ROLLING SHUTTER: THE GOOD, THE BAD & THE UGLY

ASSOCIATE PROF FRANCOIS RIGAUT & MARKUS DIRNBERGER
ADVANCED INSTRUMENTATION TECHNOLOGY CENTRE
AUSTRALIAN NATIONAL UNIVERSITY

WORK DONE WITHIN THE FRAMEWORK OF A COLLABORATION WITH PSL (D.GRATADOUR) AND SUBARU (Y.MINOWA)

BANDWIDTH, BANDWIDTH, BANDWIDTH.

(Bob Fugate, circa 1990)

LATENCY, LATENCY, LATENCY.

- Latency is not everything, but can often do or undo a system
- … especially if noise in at play (integration time)
- … and/or if you are hunting planets

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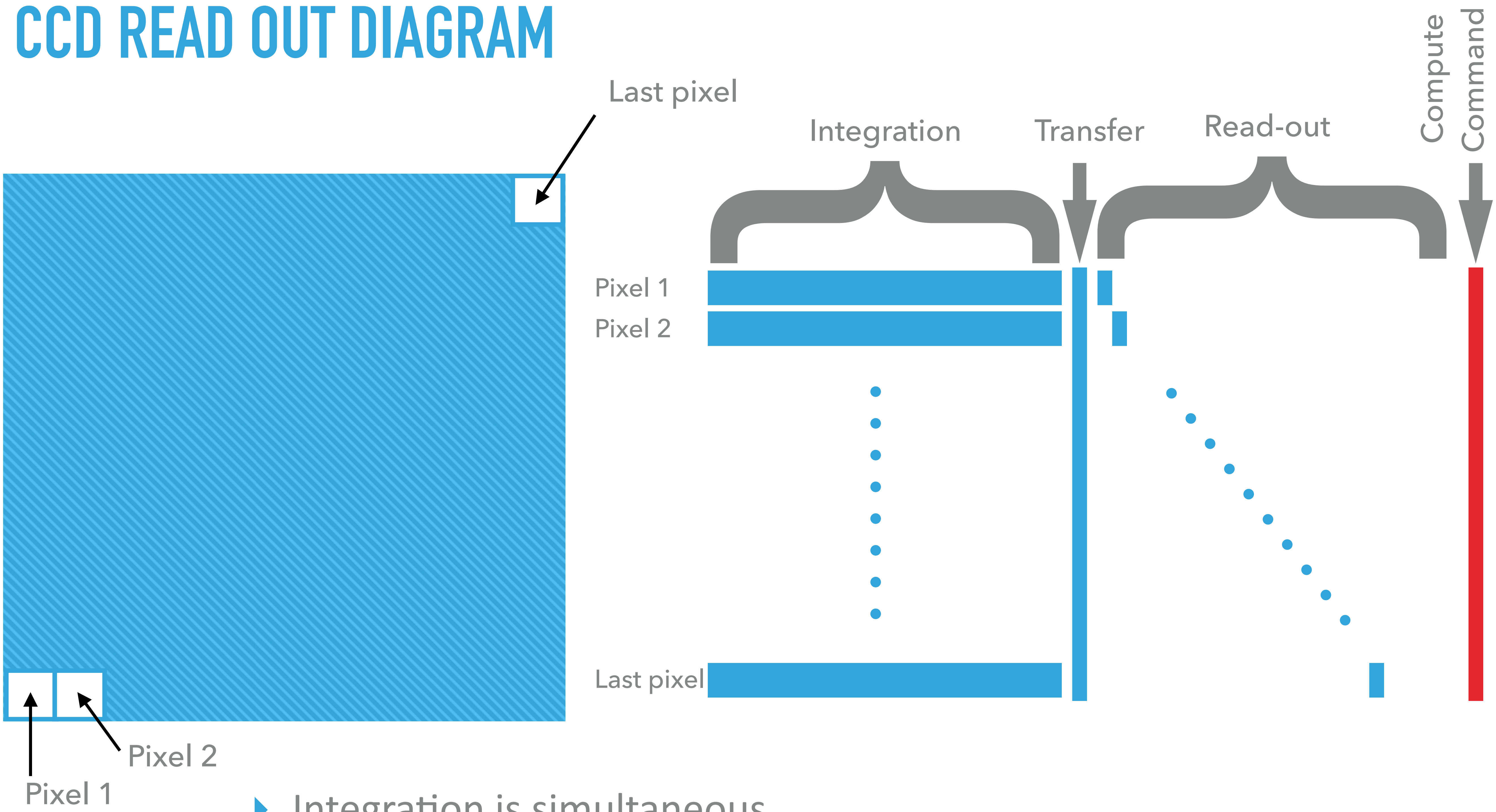
CCD VS CMOS

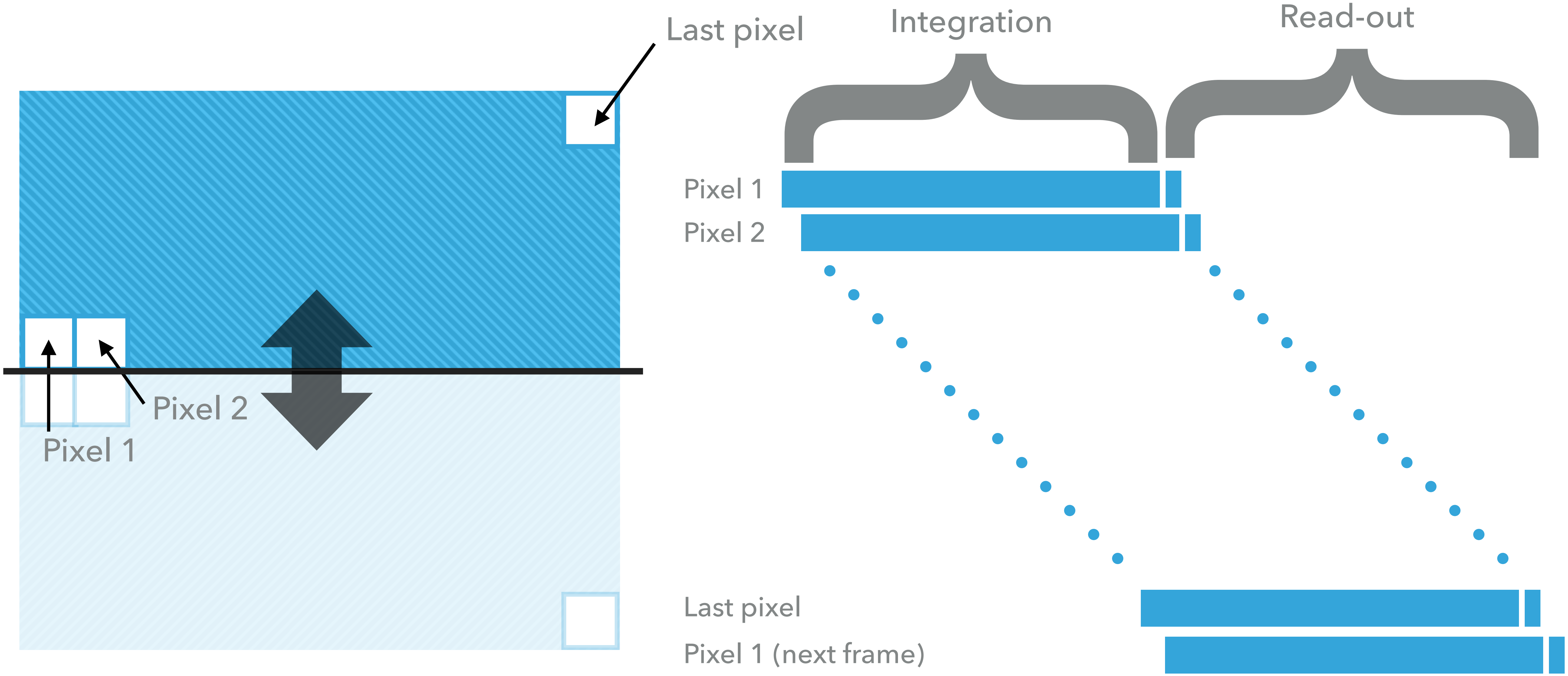
- **CCD**
  - Interline, frame transfer (regular or EMCCD)
  - Transfer into storage area happens in nanoseconds
  - Read out occurs through one or several amplifiers
  - Because noise grows with read out speed, at max CCDs read out speed, read out times = integration time
  - Relatively costly
- **CMOS (sCMOS)**
  - One amplifier/ADC per pixel. Because there is no necessity to go fast through the ADCs, and because there is very little opportunity to pick up noise (short distance pixel receptive area to ADC), very low noise can be reached (<< for CCDs, typical sCMOS median noise 1.0e-)
  - ADCs yield not perfect, so a small fraction of the pixels have larger to much larger noise (2-10e-). Notion of average vs median noise.
  - Relatively inexpensive

CCD READ OUT DIAGRAM



- Integration is simultaneous
- Read out and data access is not
- Early data utilisation would mean variable delay across the frame

SCMOS READ OUT DIAGRAM (ROLLING SHUTTER)



- Integration of all pixels is NOT simultaneous
- Last pixel almost one full frame late with respect to first pixel

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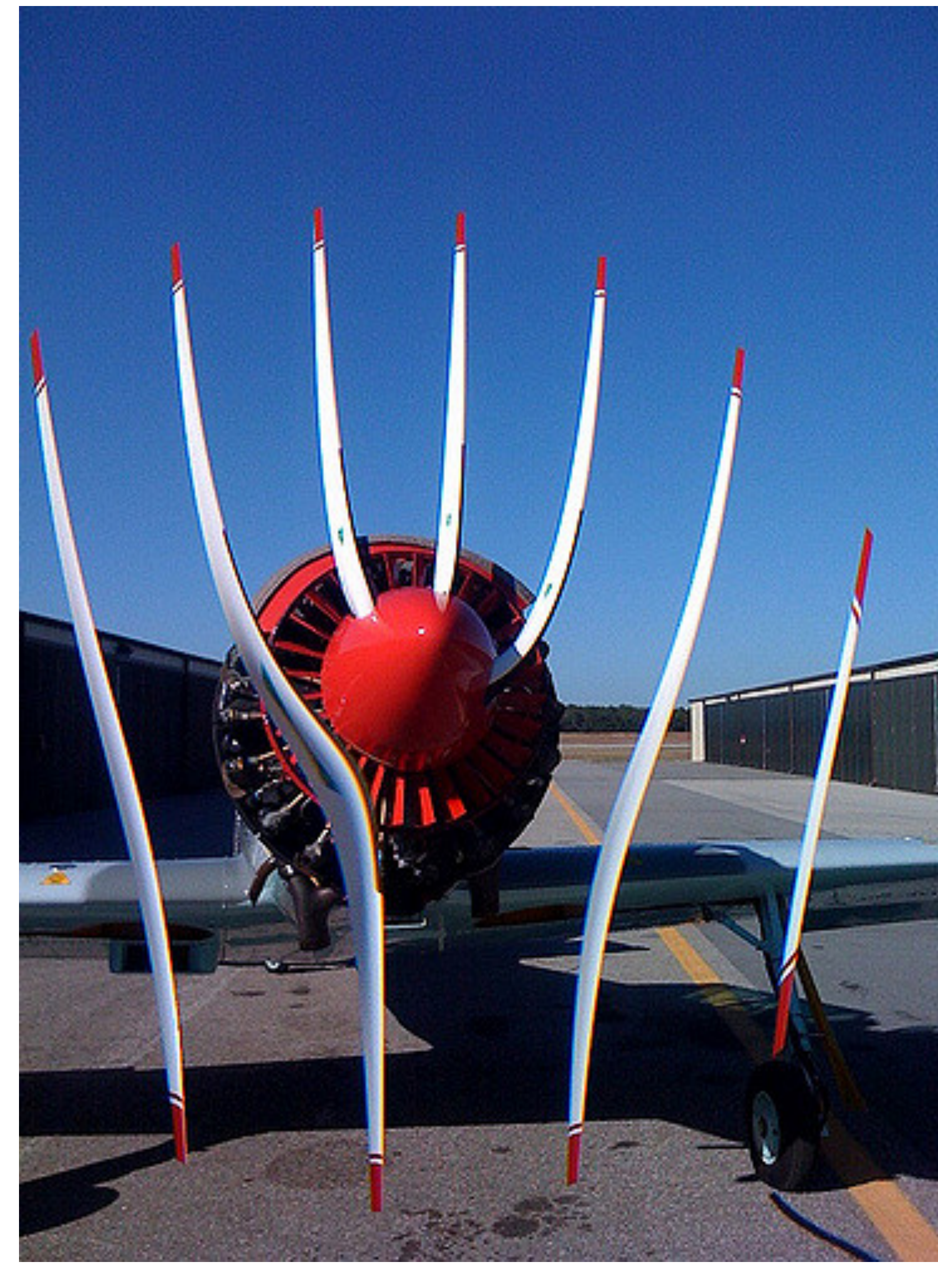
ROLLING SHUTTER IMAGES CAN BE SOMEWHAT SICKENING

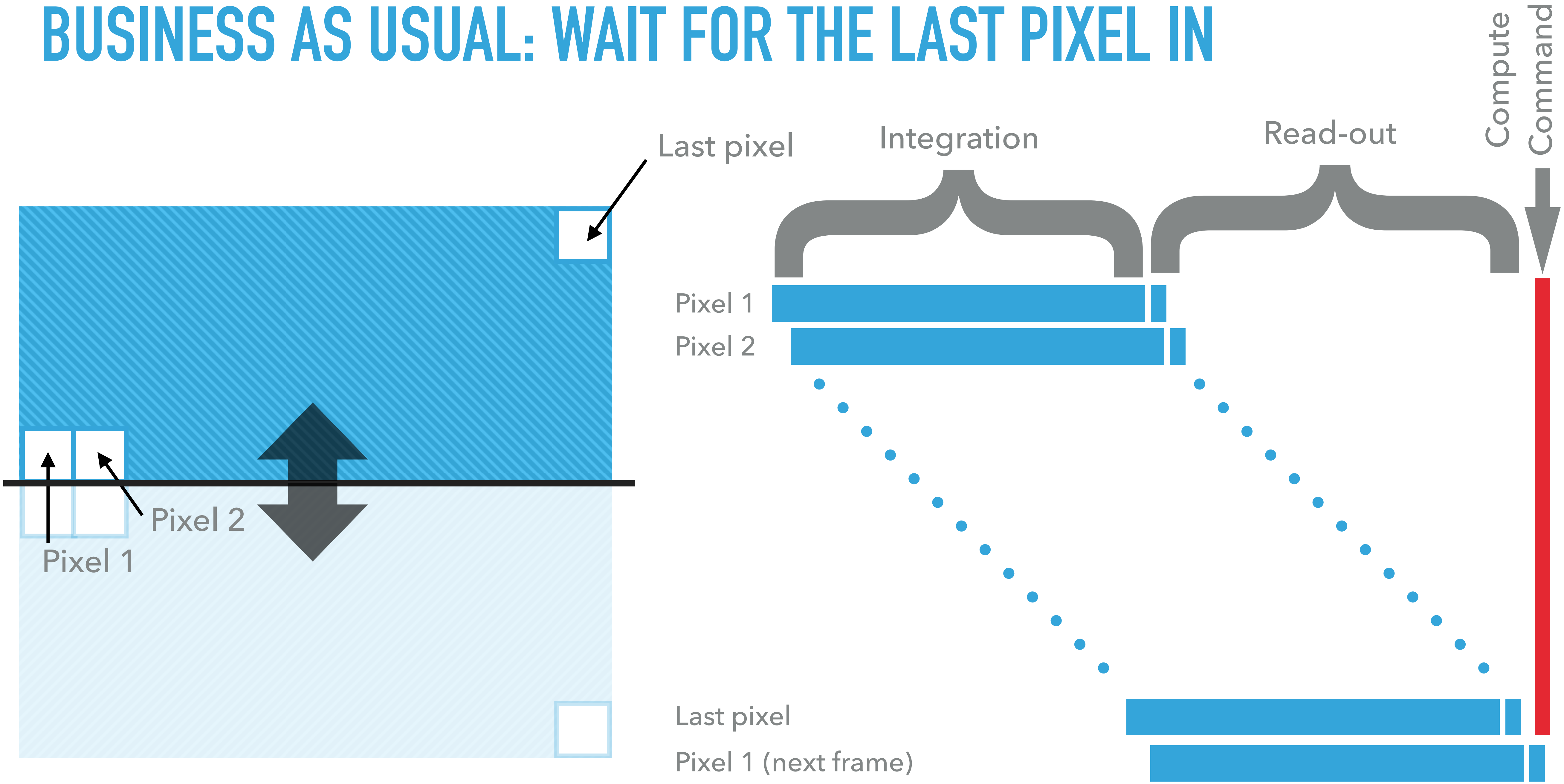
- … and do not appear to give results particularly useful for doing physics…

Global shutter

Rolling shutter



BUSINESS AS USUAL: WAIT FOR THE LAST PIXEL IN



- Integration of all pixels is NOT simultaneous
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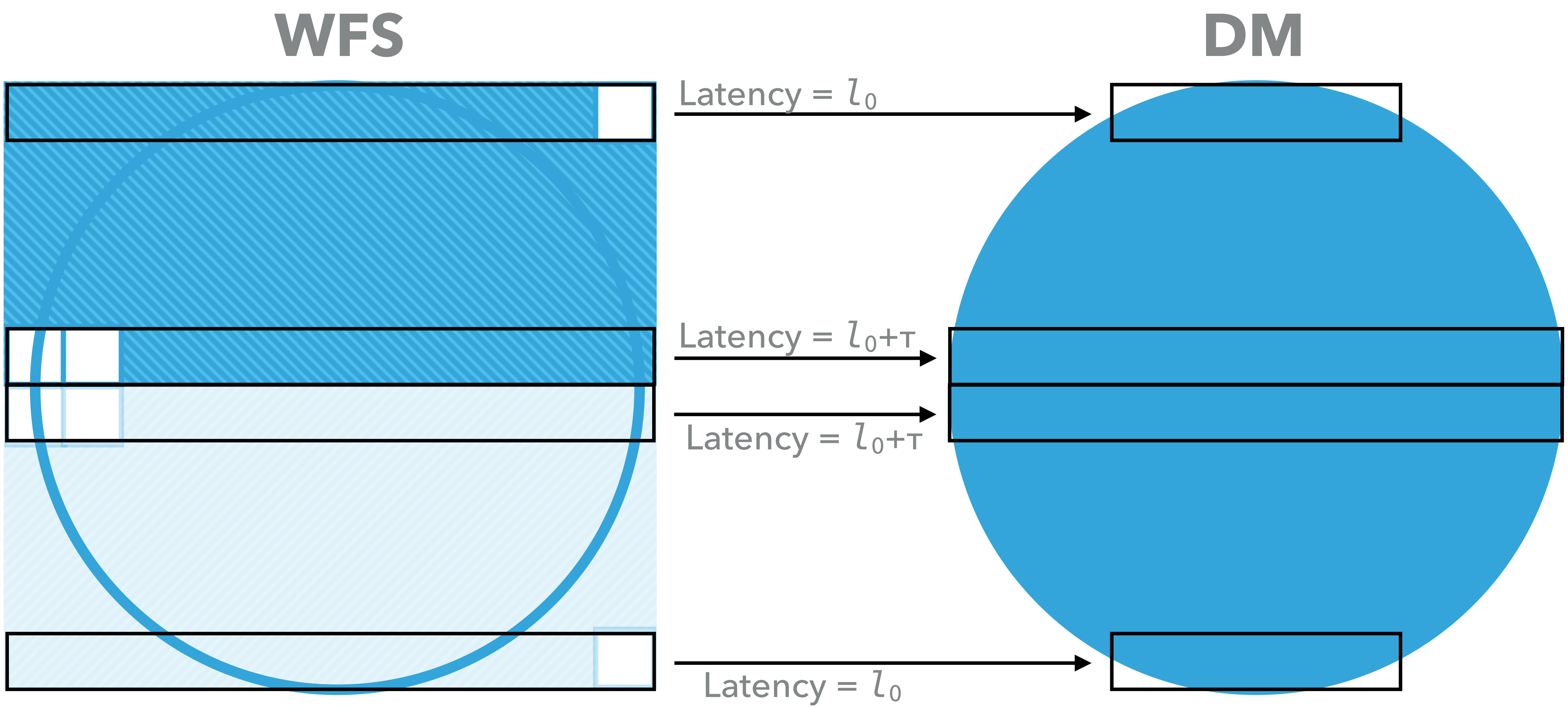
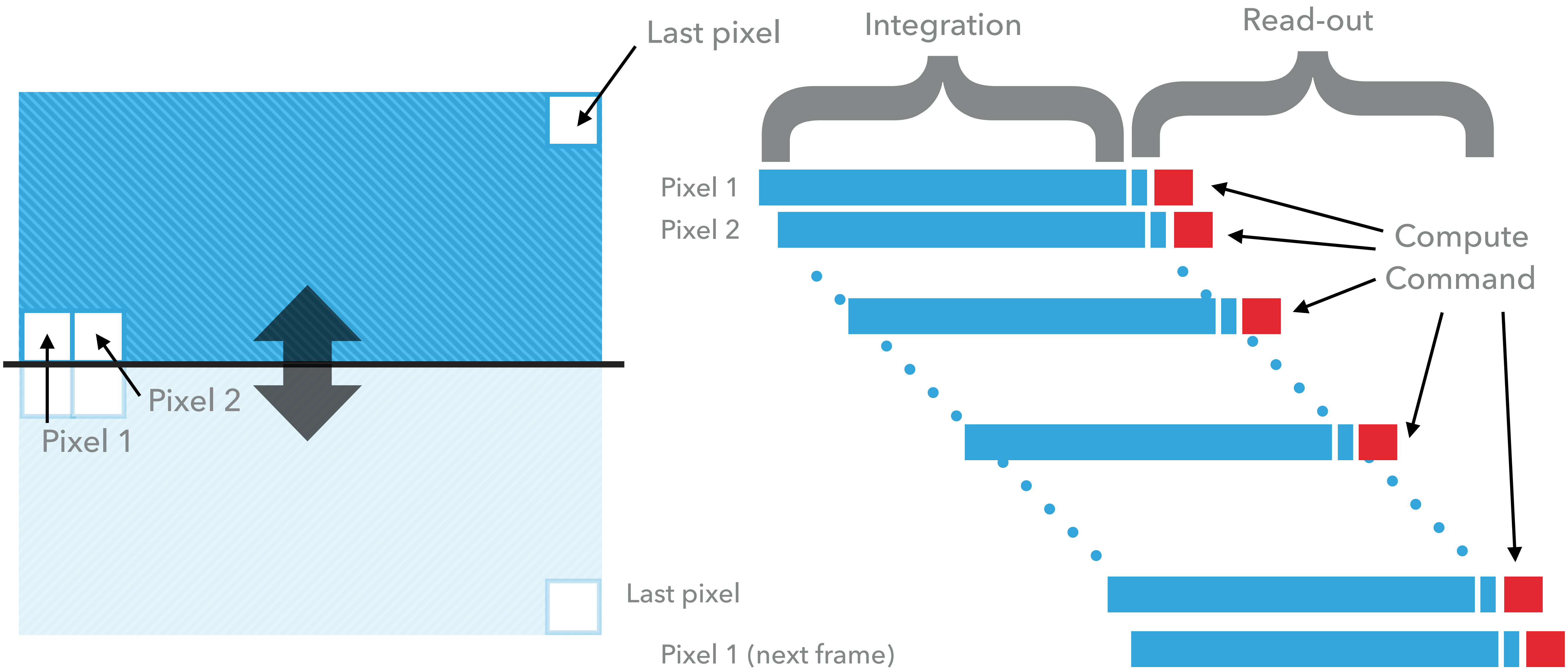
BUSINESS AS USUAL: WAIT FOR THE LAST PIXEL IN



- This is bad news: different latency mean different transfer functions
  - worse bandwidth for part of the pupil
  - resonance, noise amplification, etc…

NEW APPROACH: PROCESS AS IT COMES IN



- This is good news:
  - Same latency for all points
  - Minimal latency for everyone

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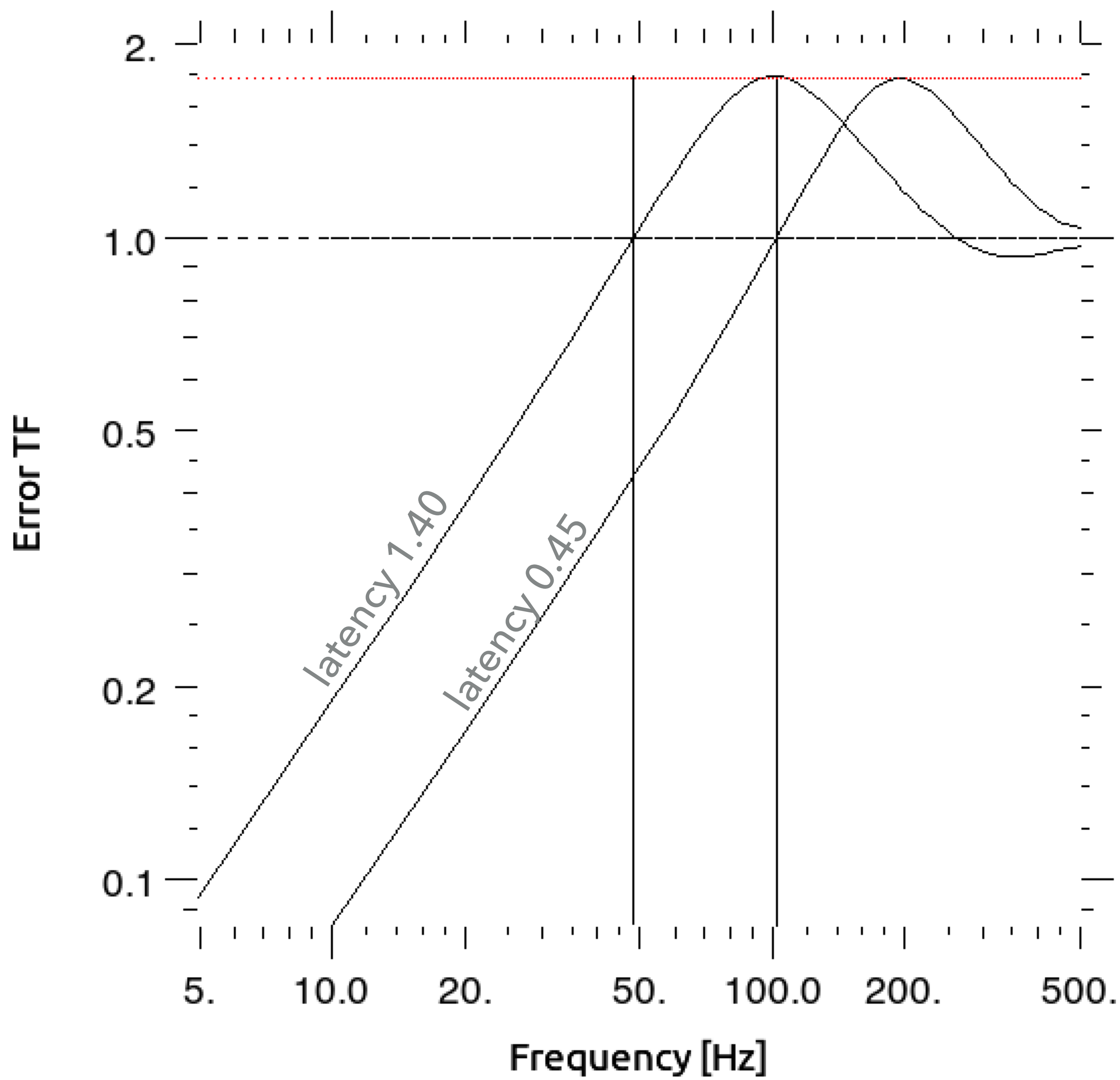
THE GOOD

- Proposed by R.Conan in GMT LTAO PDR (perhaps by others prior to that), revived recently for Subaru Ultimate GLAO
- In this presentation, I'm just going a bit further
- Typically cut full frame in 4 sub-frames
- Update commands for each sub-frames (4x faster)
- Reduce latency by 3/4 frames
- Nominal latency of e.g. **1.4 frames** in most optimised systems (in addition to 1 frame ZoH, **POLL**):
  - 1 frame read out
  - 0.4 frames matrix multiply, drivers overhead, mech BW
- Potential to reduce to e.g. 0.25 + 0.2 = **0.45 frames**

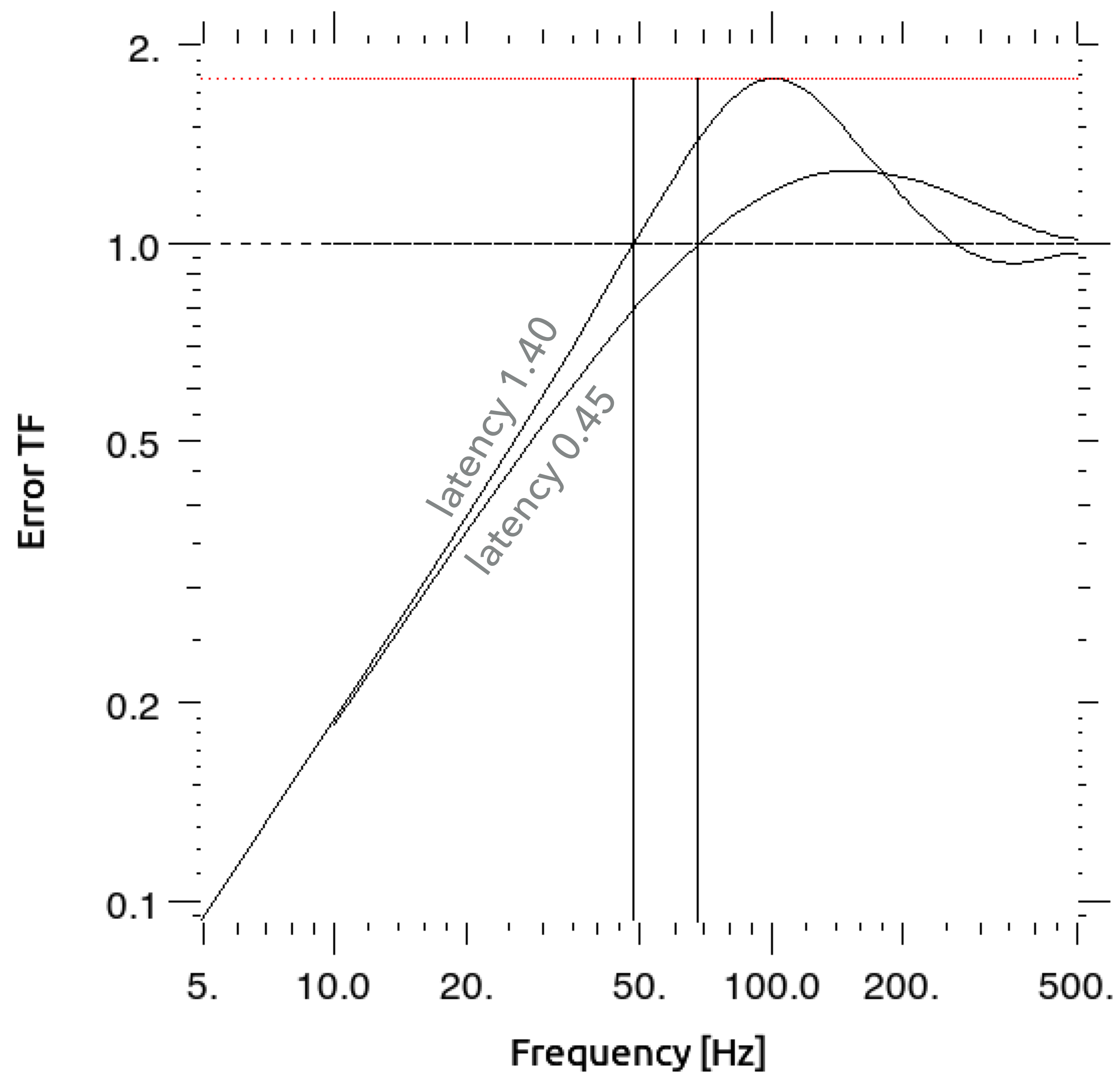
IT DOUBLES THE BANDWIDTH

- Example with
  - 1kHz sampling
  - 1 frame ZoH
  - 1.40 vs 0.45 latency
  - BW: 48 ➜ 102 Hz.
  - Max gain: 0.33 ➜ 0.73 for overshoot = 2.5dB
- Noise: BW doubling means one can sample twice as slow and get twice the number of photons (0.7 mag gain)



… AND/OR REDUCES NOISE PROPAGATION

- Example with
  - 1kHz sampling
  - 1 frame ZoH
  - 1.40 vs 0.45 latency
  - BW: 48 ➜ 67 Hz.
  - Noise variance ÷ 2

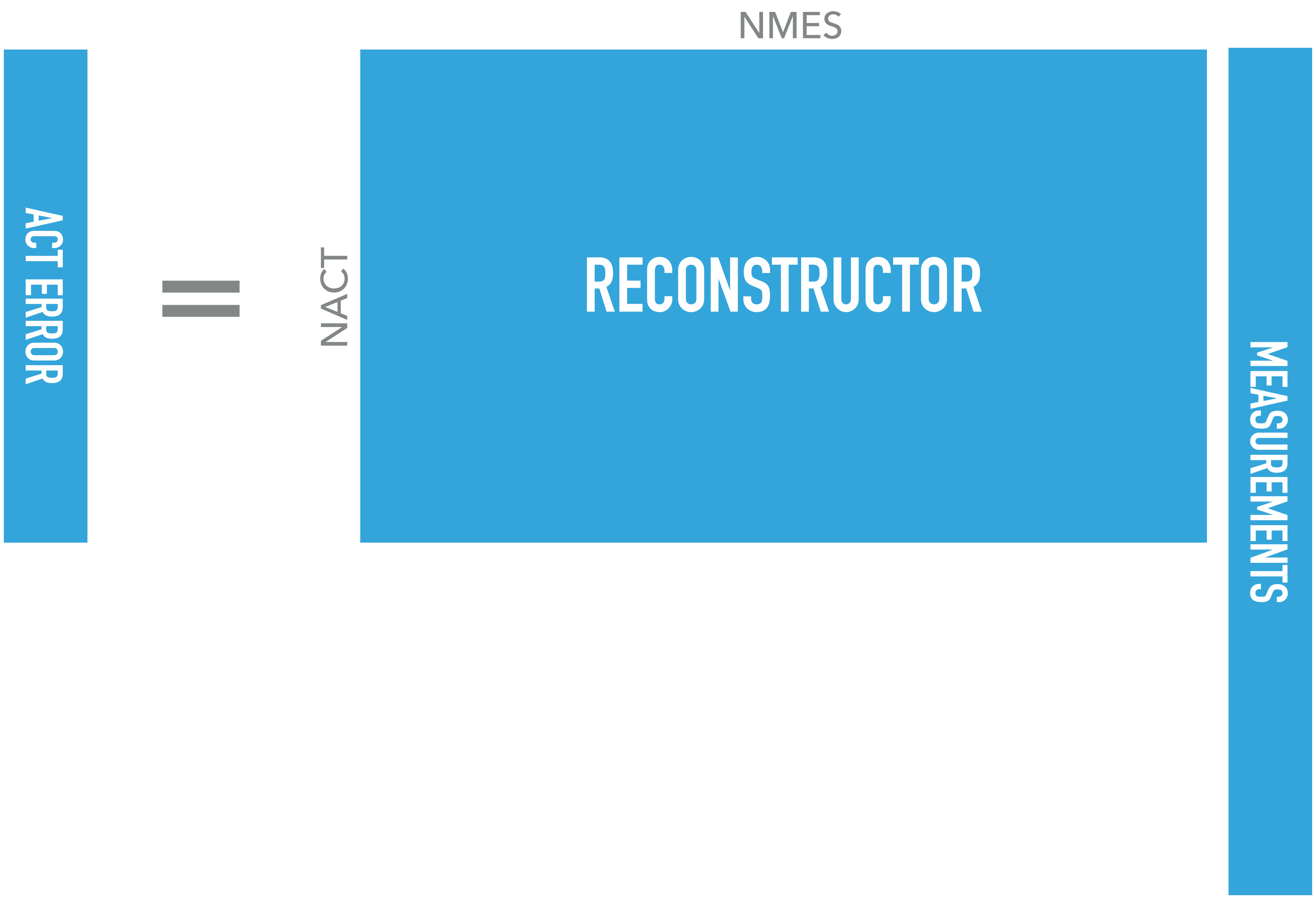


THE BAD

- A more complex control scheme,
  - … but not necessarily much more calculations (next slides)
- Needs e.g. 4x the bandwidth to the DM (compatible drivers)
- Need digging into frame grabber/CCD controller code
- Need good control of all other latency terms, but reward is high

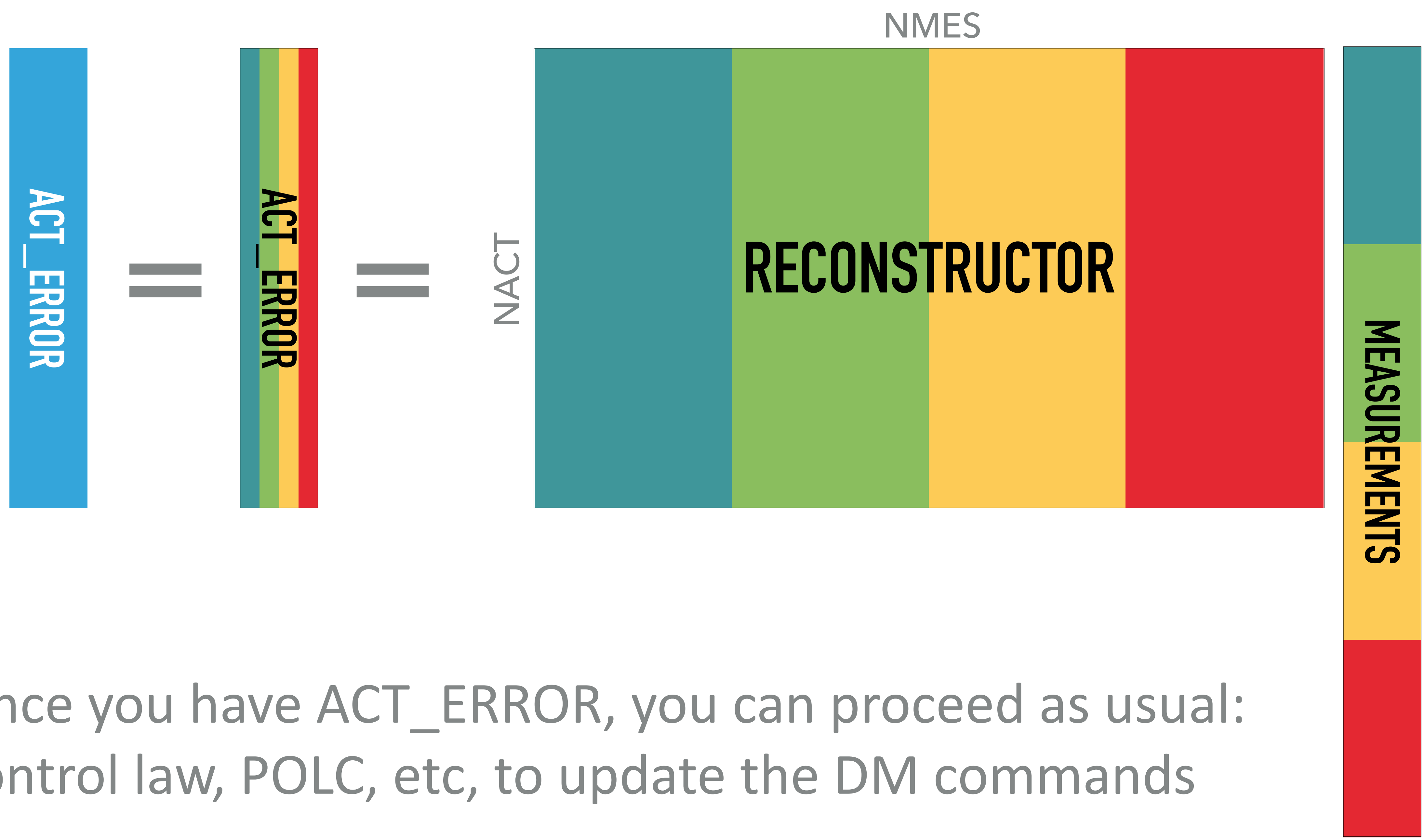
ONE MATRIX MULTIPLY, GLOBAL APPROACH

ACTUATOR ERROR = RECONSTRUCTOR ⊗ MEASUREMENTS



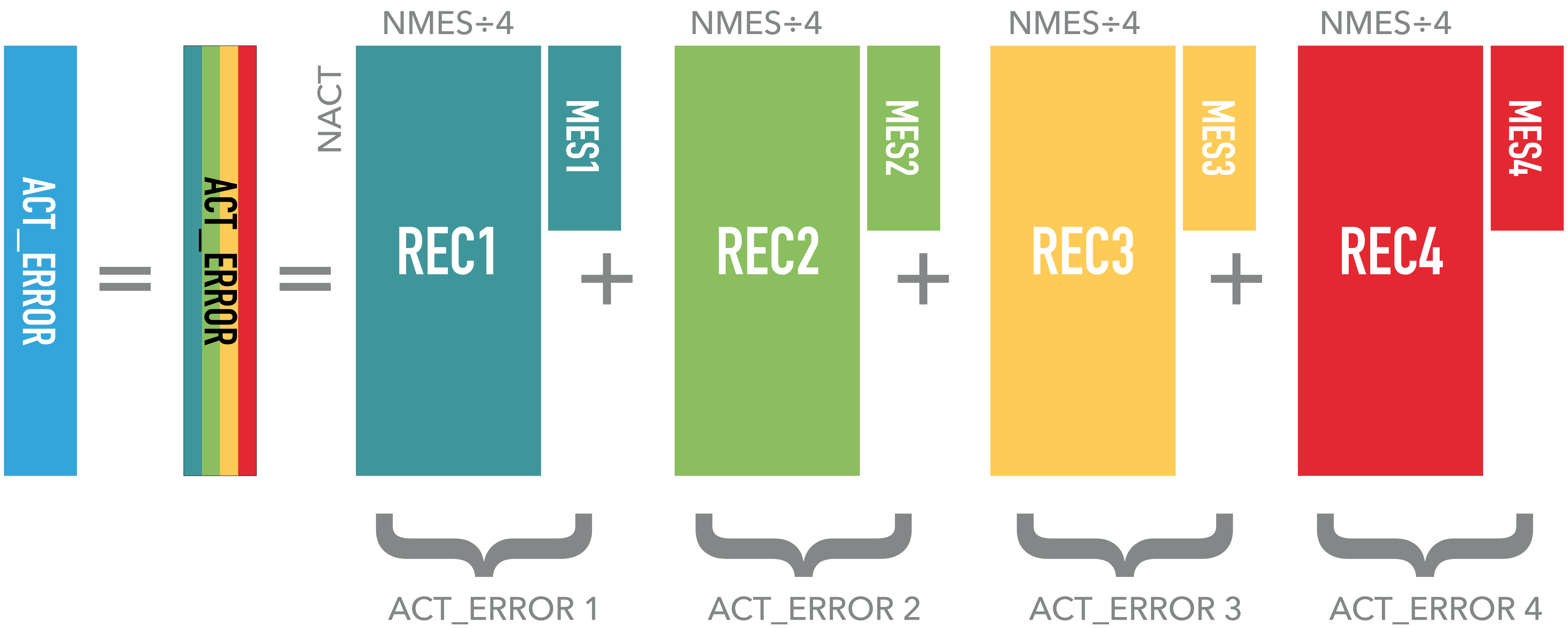
ONE MATRIX MULTIPLY, GLOBAL APPROACH

ACTUATOR_ERRORS = RECONSTRUCTOR ⊗ MEASUREMENTS



- Once you have ACT_ERROR, you can proceed as usual: control law, POLC, etc, to update the DM commands

...SPLIT TO PREPARE PARTIAL UPDATES

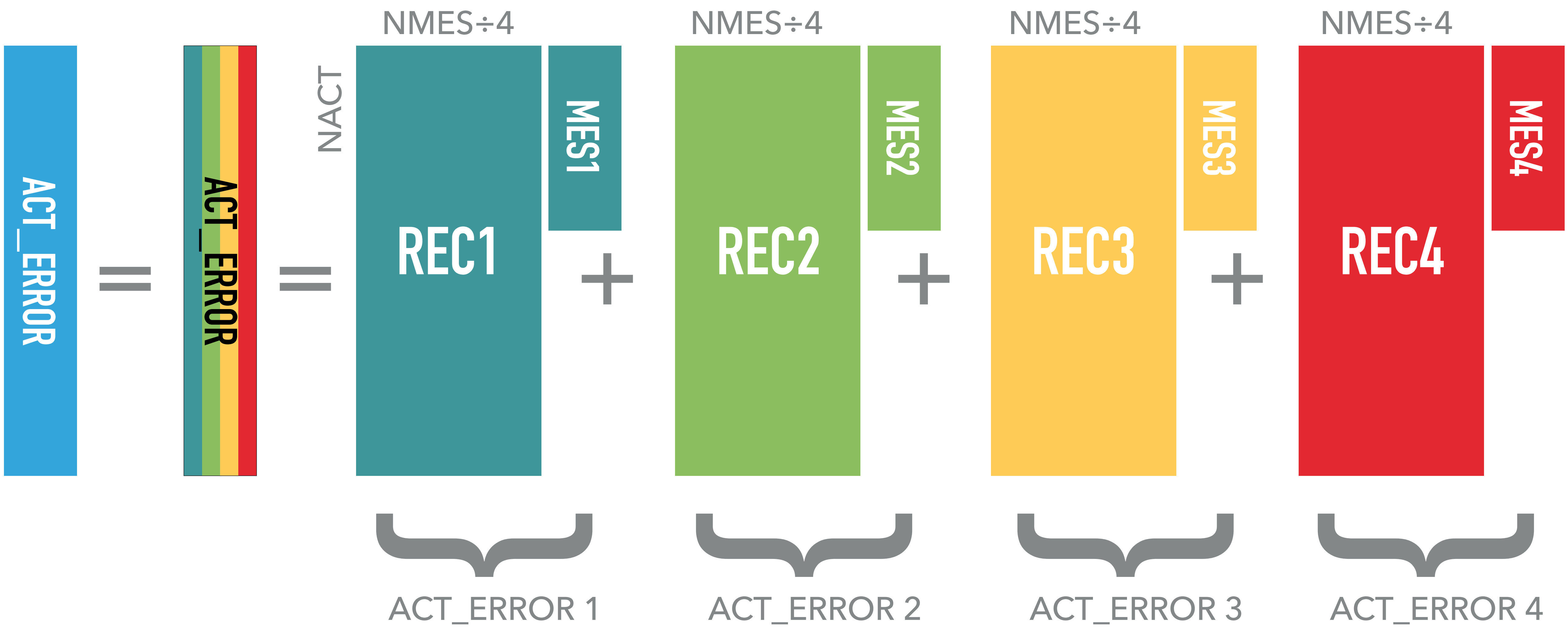


- Each 1/4 frame, compute new ACT_ERROR i (1/4 FLOPS)
- If using a single matrix multiply and a simple integrator with gain

$$C_{\text{new}} = C_{\text{old}} + gE\,|w\rangle$$

then it's all linear and there is nothing to do (just add ACT_ERROR i instead of ACT_ERROR, just 4 times as often)

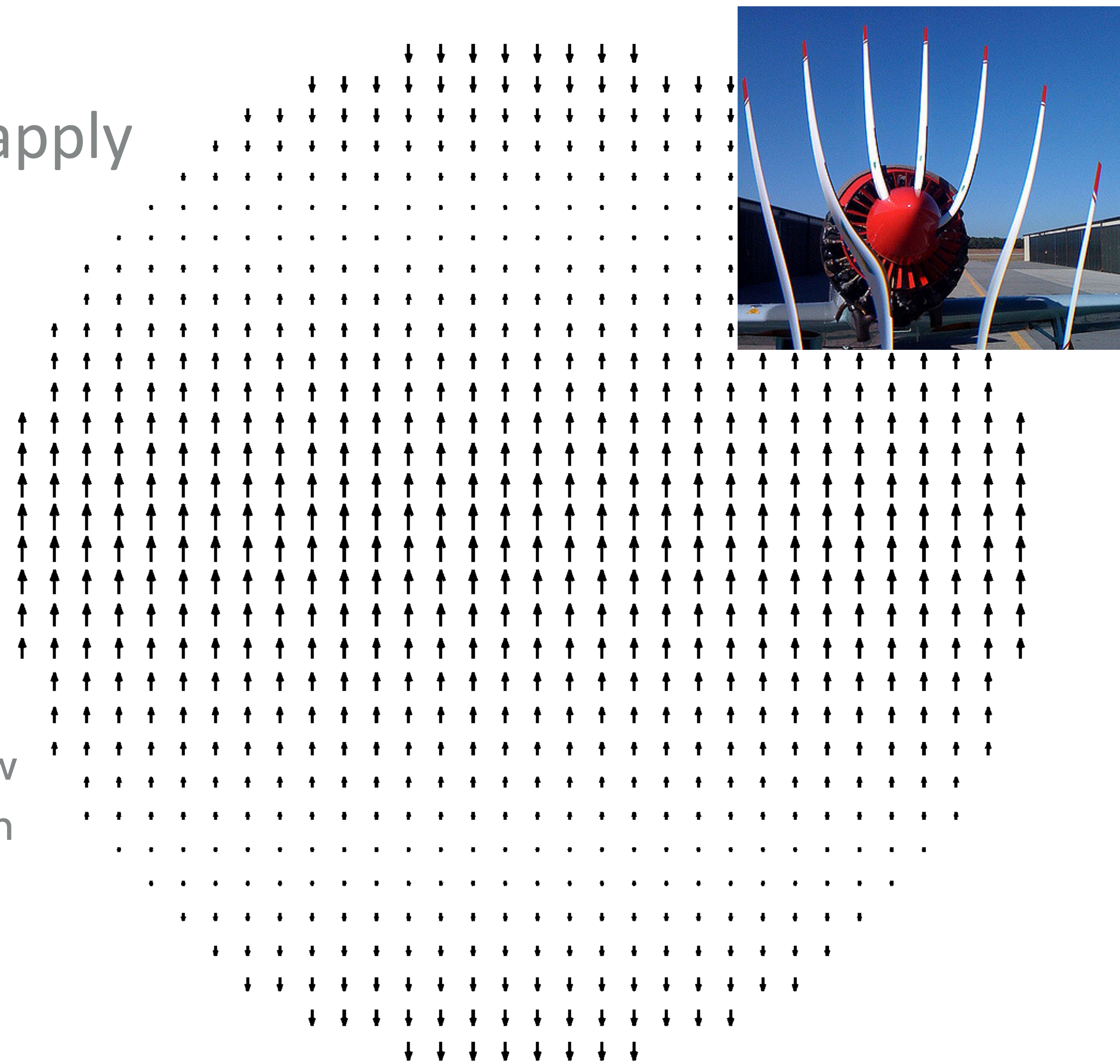
…SPLIT TO PREPARE PARTIAL UPDATES



- Each 1/4 frame, compute new ACT_ERROR i (1/4 FLOPS)
- If using a POLC or more complex control scheme, then update the new ACT_ERROR vector by replacing ACT_ERROR i values by new ones (NACT subtractions, NACT additions).

THE UGLY

- Usual assumptions on simultaneity of measurement are dead
  - Properties of phase, e.g. $grad(rot(\vec{\varphi})) = 0$ do not apply
- Filtering of TT and other modes will behave differently
- Coupling from TT (vibrations) into other modes! Coupling of time and space*



Extreme example of how Tilt may be seen through a rolling shutter

* no, not like wormholes

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ROLLING SHUTTER IS NOT YOUR ENEMY

- sCMOS have great potential for WFS (low cost, low noise, good QE)
- sCMOS camera implement a rolling shutter mode
- Strategy of command can be changed to take advantage of this
- Potentially allows reduction of latency by a factor 2-4
  - which translate into bandwidth gain (typ. 2x)
  - but has implications on control schemes
  - and hardware (e.g. DM drivers and BW)
- Still need quite a bit of work to work out the details of the maths (compatibility with Kalman etc, clean up process, etc).
- Simulations needed for a full end to end investigation
- Potential applications for Ultimate GLAO, GMT LTAO, etc
- Demonstrator being put together at ANU (Markus Dirnberger) on a Hamamatsu ORCA Flash 4