAR: Image Formation



Single-photon sensors: high sensitivity & resolution

$$30 \text{ frames/s} \times 10^6 \text{ pixels/frame} \times 1 \text{ histogram/pixel} \times 1000 \text{ bins/histogram} \times 1 \text{ byte/bin} = 30 \frac{\text{GB}}{\text{sec}}$$

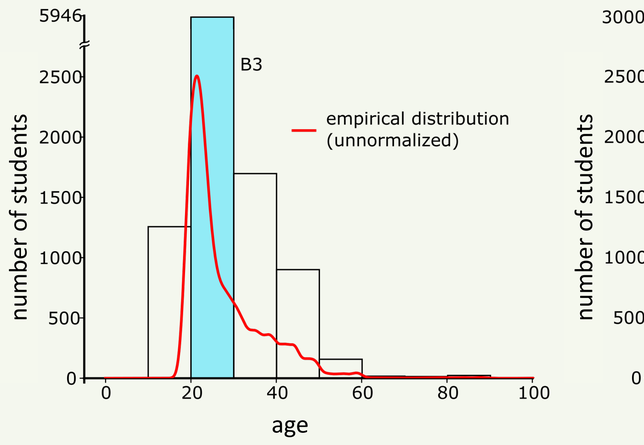
Key Ingredient #1: Race Logic



Race logic encodes signal values in terms of time delays.

Naturally suited to single-photon LiDAR.

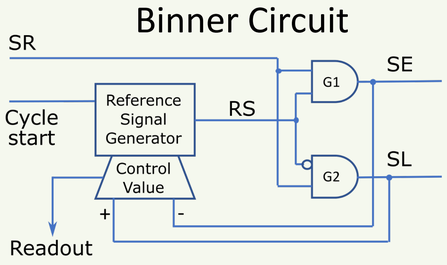
Key Ingredient #2: Equi-depth Histograms



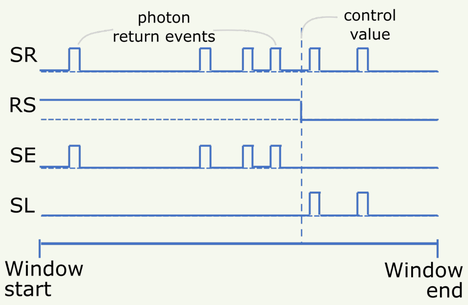
Equi-depth histograms adaptively capture "peaky" distributions.

A 2-bin Equi-depth Histogram: The "Binner" Circuit

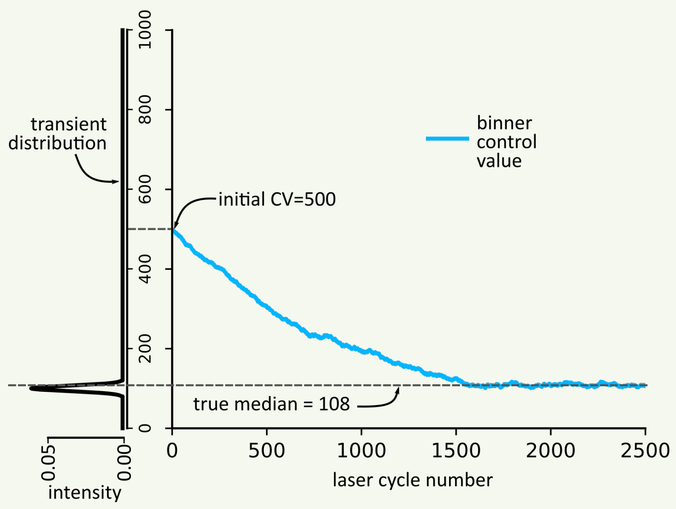
Binner Circuit



Timing Diagram

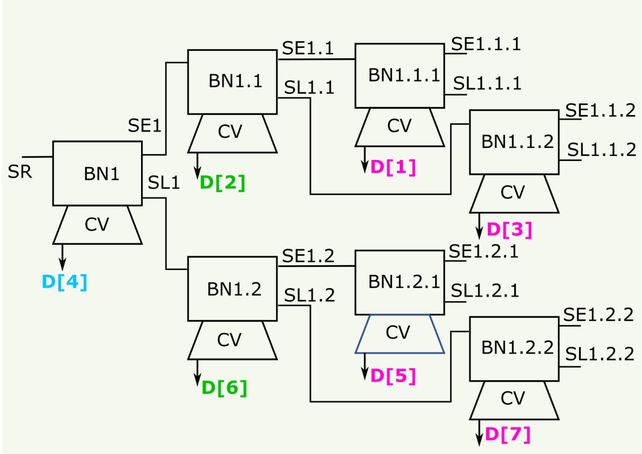


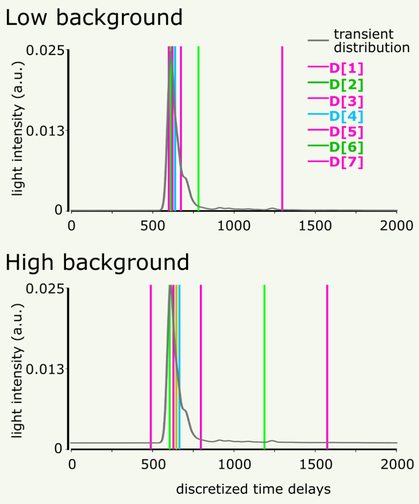
A Typical Run of a Binner



Binner control value probabilistically tracks the overall median

Equi-depth Histogrammer (EDH)



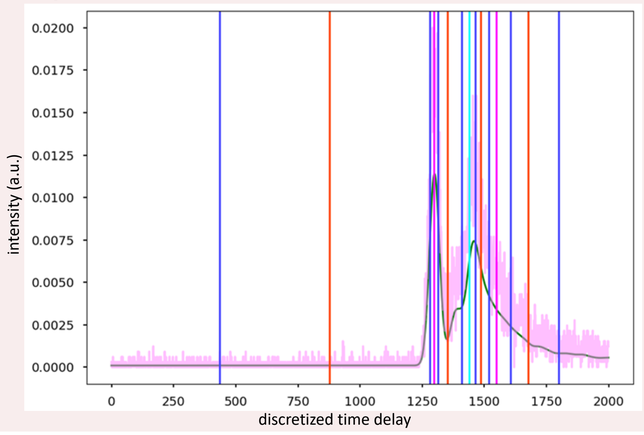


A recursive tree of binners adaptively captures the signal peak.

ED bin boundaries cluster around the peak even in high ambient light conditions.

Advantages of Equi-depth Histograms

- Reduced bandwidth and lower energy requirements
- Avoids time-to-digital conversion
- Modest circuit complexity
- Does not need the complete history of photon timestamps or photon counts



- Can capture complex return distributions (e.g., multiple returns, interreflections and multipath)

Ongoing Activities

- Hardware prototyping and FPGA implementation of a binner element and recursive tree
- Control value stepping strategies for improved convergence and accuracy

International Image Sensors Workshop 2023

Funding: NSF Award # 2138471