NUTIK: A Testbed for Functional Post-Capture Manipulation of Time and Gain

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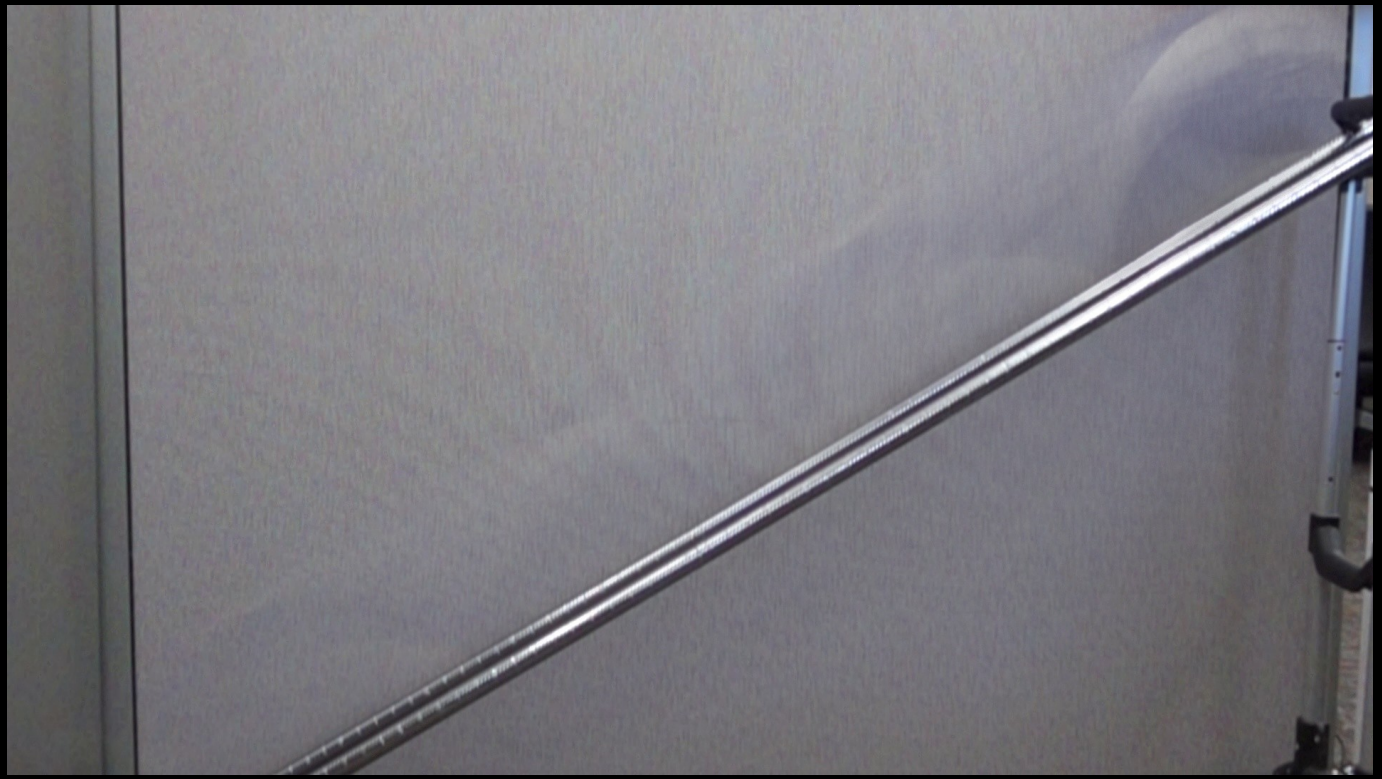


A conventional camera image of a suitably UK branded basketball rolling down an incline…

Not very exciting, is it?

Digital Cameras are Treated as Film Camera Simulacra

- Film cameras pretend† to **simultaneously expose the whole frame** for a **fixed interval** with **uniform sensitivity**

†*most shutter mechanisms can't really do this*

- **Convolves capture** with **integration**
- There is no inherent reason a digital camera has to abide by those rules

What happens if we don't?

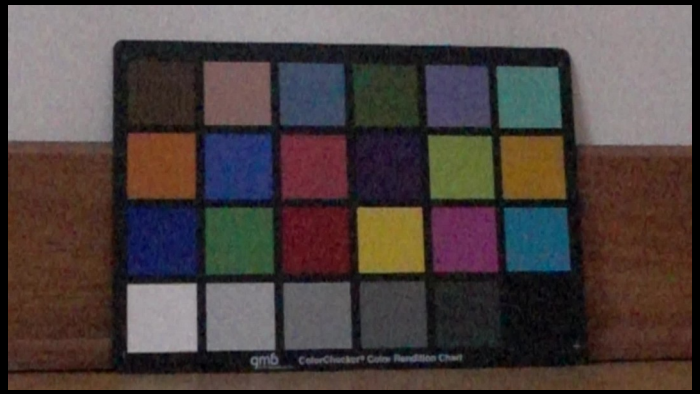
IMage EVolution model (IMEV)

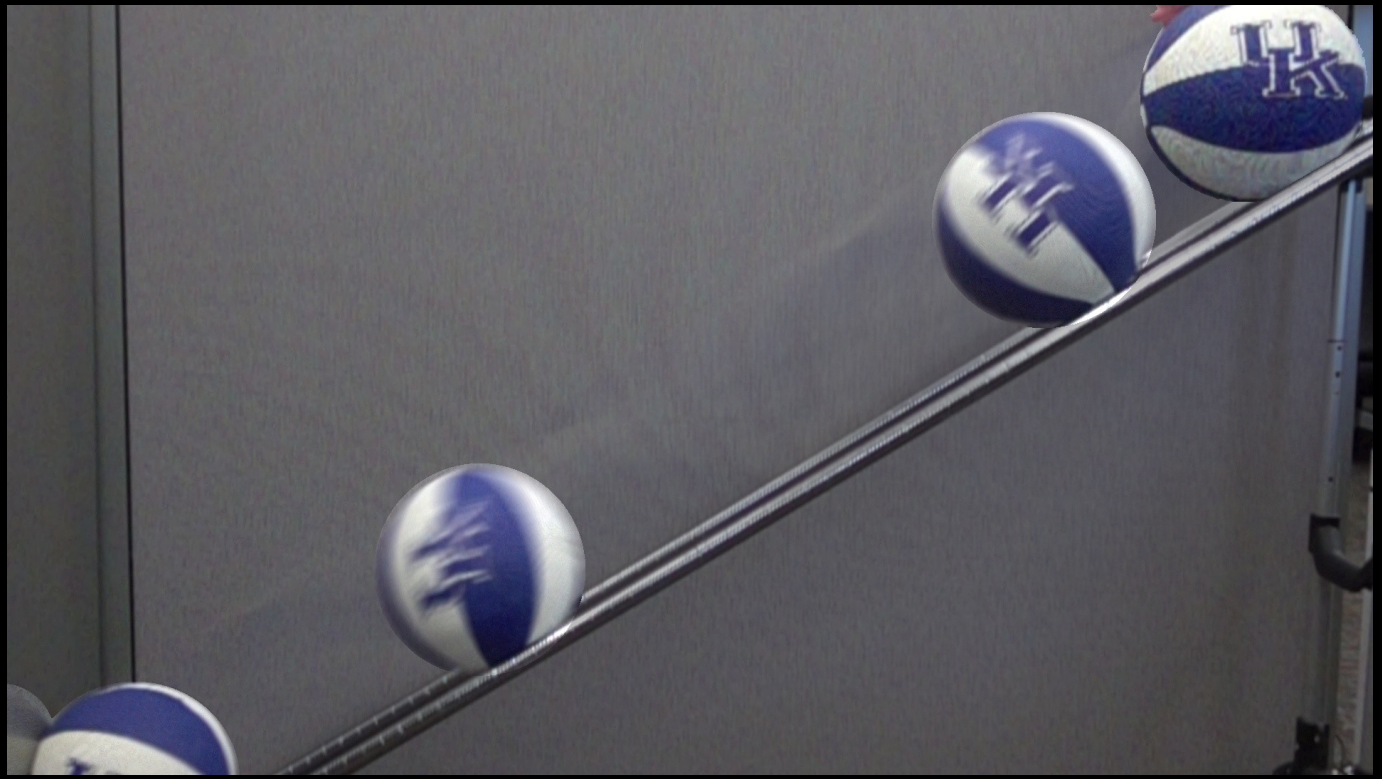
- IMEV capture
  - Any form of stream data describing the evolution of scene appearance over time, thus allowing post-capture integration
  - Ideally, **a continuous waveform per pixel**
- Still frame sequences and videos can be used as IMEV
- **Time Domain Continuous Imaging** (**TDCI**) is a type of IMEV
  - TDCI was introduced at EI2014, development continues
  - TDCI uses a piecewise-linear approximation to recording a compressed continuous waveform per pixel

Time Domain Continuous Imaging (TDCI)

- **TDCI** is a type of frameless imaging that can
  - Capture high dynamic range with low noise
  - Render a virtual exposure for any time interval
  - Render video at any frame rate and shutter angle
- Records each time a pixel changes its expected value, compressing by skipping unchanged pixel value predictions

Some Old TDCI Renders using TIK





An **IMEV rendered** into a motion study of the same ball rolling down the same incline…

A rendering choice made after capture!

Rendering from an IMEV Capture

- The previous image was created from one IMEV
  - One Ball
  - One Roll down the incline
  - One Capture
  - One (virtual) Exposure
  - No additional data (nothing synthesized)
- The decisions about the image are made at the time of rendering, not at capture, and can be based on full knowledge of the capture

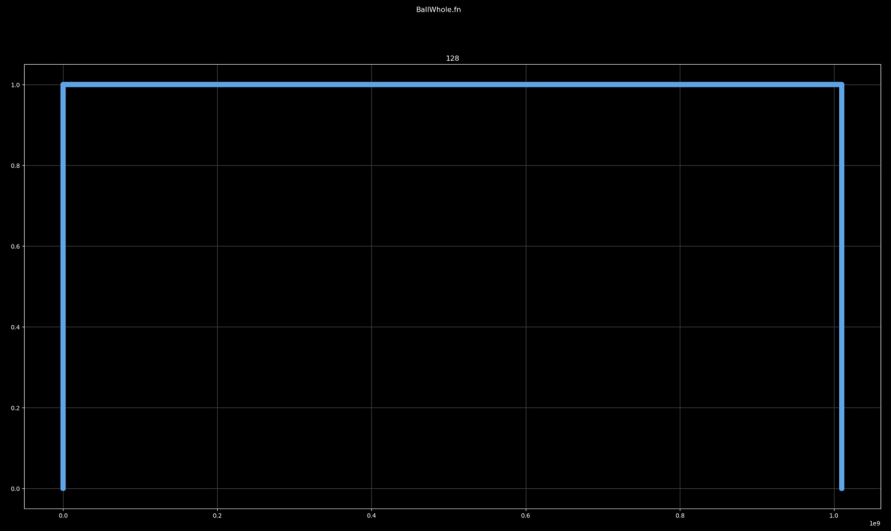
Integration from an IMEV Capture

- Sampling and gain can be non-uniform
  - **Over Time**
  - **Over Space** – masking or dodge/burn functions
- Time is a complete dimension
- Integration can be performed as many times as desired on a captured IMEV

TIK

- **Temporal Imaging from Kentucky** (the process) or **Temporal Image Kontainer** (the image data storage format)
- TIK IMEV data can be
  - Directly captured (using something like SPAD sensors, e.g., **EI26: TDCI using LED sensels**)
  - Synthesized from a temporally-indexed frame sequence – which is what the TIK tool implements
- TIK IMEV rendering only supports boxcar functions in time

Global Shutter ⇔ Boxcar Temporal Integration



- The first image shown in this talk is a boxcar temporal integration (i.e., global shuttering) lasting the complete duration of the IMEV

Functional Manipulation in IMEV Rendering

- 1st proof-of-concept implementation was presented at **EI20: Non-Uniform Integration of TDCI Captures**
- **Lessons learned**
  - **Weak IMEV** directly reprocessing video frames, which lead to lots of temporal artifacts
  - **Uses a spline function specification**, which is very powerful, but makes useful cases very awkward to specify
  - **PGM Masks** for associating functions with areas
  - **Agonizingly slow** implementattion, hard to experiment

NUTIK

- Built upon and improves the existing TIK code base;
  e.g., replaced some FFMPEG hacks with OpenCV code
- New abilities in NUTIK (**Non-Uniform TIK**)
  - Can specify **arbitrary functions over time and gain**
  - Each function can be **applied to an arbitrary region selected by a mask**
- NUTIK IMEV rendering is much faster and has fewer artifacts

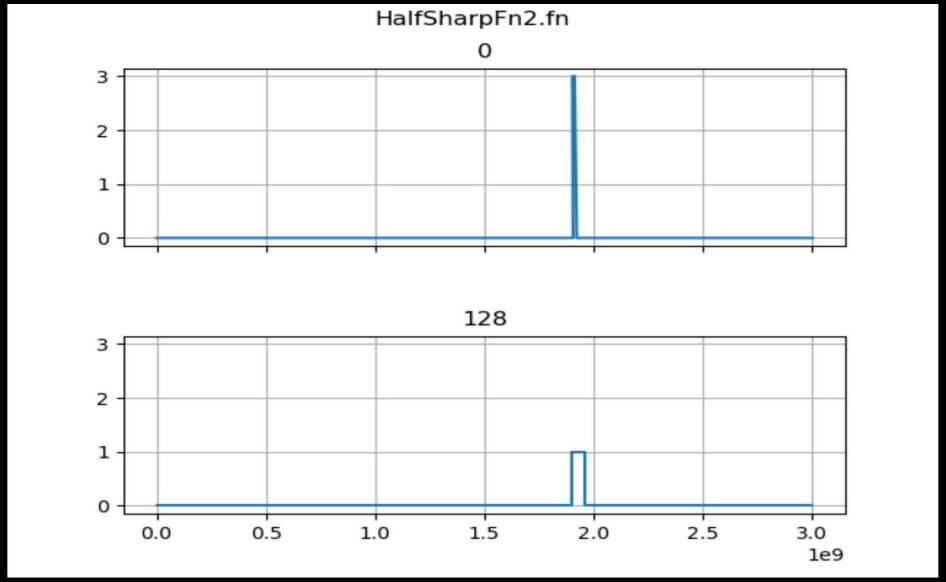
NUTIK Functions

- Specified as a series of control points
  - Linear interpolation between points – not splines
  - Easier to specify boxcars, which are most common
  - Each tagged with the area mask it applies to
- Python helper that ingests the same grammar gives a graphical representation of the functions

Example Function for NUTIK

Two *temporally overlapping* boxcar functions,

one short and high gain,
one long and lower gain



Tag for mask area

nS Scale

```
M0 {[0:0] , [1904999999:0] , [1902000000:4] , [1912000000:4] ,
[1922000001:0] , [3000000001:0]}
M128 {[0:0] , [1899999999:0] , [1900000000:1] ,
[1960000000:1] , [1960000001:0] , [3000000001:0]}
```

NUTIK Masks: Spatial Partitioning of Functions

- A ***set of masks*** is encoded as a PGM image
  - Allows pixel locations to be **partitioned into up to 255 groups**, one per gray level in the PGM image (a scheme used in `https://aggregate.org/NODESCAPE`)
  - Easy to create, visualize, & edit with existing image editors
- **You can use NUTIK renderings to refine masks**: often, the mask image is created by iteratively adjusting NUTIK integration functions and then using the rendered image to tune the mask

Nodescape PGM Mask Example

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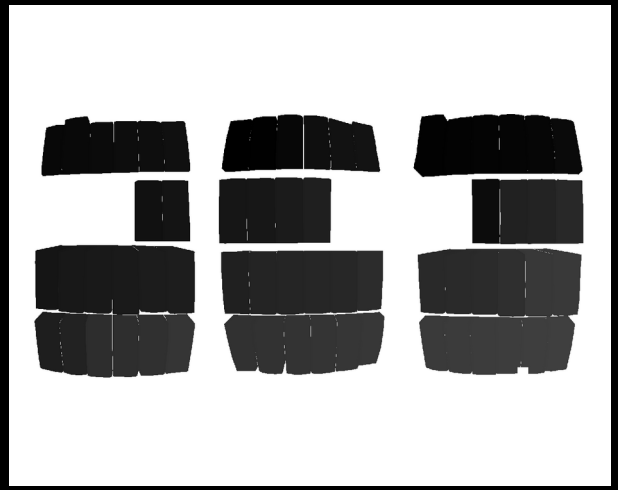

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Using NUTIK

- Scriptable, command-line interface with many options… here, we'll keep the examples simple
- Create a TIK IMEV from a video:

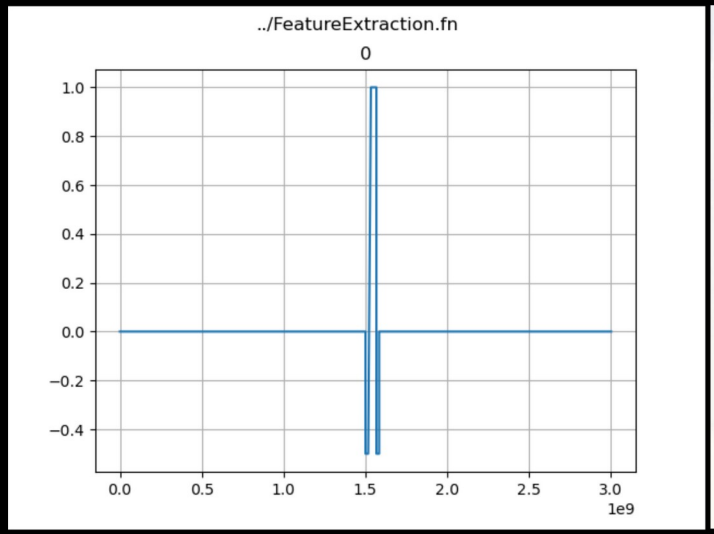
`tik -f`Framerate `-a`ShutterAngle ClipName`.mp4` ClipName`.tik`

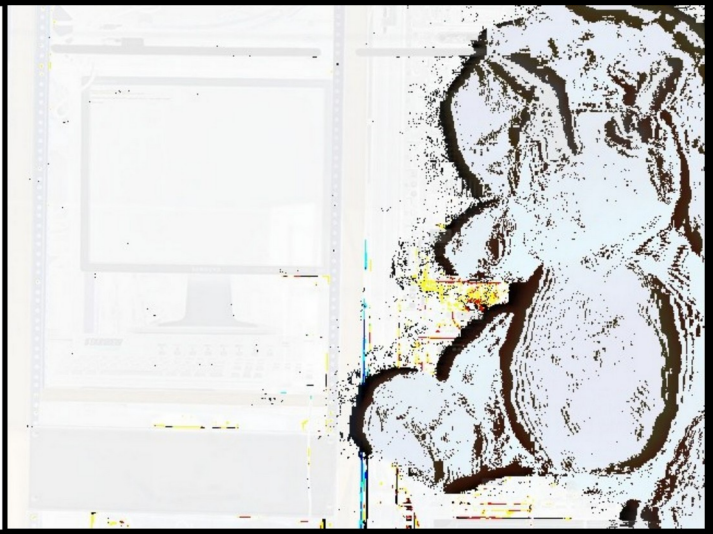
- Render a frame from a TIK model using NUTIK:

`tik -m`Mask`.pgm -k`Fn`.fn` ClipName`.tik`

Example: Negative Exposure

- Emphasize/Isolate/Difference features that are unique relative to the surrounding interval

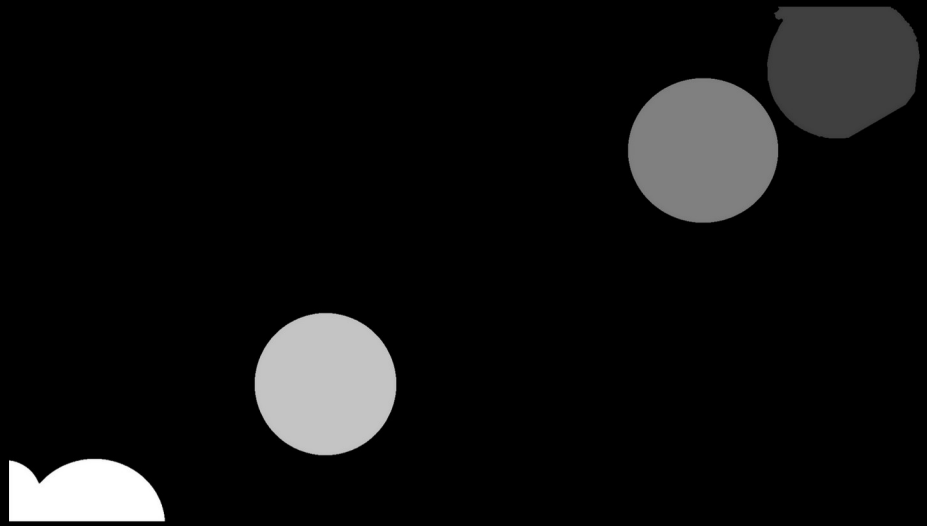




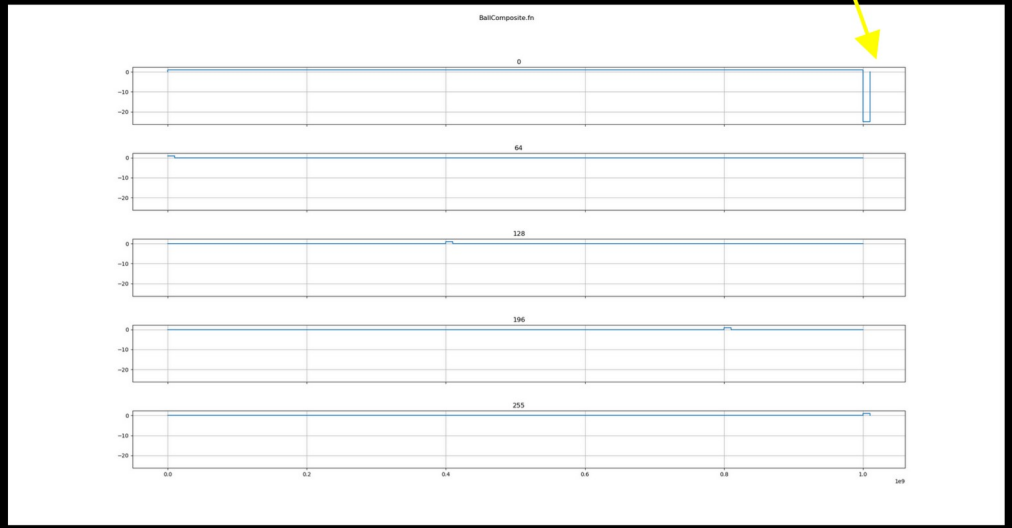
```
./tik -m../AllZero.pgm -k../FeatureExtraction.fn OrangeFast.tik
```

Example: Composite Motion Study

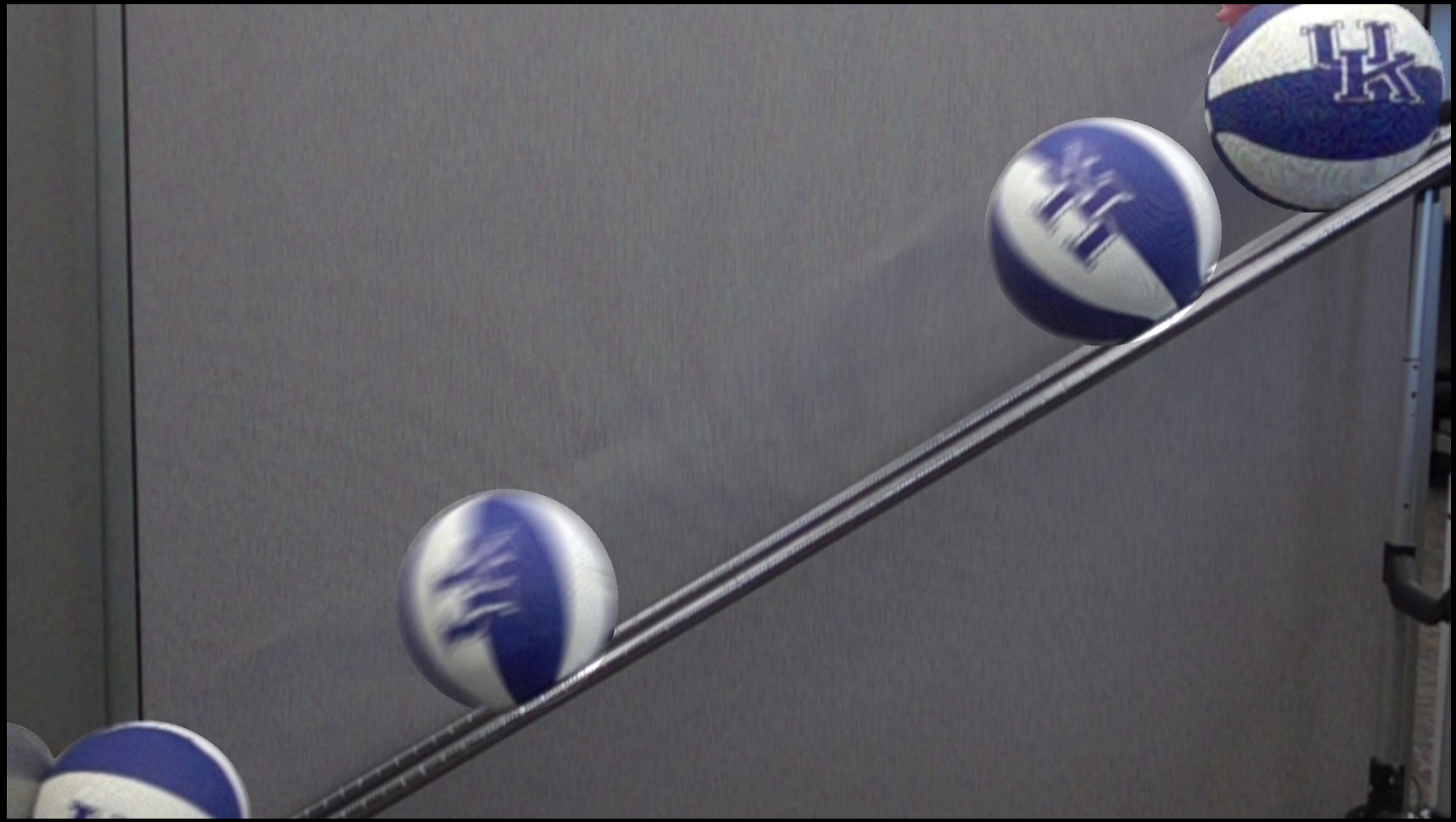
Negative spike
to normalize



BallCompositeMask.pgm



BallComposite.fn



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Conclusions

- NUTIK makes time a full dimension, directly manipulable
  - **All temporal decisions are made after capture**, and with full access to the complete evolution of scene appearance
  - **Exposure can be a varying function over time & space**
- We need a better tool for controlling these new parameters; not a scary command line, scripts, function grapher, and image editor
- Still working on direct capture of high-quality IMEVs...
  EI26: Time Domain Continuous Imaging using LEDs