Temporal super-resolution for time domain continuous imaging

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COIMG-430, 11:10AM January 31, 2017

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Time Domain Continuous Imaging (TDCI)

- Cameras create scene appearance models that change (mostly) continuously over time
  - A capture is represented as a continuous waveform per pixel
  - Compression is (mostly) in the time domain, based on a pixel value error model
- Virtual exposures are computed for any time interval by integrating area under each pixel's waveform over the specified interval

Temporal Super-Resolution

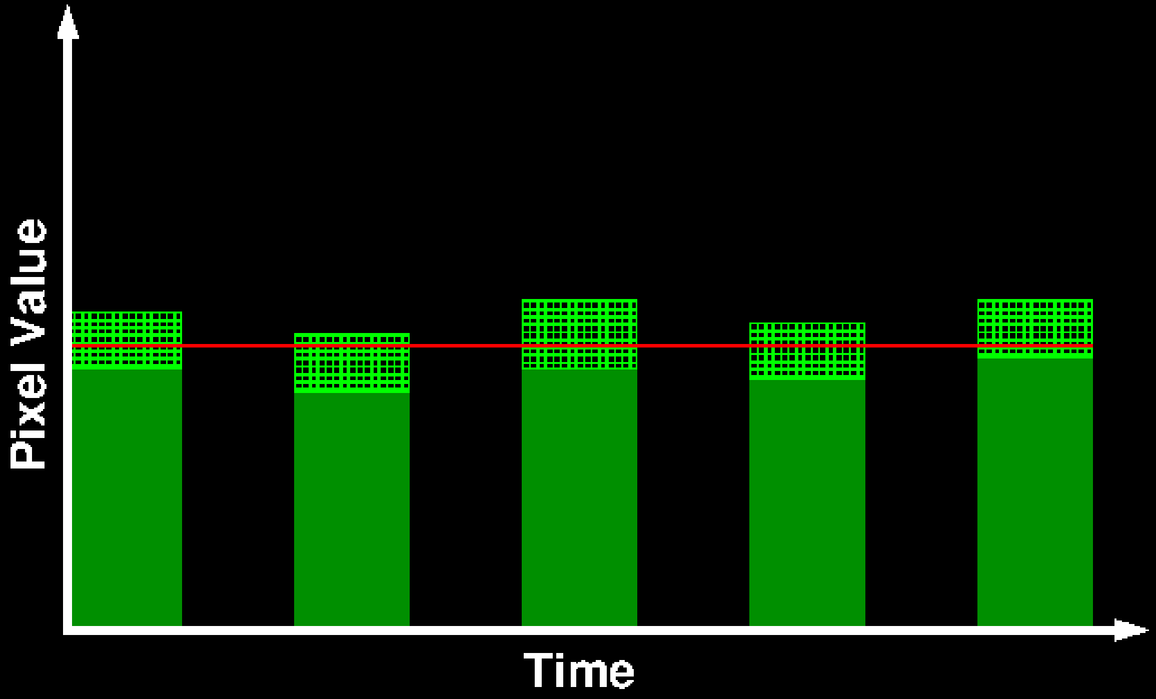
- Super-resolution (SR) means resolving details smaller than sample period (e.g., pixel size)
- Temporal SR (TSR) means resolving time in units smaller than the frame time
- Usually, this is done assuming:
  - Pixel values in each frame are correct
  - Majority of change between frames is from scene changes (scene faster than lighting)
  - Result is multiplied framerate

Different Assumptions for Temporal SR in TDCI

- Pixel values in each frame are noisy samples of the correct values, with error bounds
- Majority of change between frames is due to lighting changes (lighting faster than scene – a really good bet with high framerate capture)
- Result is more precise pixel-change event times, not related to a regular framerate

… any improvement helps

Changes That Aren't Changes



- Within error bounds is probably constant

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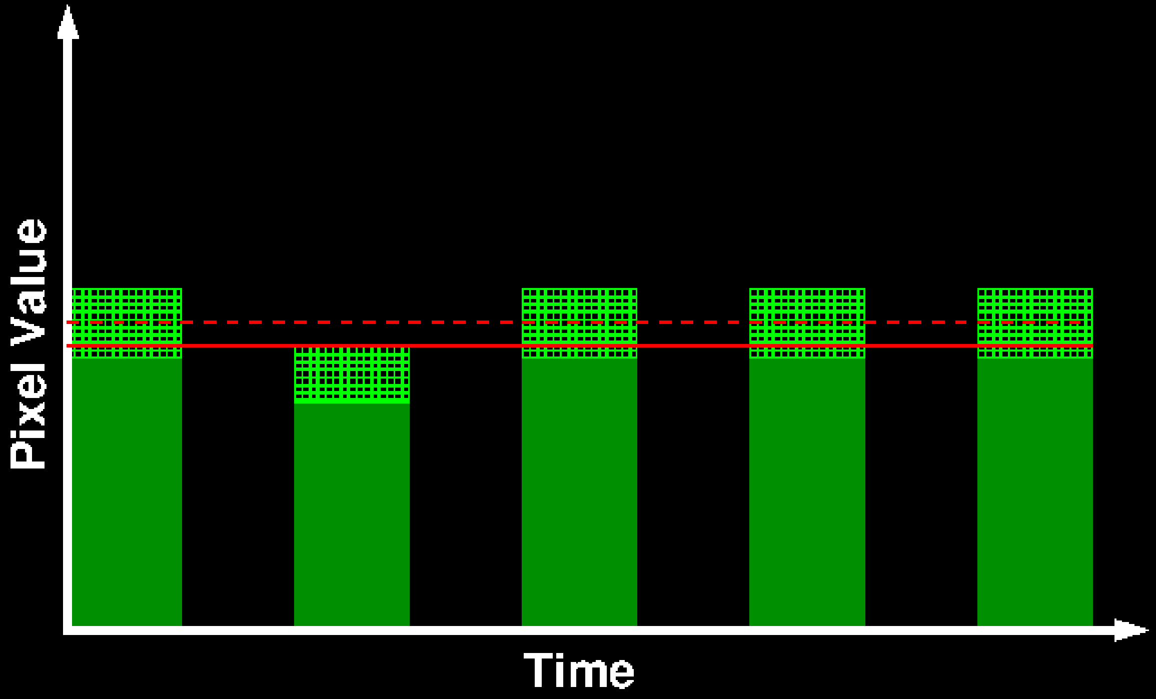
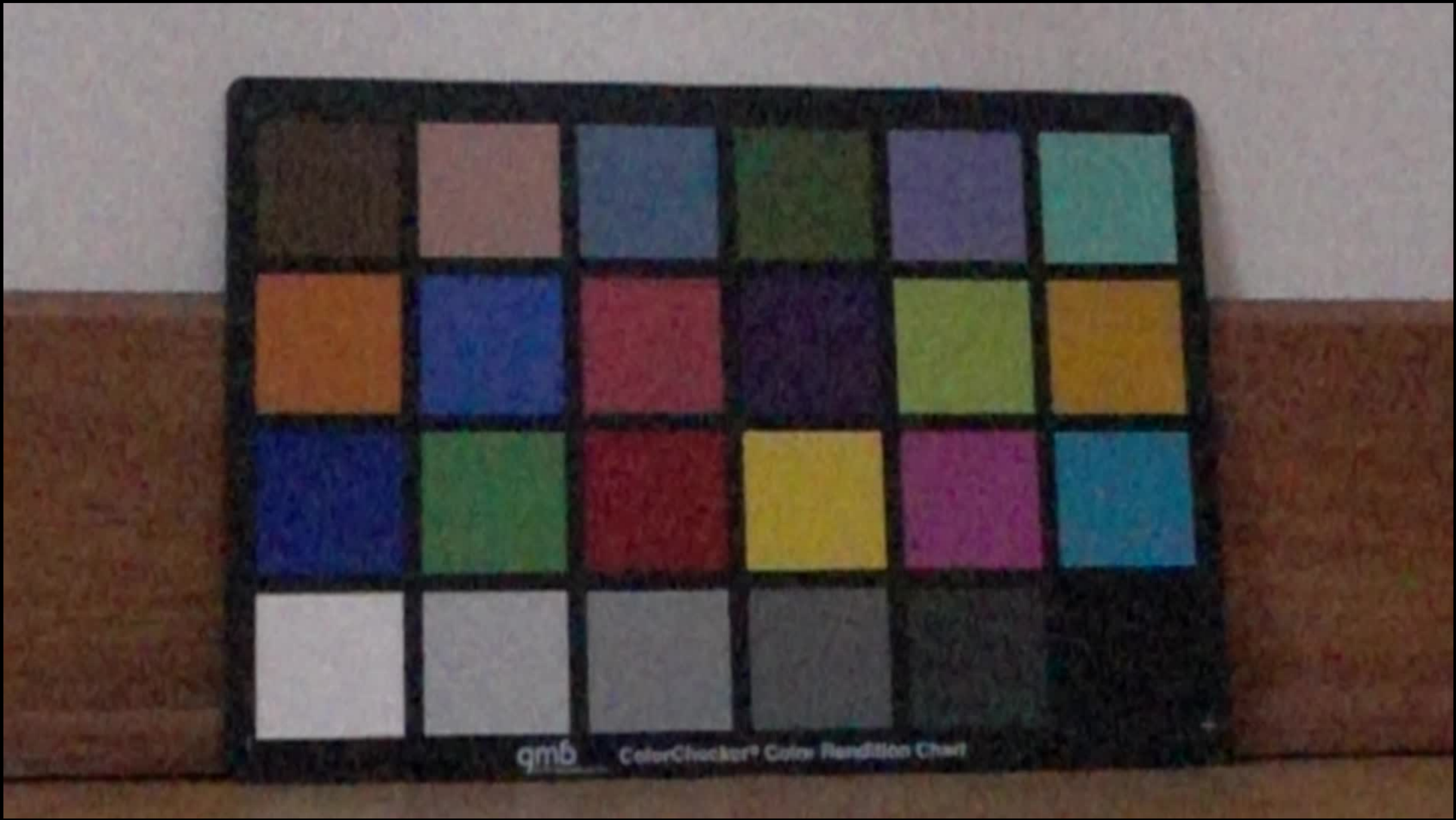
Changes That Aren't Changes

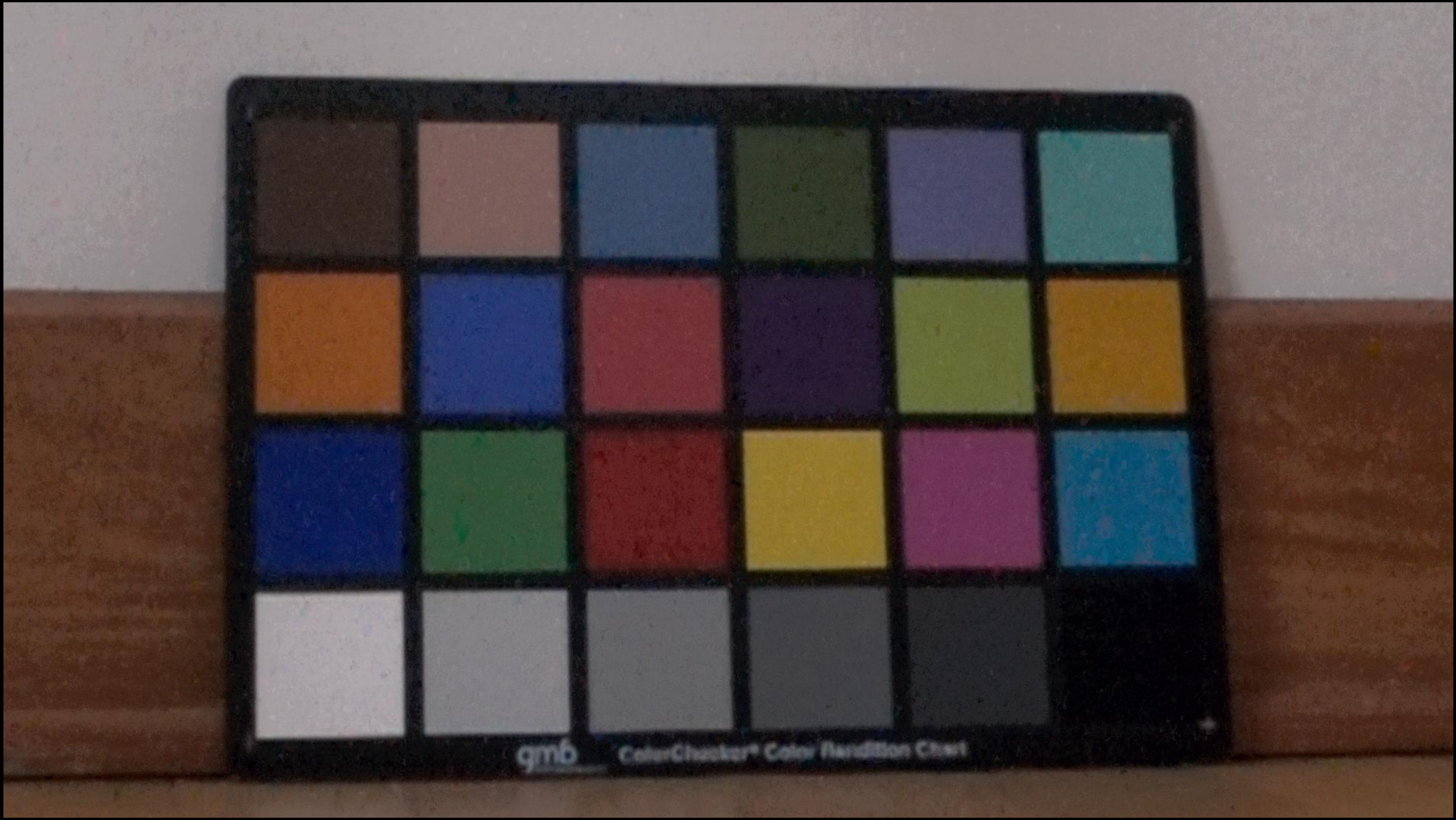


- Not just average; constrain to error bounds

A 960FPS Video Frame



A 1/960s Virtual Exposure



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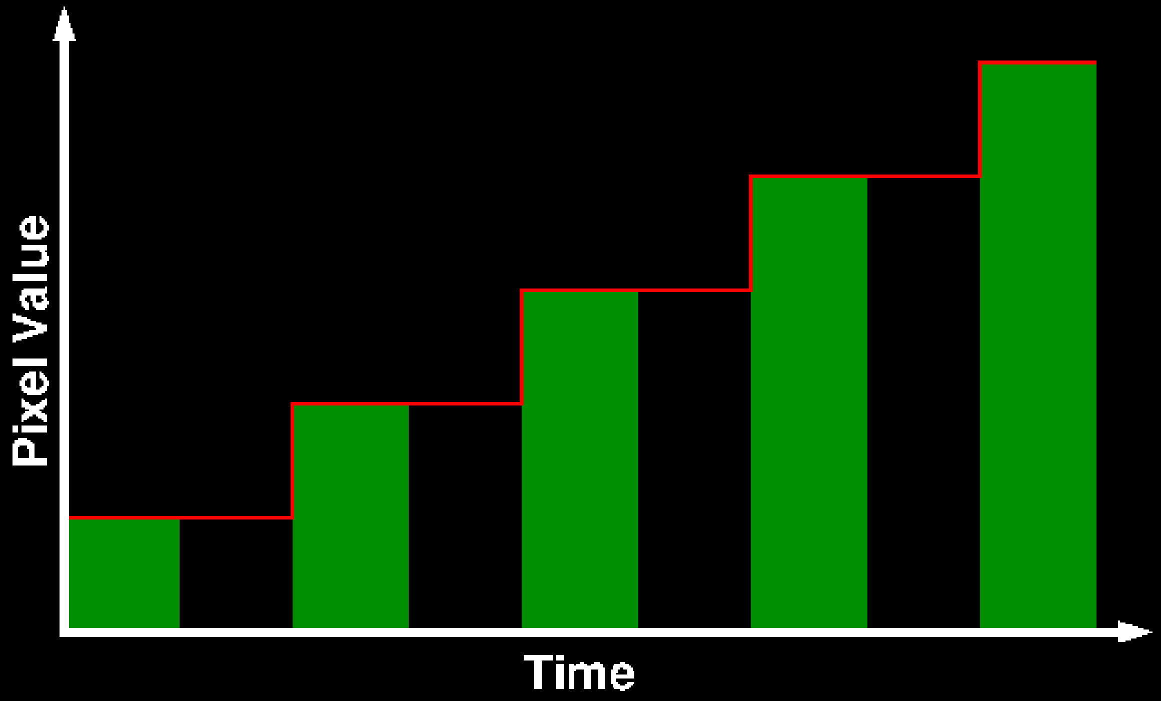
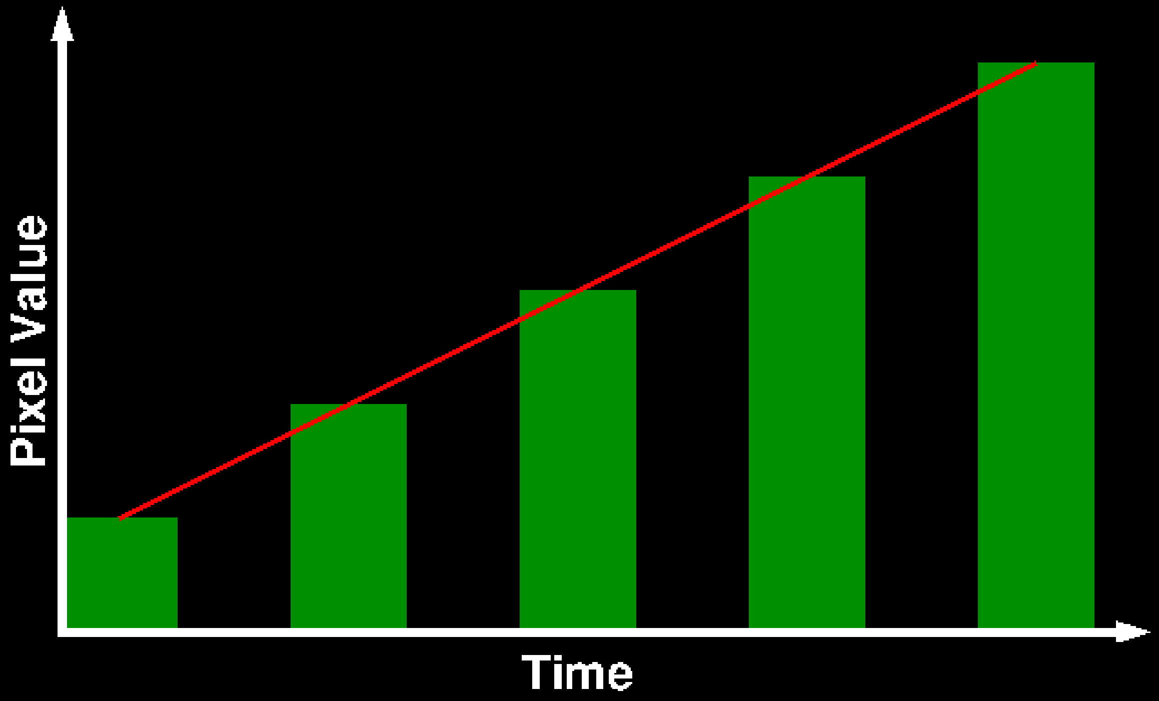
Slopes – Traditional Video



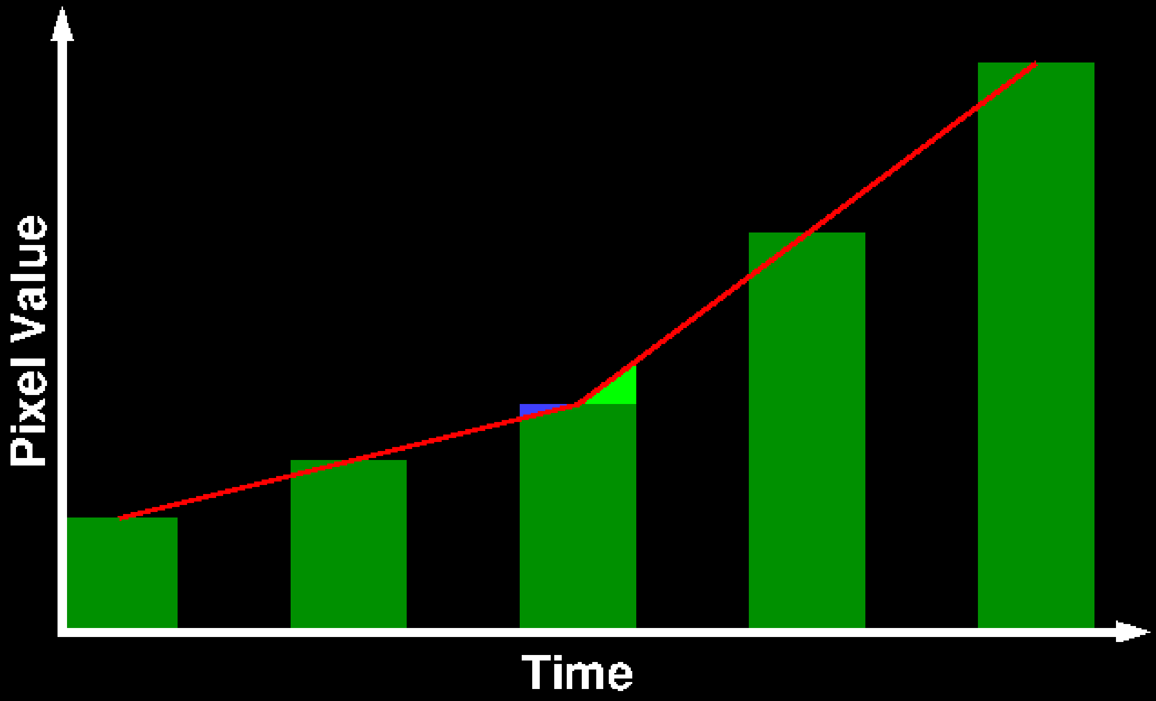
- Ignores difference between integration interval and 1/framerate

Slopes – Other TSR Work



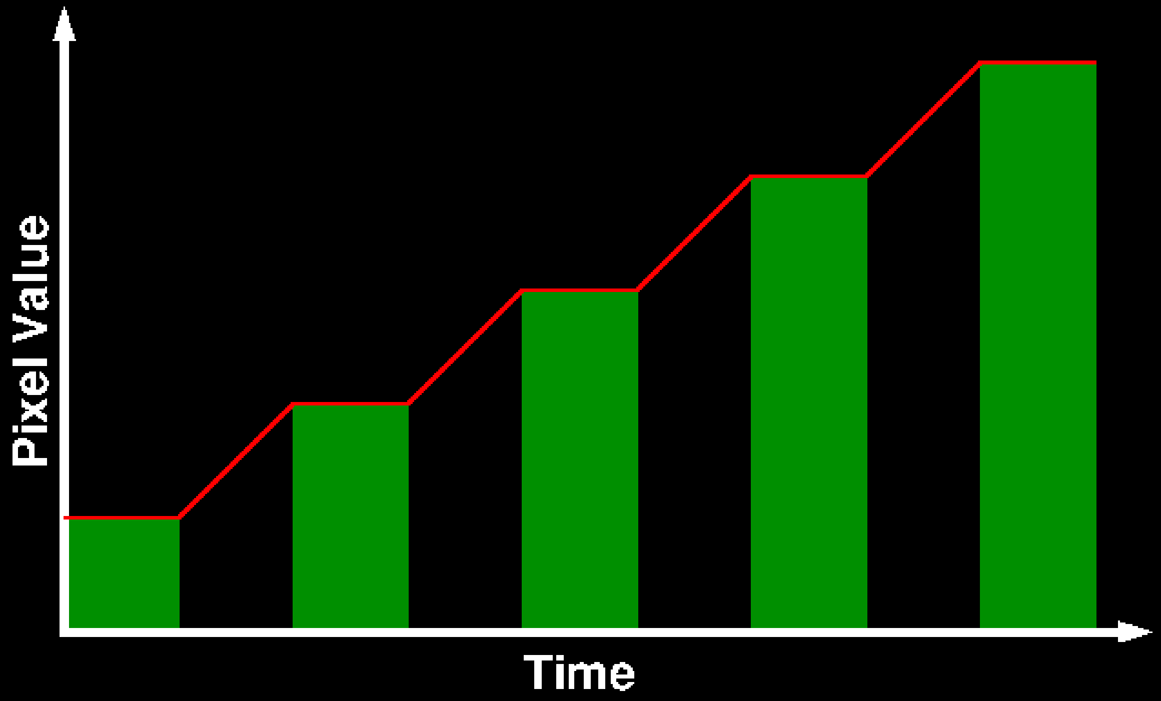
- Assumes precise instantaneous pixel values

Slopes – Other TSR Work



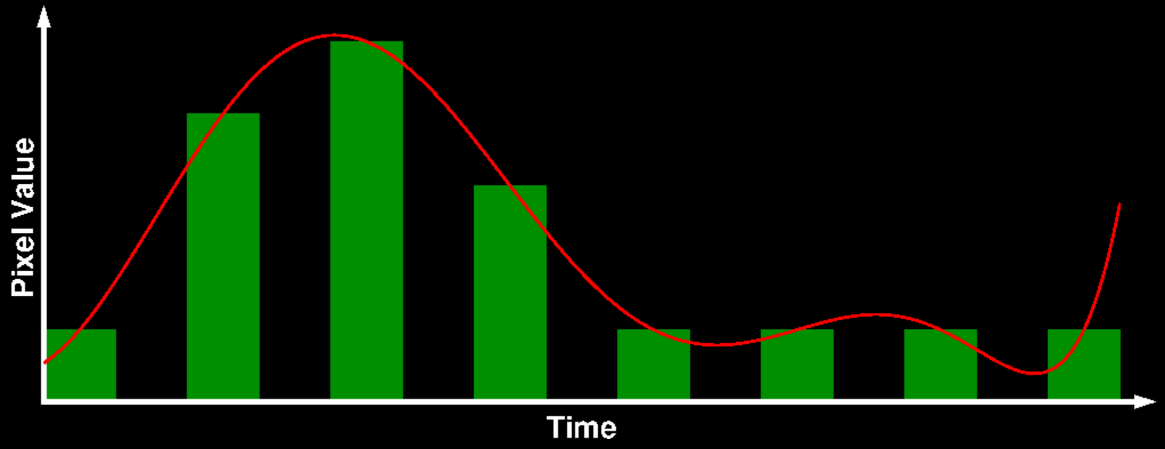
- Does **not** preserve actual value samples!

Slopes – TDCI TSR



- Pick a curve that preserves value samples

A Smooth Curve?



- Splines (NURBS), Bezier, Lagrange…
- Polynomials are bad at lying flat
- Do smoother curves preserve value samples? Adjust control points within error bounds

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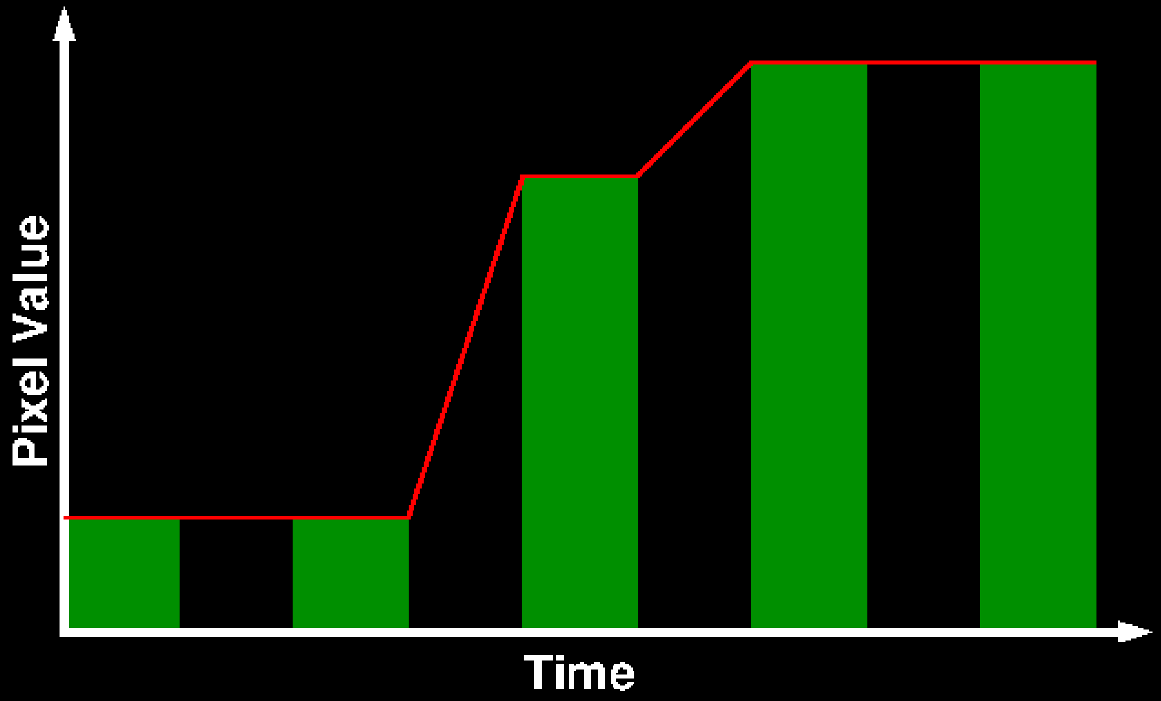
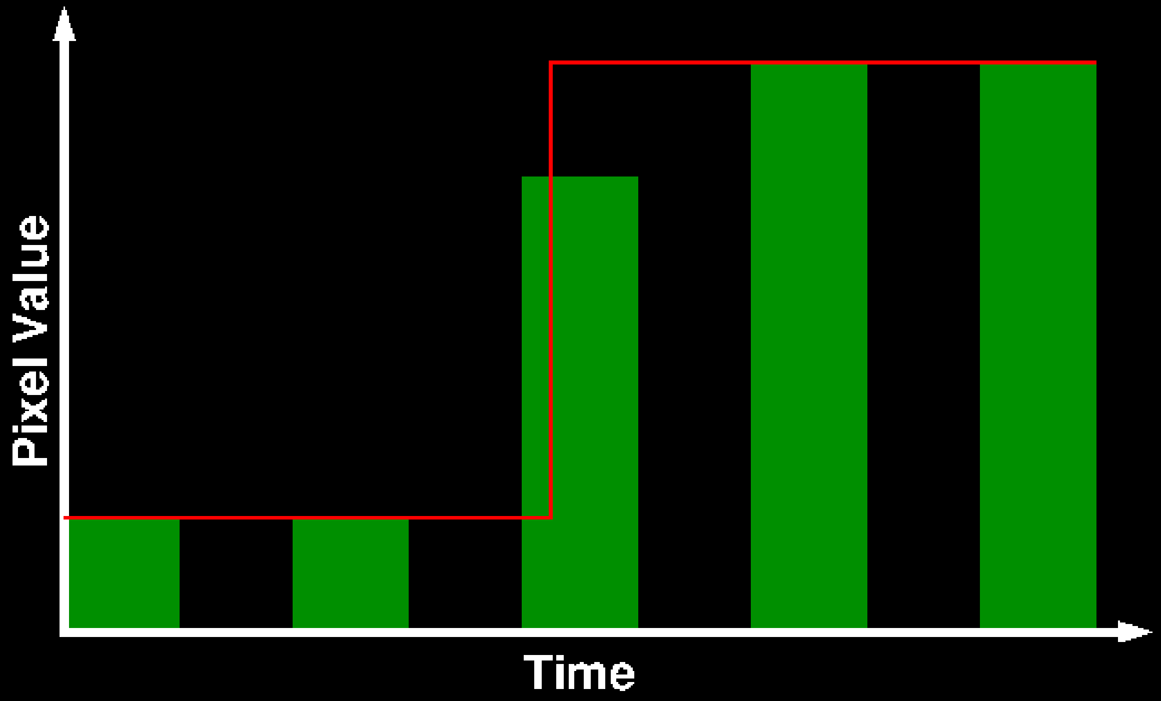
Edges – Linear TDCI TSR



- Edge missed by linear approx. to smoothing

Edges – Edge Localization



- Abrupt transition between stable values allows SR localization of edge!

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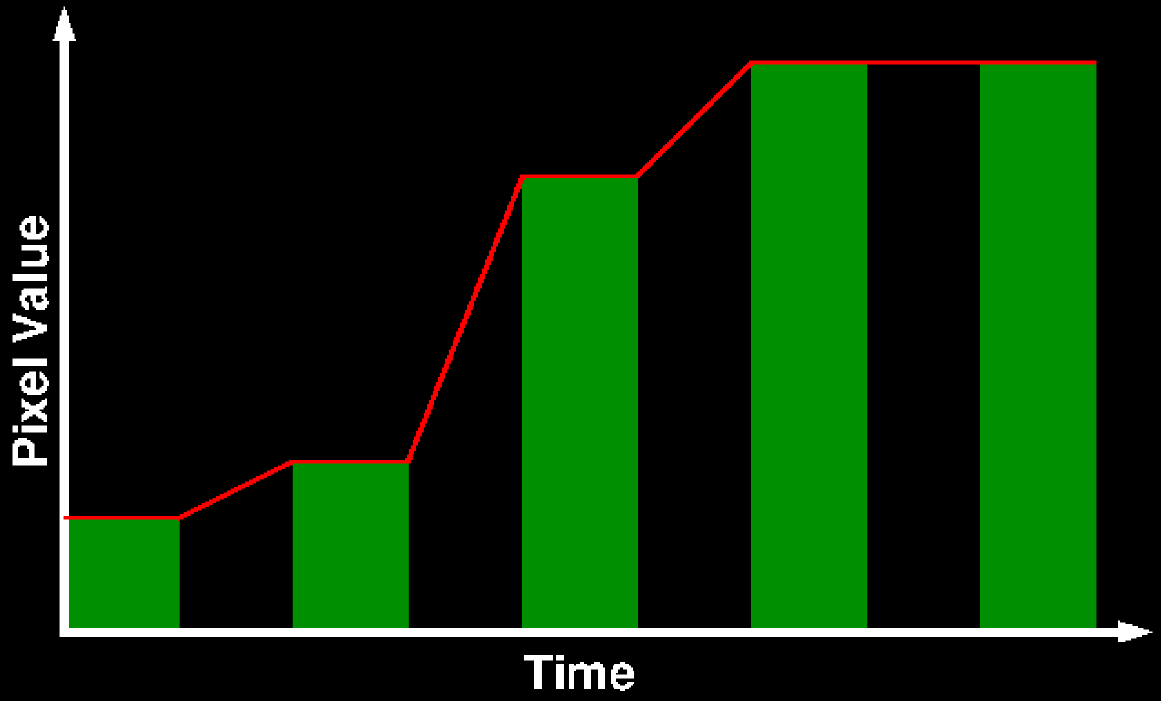
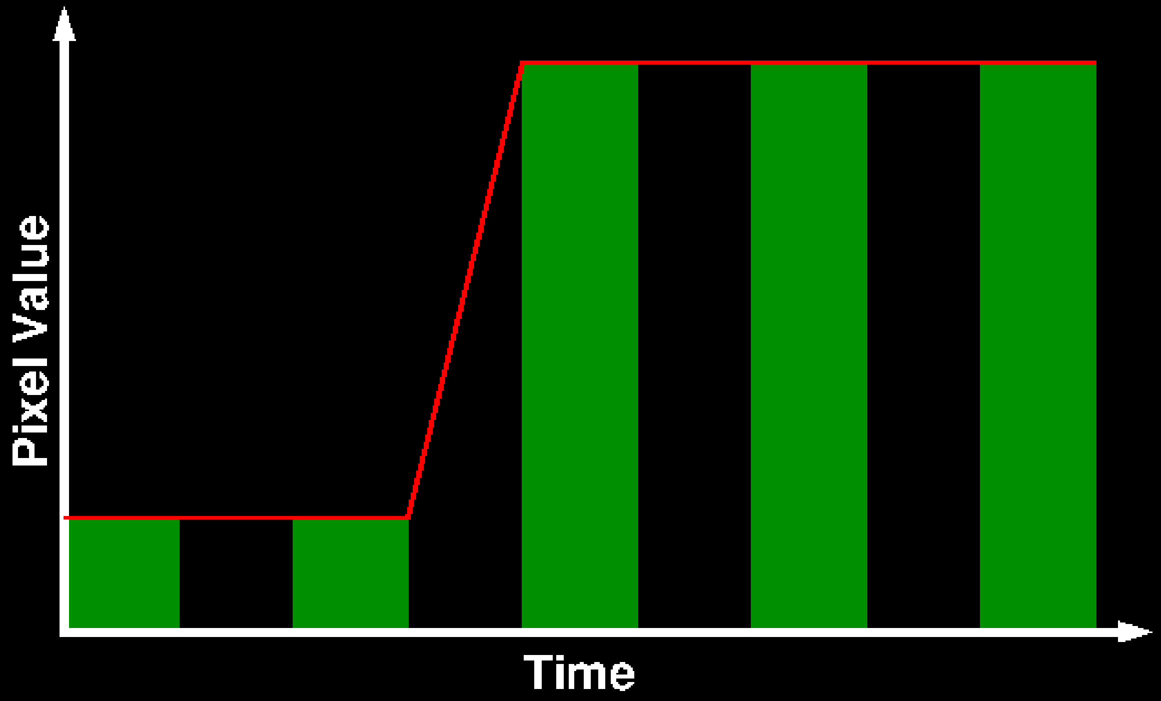
Edges – Edge Localization Fails



- SR requires a single-sample transition; this has two

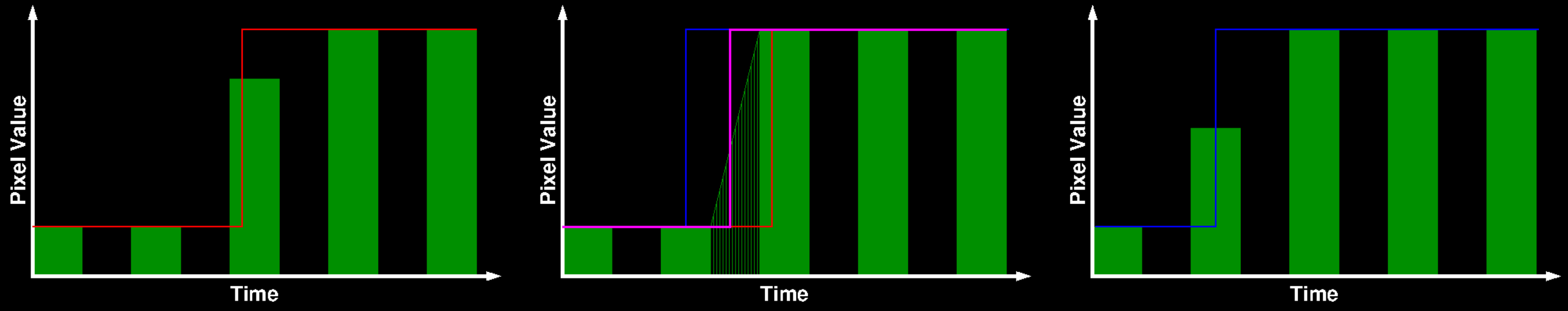
Edges – Edge Localization Fails



- SR requires a single-sample transition; this has none

Temporal Synchronization

- Transitions should be temporally correlated across neighboring pixels – thus, timing can be spatially interpolated
- Consider three neighboring pixels:



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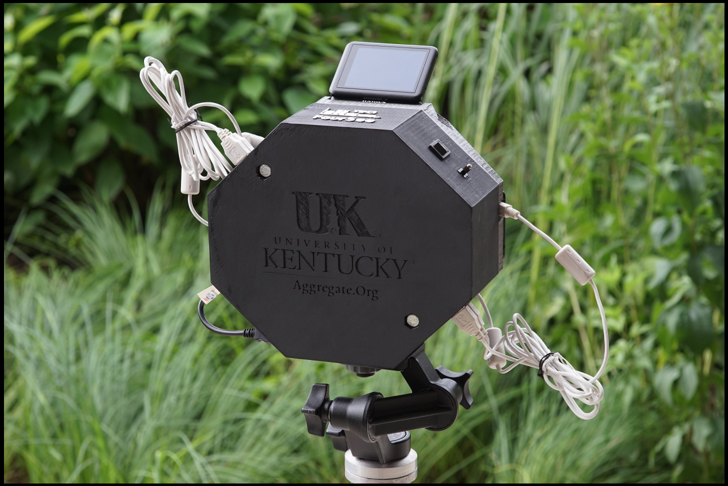
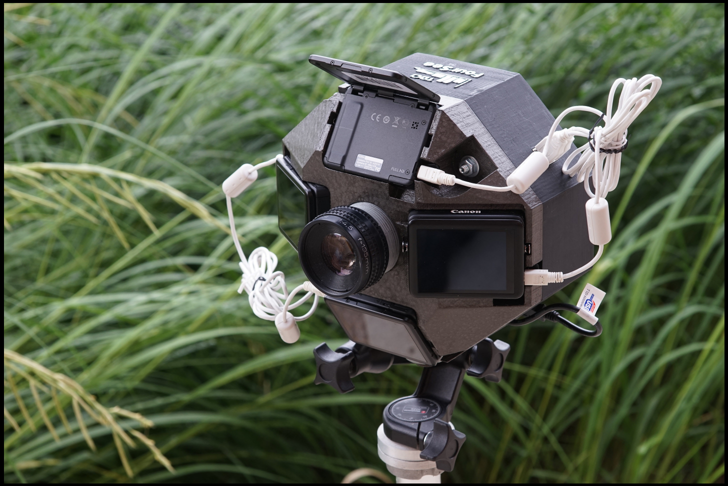
Skew Of Sample Timing

- TDCI doesn't require evenly-spaced samples
- Sample skew can enhance timing:
  - Focal plane & electronic rolling shutters skew sample timing within a frame
  - True TDCI measures time to threshold, inherently skewing pixel integration times
  - TDCI cameras, such as **FourSee**, obtain temporally-skewed samples for all pixels

The FourSee Multicamera





- Four Canon PowerShot N photograph image projected by central lens
- Software under CHDK controls timing: 240FPS, 240FPS (1/480s late), 24FPS, stills

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Summary

- At high sample rates (e.g., 240FPS), noise is more significant than large-scale motion
- TSR should respect sample error bounds
- Polynomial interpolation doesn't directly apply
- Temporal skew in sampling can be beneficial
- TDCI TSR implemented in `tik` (DPMI-081)

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