Computer Vision on Rolling Shutter Cameras

PART I: Introduction

Per-Erik Forssén, Erik Ringaby, Johan Hedborg

Computer Vision Laboratory
Dept. of Electrical Engineering
Linköping University

Linköping University
INSTITUTE OF TECHNOLOGY

Lectures by

Per-Erik Forssén

Erik Ringaby

Johan Hedborg

Tutorial overview

1:30-2:00pm	**Introduction**	**Per-Erik**
2:00-2:15pm	Rolling Shutter Geometry	Per-Erik
2:15-3:00pm	Rectification and Stabilisation	Erik
3:00-3:30pm	Break	
3:30-3:45pm	Rolling Shutter and the Kinect	Erik
3:45-4:30pm	Structure from Motion	Johan

http://www.cvl.isy.liu.se/education/tutorials/rolling-shutter-tutorial

What is a rolling shutter?

- Hand held ⇒

  non-smooth camera path

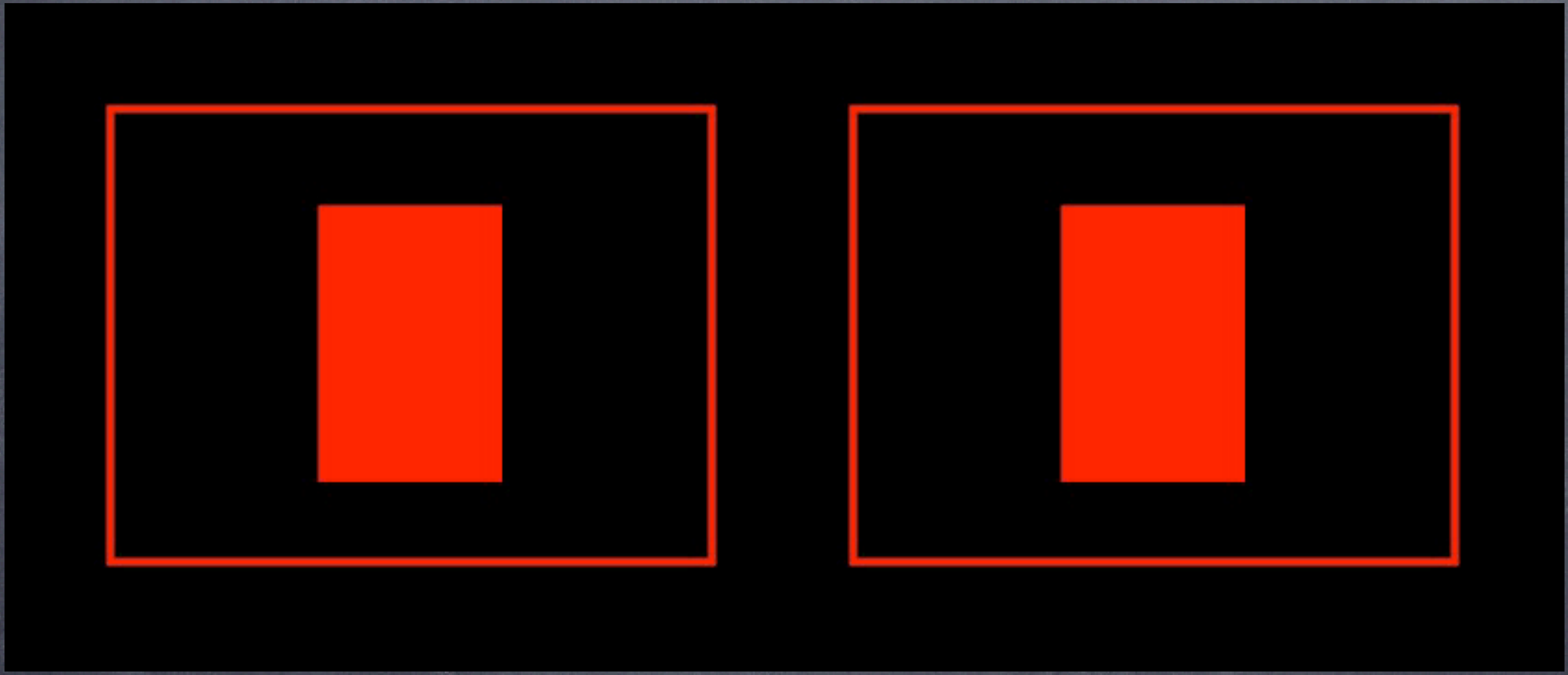
- Geometric distortions (wobble)

- HTC desire (Q2 2010)

What is a rolling shutter?

What is a rolling shutter?

- In rolling shutter image acquisition, rows are exposed sequentially



Static Scene

Captured Image

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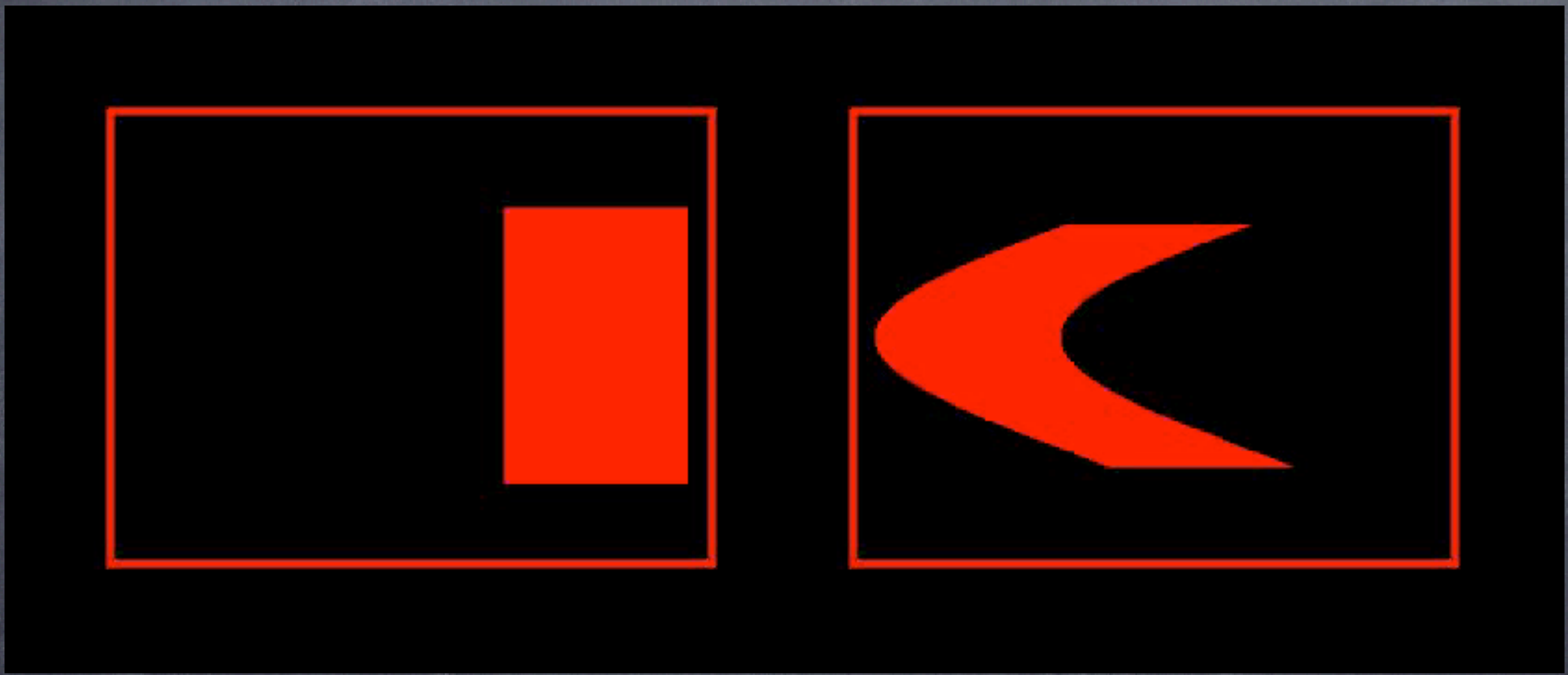


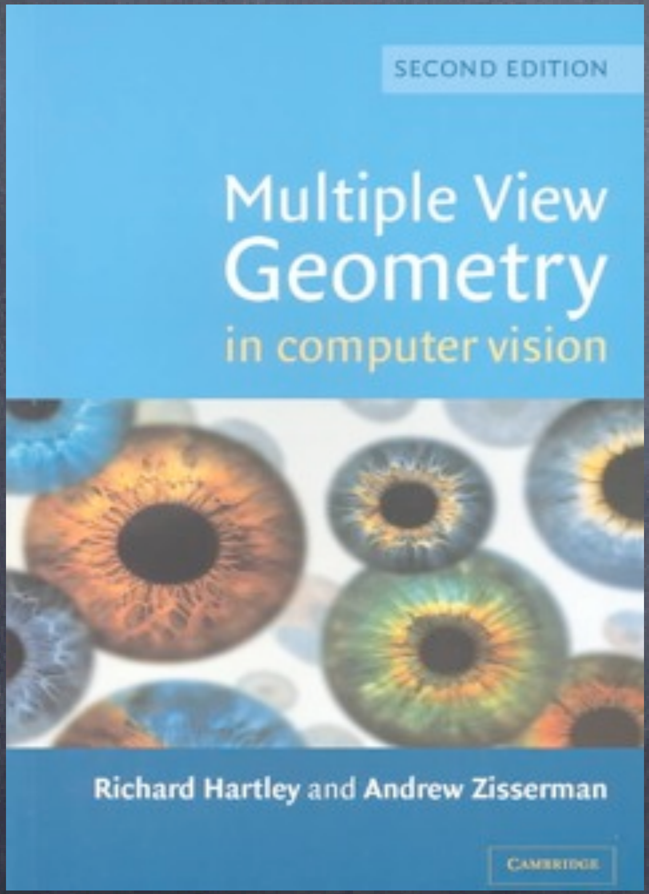
Dynamic Scene   Captured Image

Why care about rolling shutters?

- The scientific perspective: Problem not solved yet.

Why care about rolling shutters?

- The scientific perspective: Problem not solved yet.
- Hartley & Zisserman Multiple View Geometry 2nd ed 2004



- THE reference on geometry in Computer Vision
- 10,000+ citations in Google Scholar
- Does not mention rolling shutter

Why care about rolling shutters?

- The scientific perspective: Problem not solved yet.
- The practical perspective: I want to do computer vision on consumer cameras or new robot platforms.

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- The scientific perspective: Problem not solved yet.
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"Research PatrolBot" from
Adept MobileRobots
Demoed at ICRA 2012

"Scout" from ReconRobotics
Demoed at ICRA 2012

AUTOMATON The future of robots and other silicon-brained machines

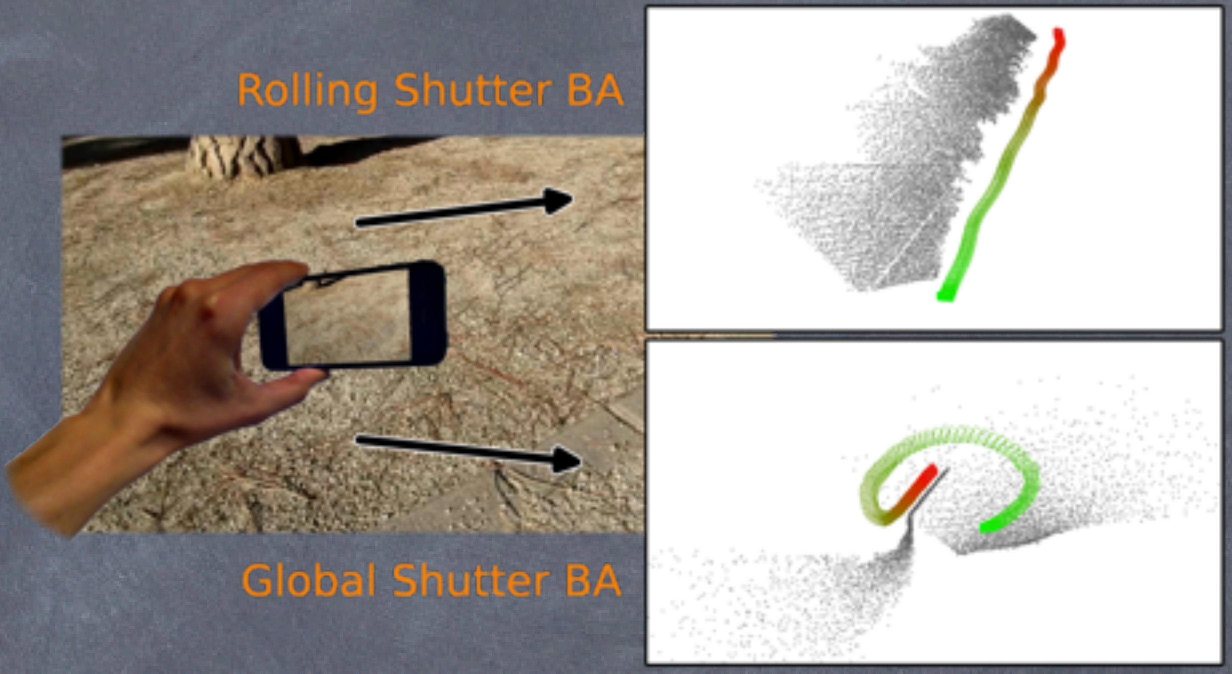
ieee spectrum INSIDE TECHNOLOGY

Computer Vision

- When is the rolling shutter effect relevant for computer vision?

Computer Vision

- When is the rolling shutter effect relevant for computer vision?
  - 3D modelling from images
  - Visual SLAM
  - Video stabilisation algorithms, Video panoramas etc.



Computer Vision

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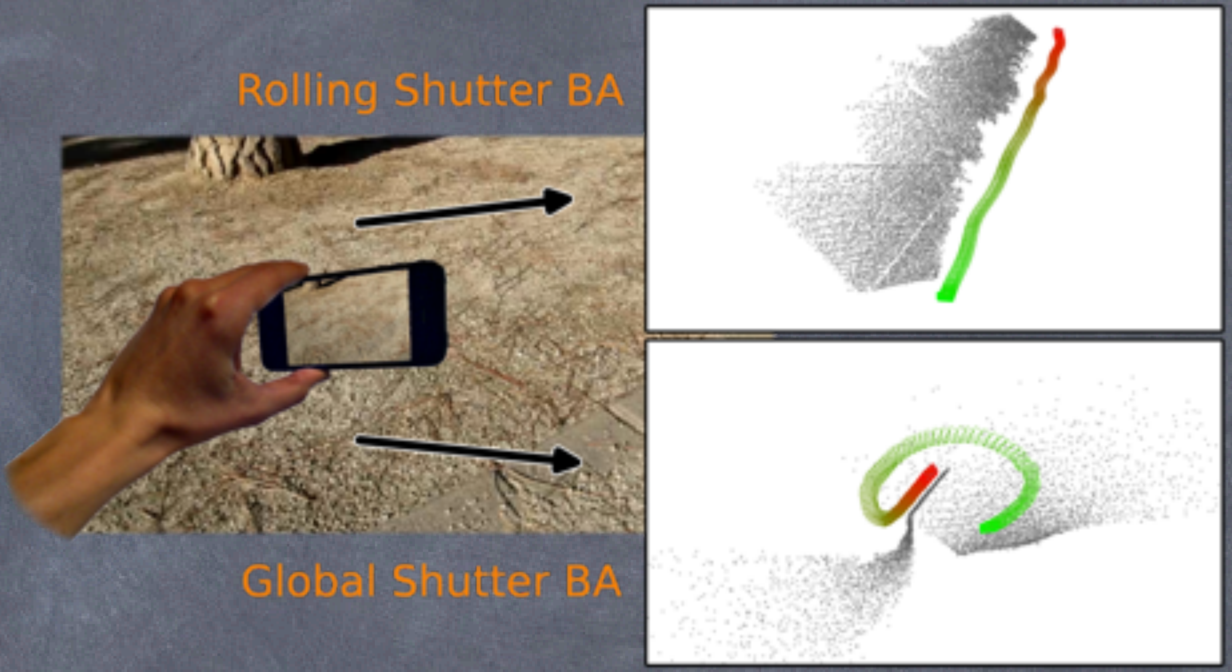
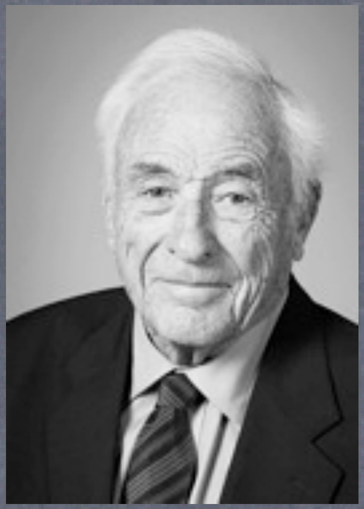


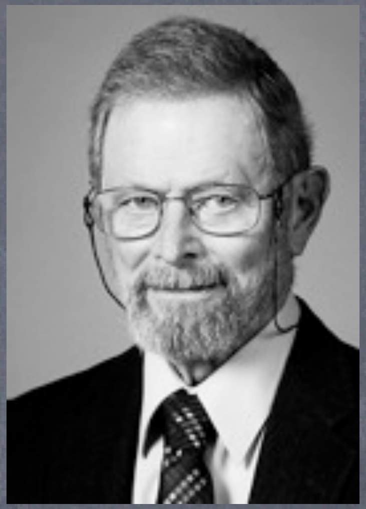
  - Video stabilisation algorithms, Video panoramas etc.
  - Any geometric measurement from images

Image sensors: CMOS vs. CCD

- Nobel Prize in Physics 2009

  to Willard S. Boyle
  and George E. Smith





"for the invention of an imaging semiconductor circuit – the CCD sensor"
Invented around 1970, patent filed September 1971.

Image sensors: CMOS vs. CCD

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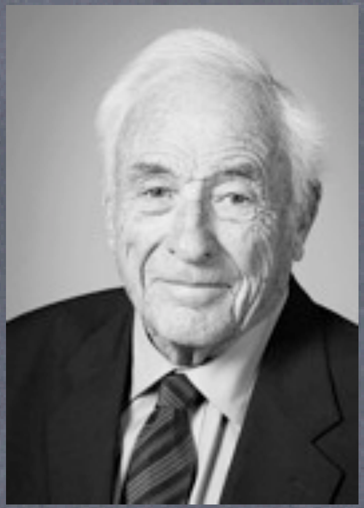

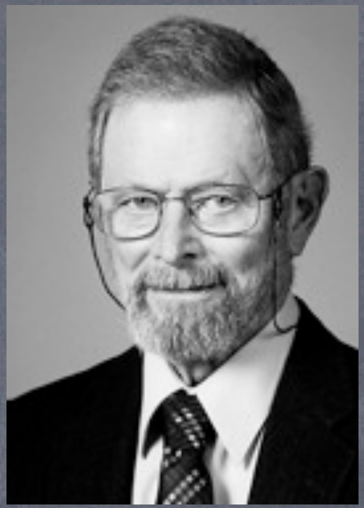

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- CMOS – The new deal
  Modern CMOS sensor work started in mid 1980s
  at VLSI Vision Ltd and at the Jet Propulsion Laboratory (JPL)

- Most CMOS sensors, by design, have rolling shutters

CMOS and CCD markets 2012

- CCD sensors in Astronomy and MachineVision

Spectral Instruments
12MP CCD 95x95mm

PointGrey Research
Gazelle2 and Bumblebee2
Machine Vision cameras

CMOS and CCD markets 2012

- CMOS sensors everywhere else



Hand-held devices
with cameras

Camcorders

compact and
SLR cameras

Robots and toys

Consumer Structured Light
Sensors (e.g. Kinect)

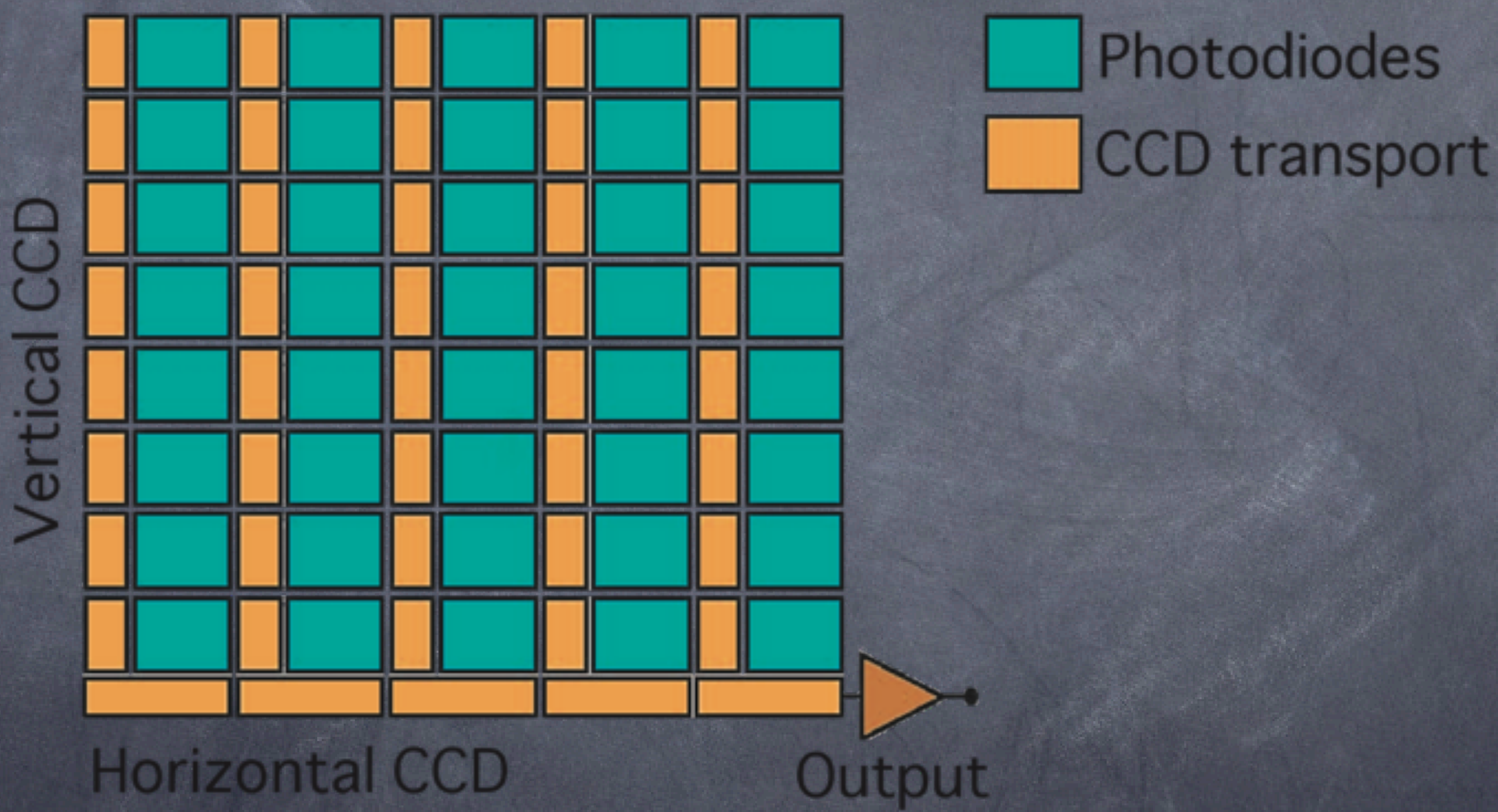
High-end
motion-picture cameras

Why is CMOS winning over CCD?

- New chips are designed for the consumer mass market. Advantages for CMOS here:
  - Cheaper manufacturing (lower price)
  - Allows on-chip processing
  - Makes HD video affordable
- Rolling shutter is not a big problem for consumers (casual users cause worse artifacts themselves)

The CCD sensor

- Charged Coupled Device (CCD)



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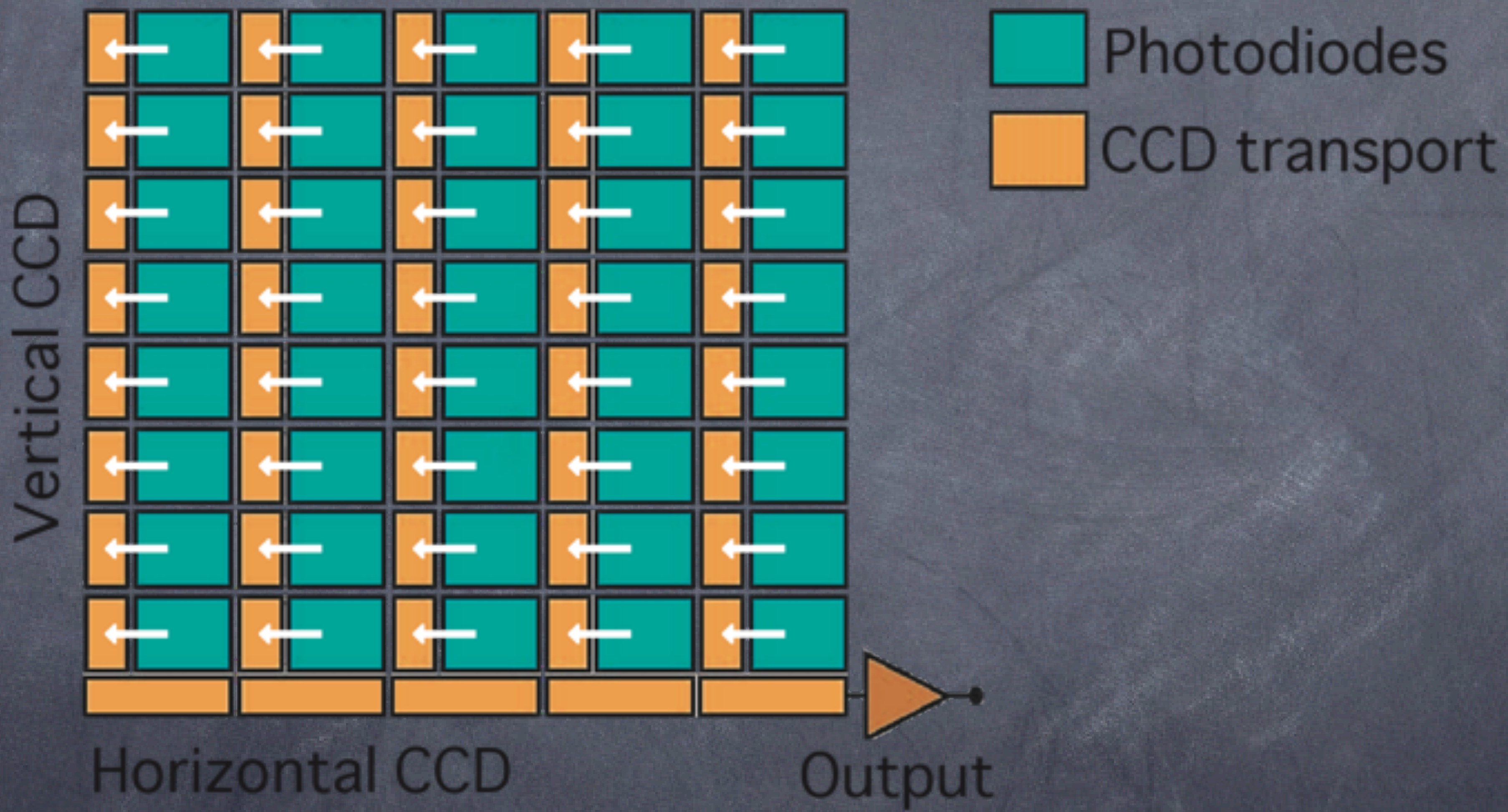
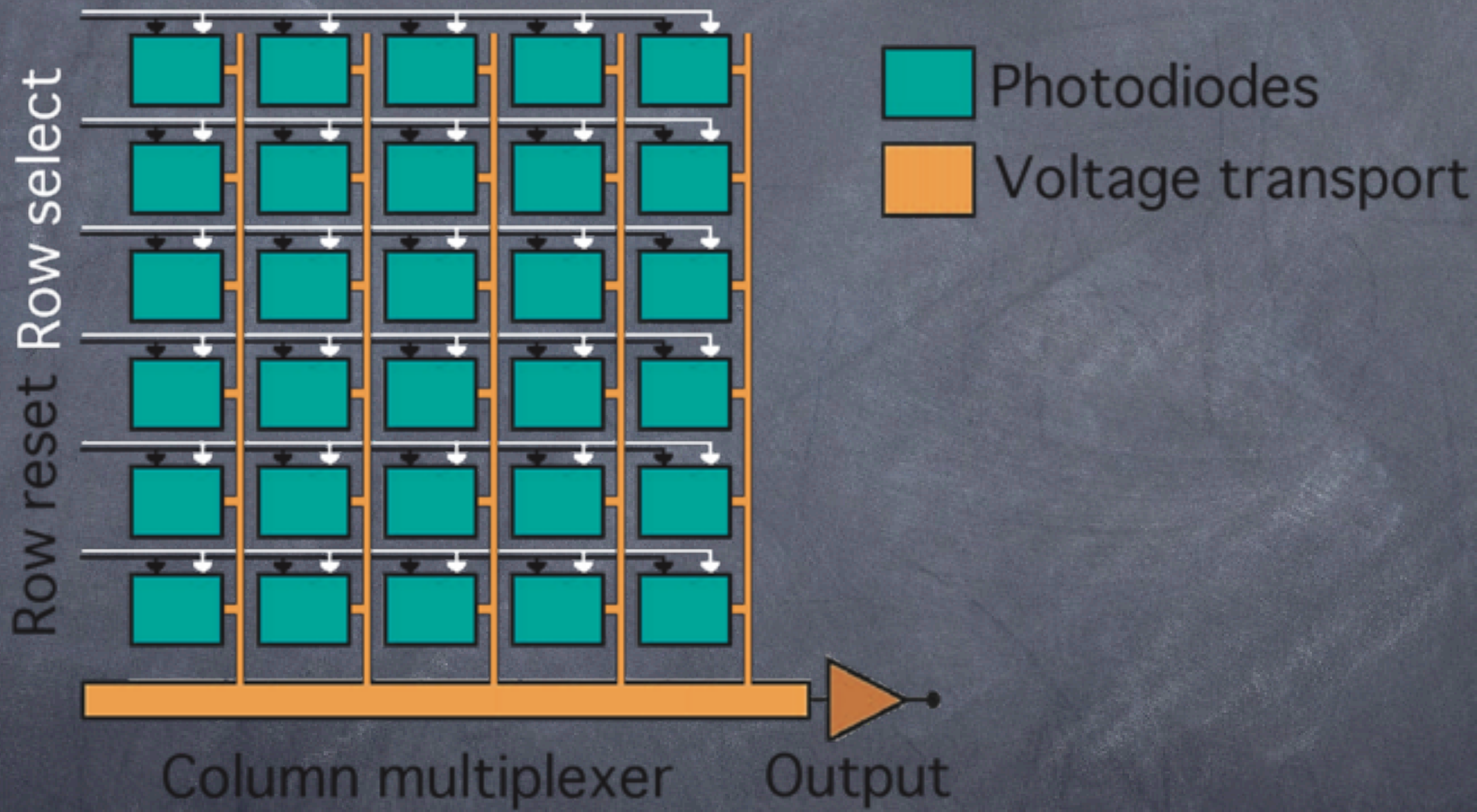


The non-buffered CMOS sensor

- Complementary Metal Oxide Semiconductor (CMOS)



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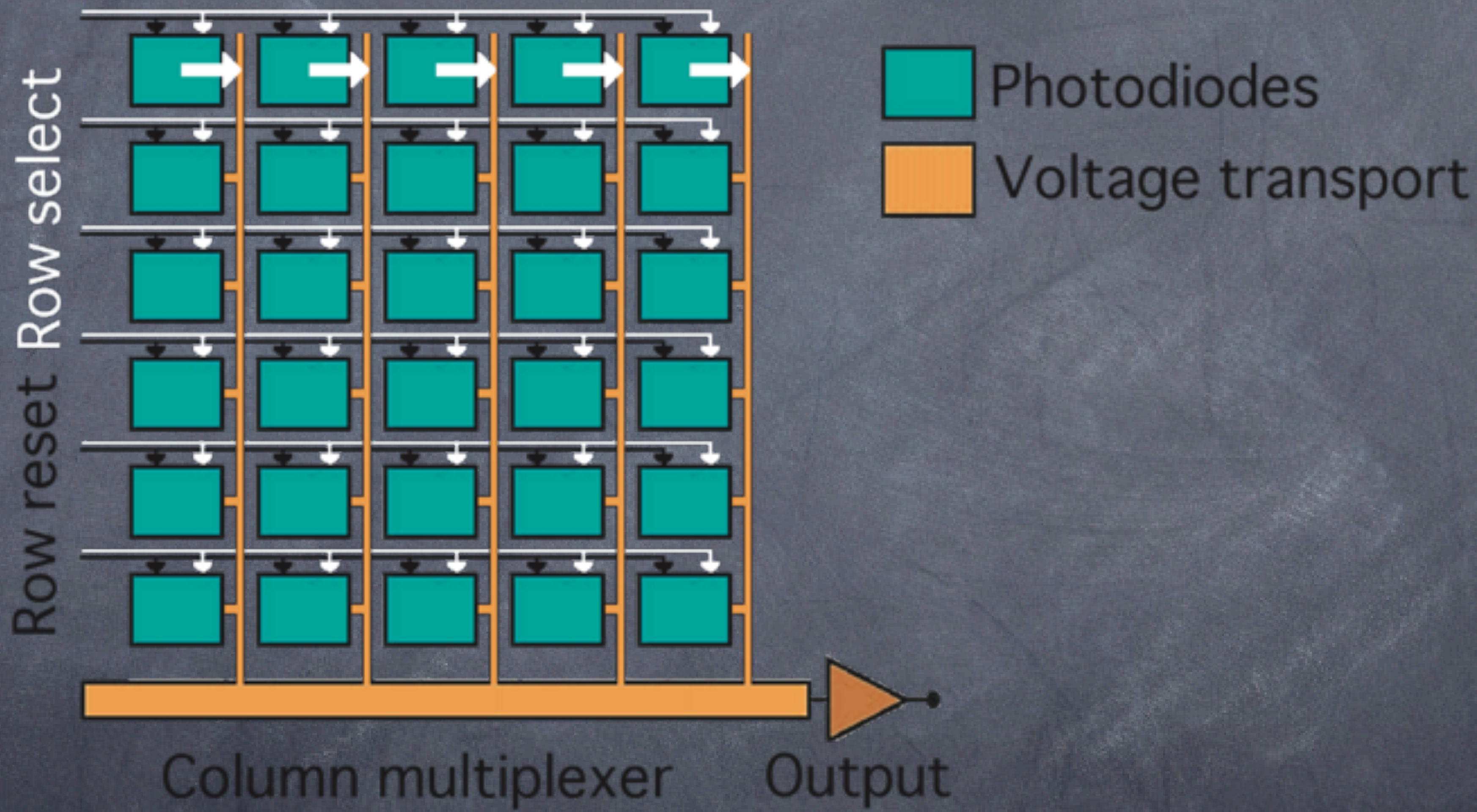

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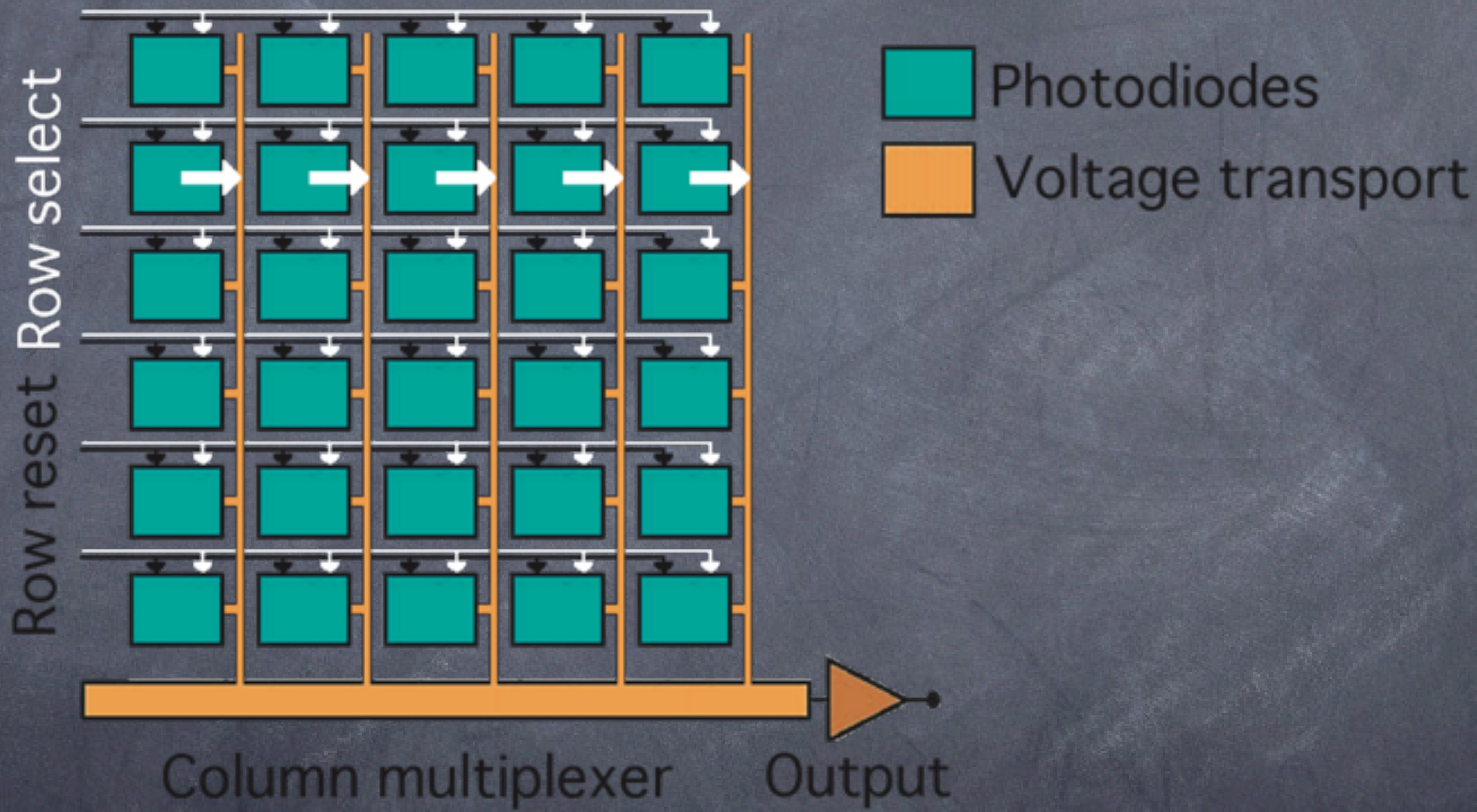

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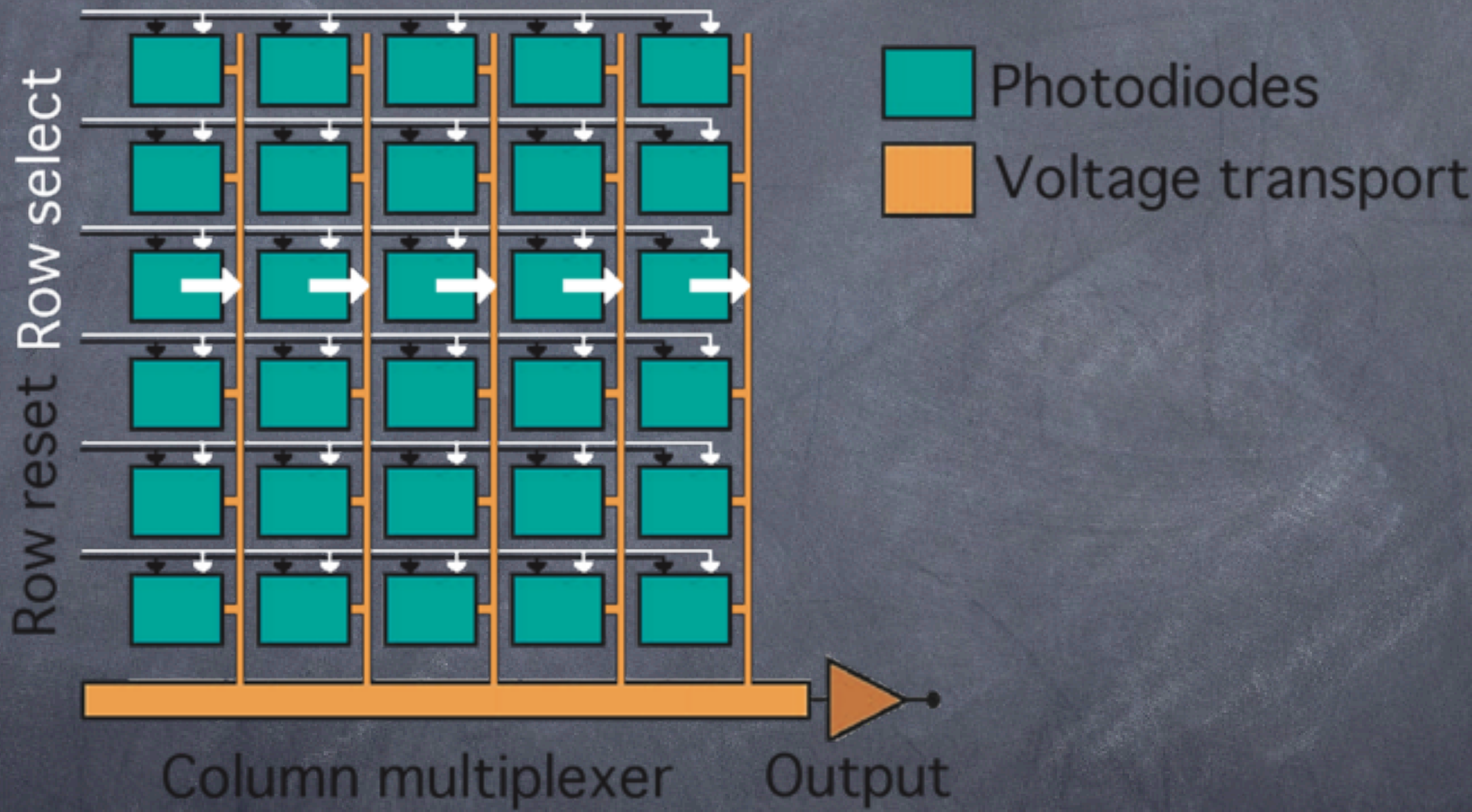

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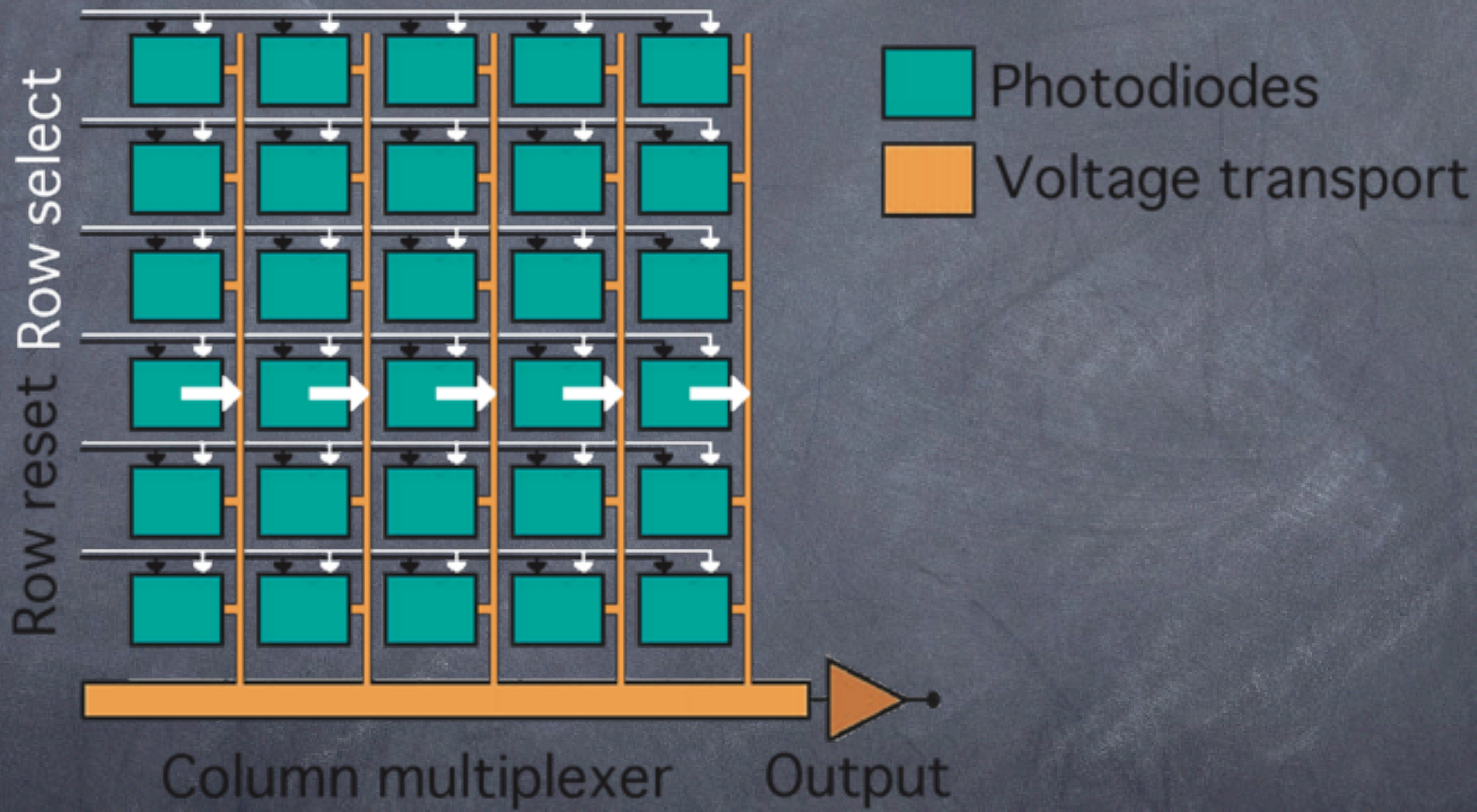

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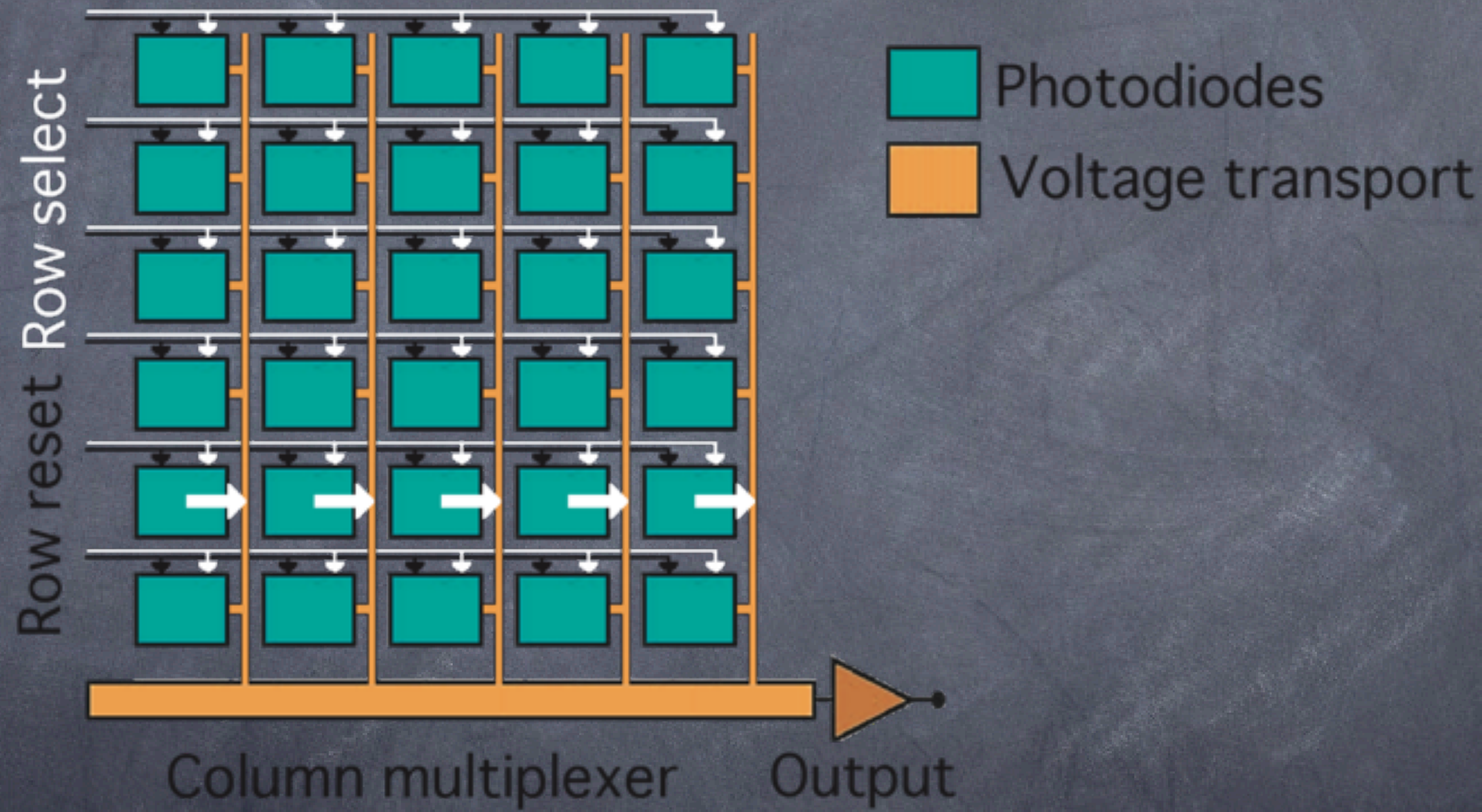

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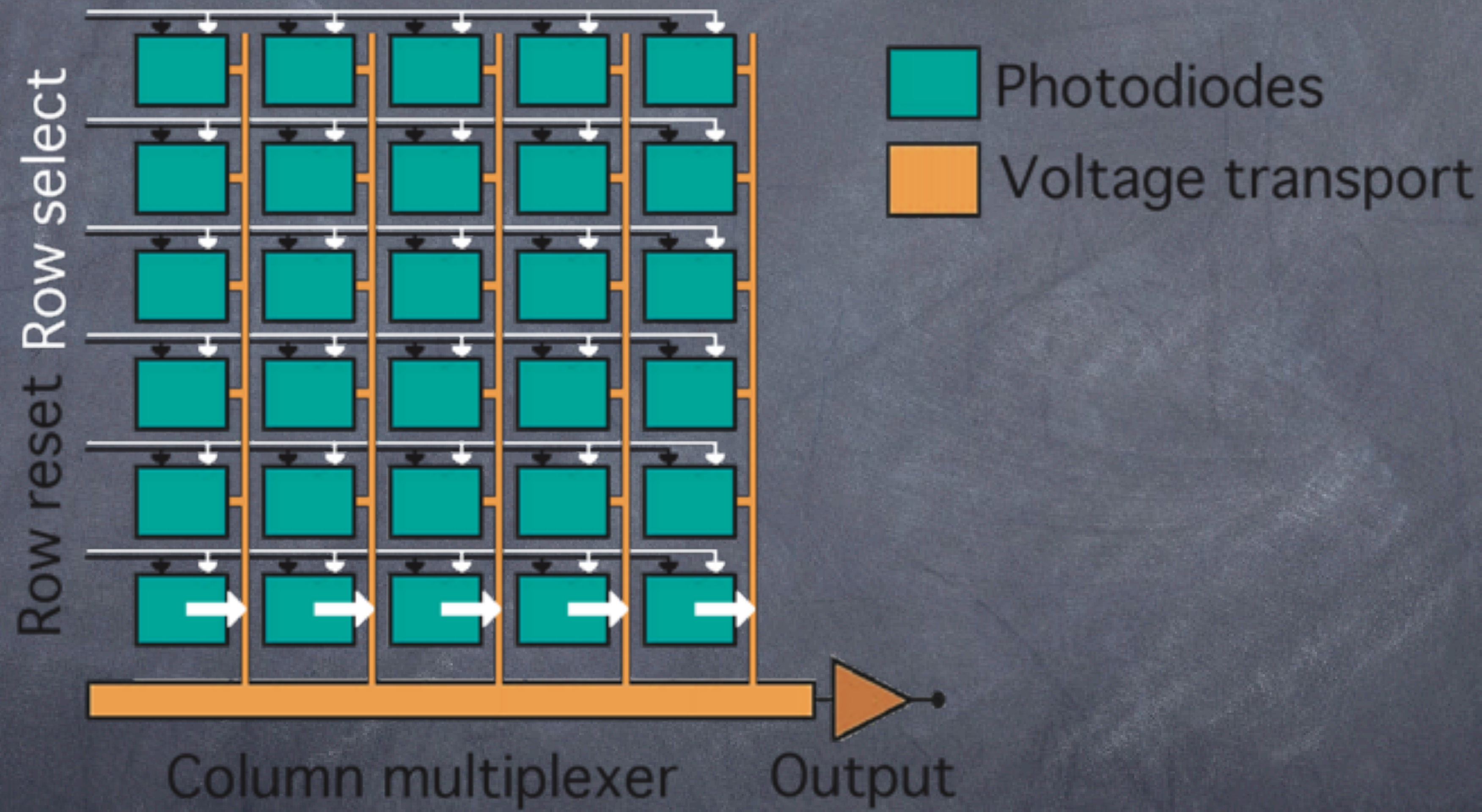

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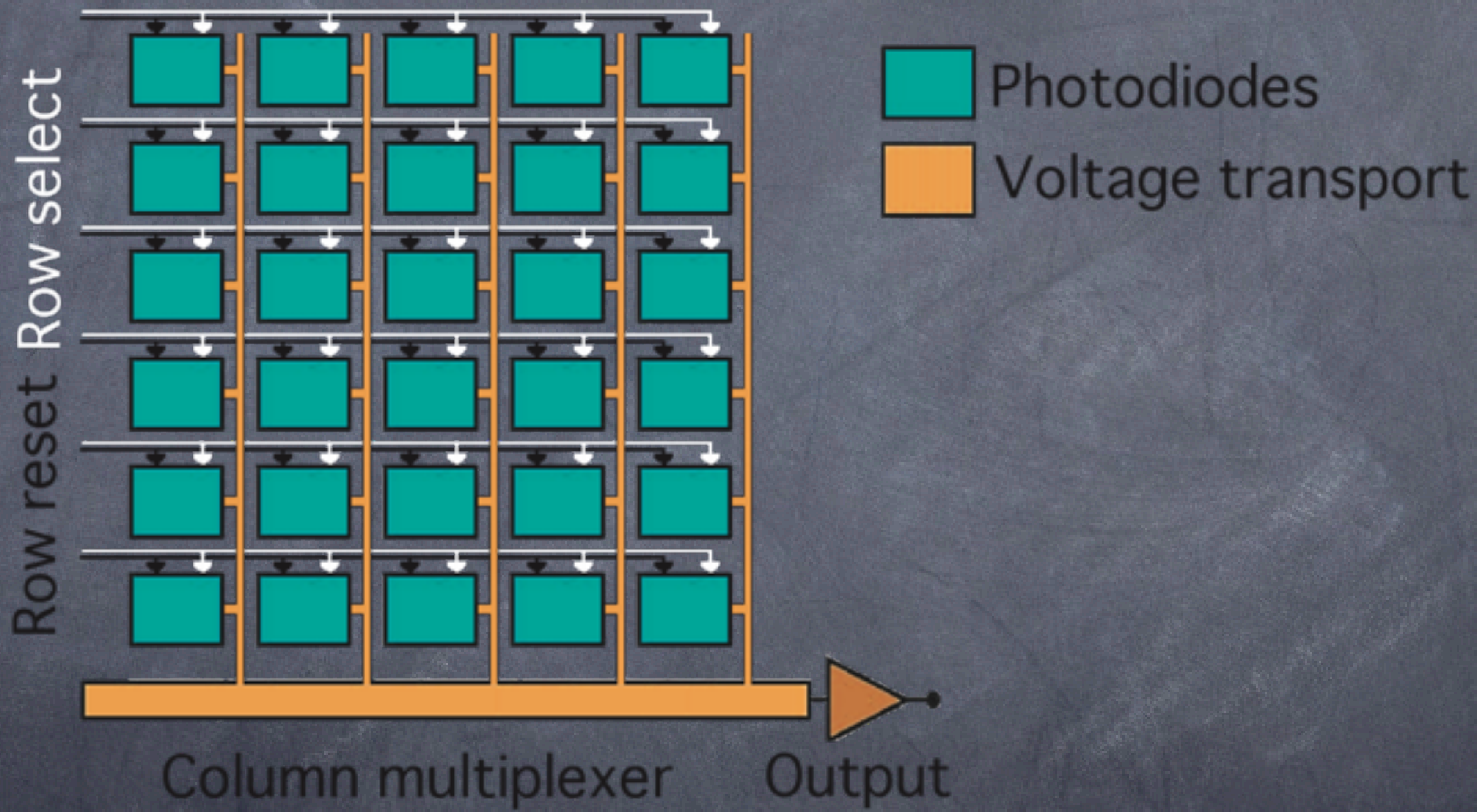


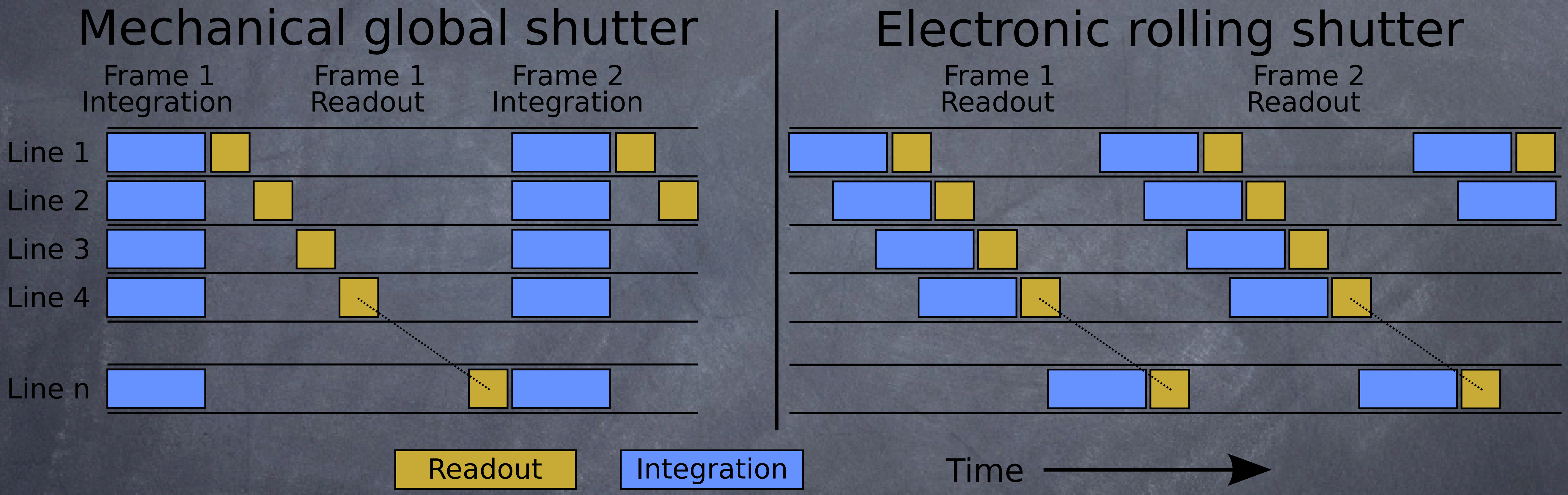
- Electronic Rolling Shutter (ERS)

Buffered CMOS sensors

- CMOS sensors with global-shutter since 1999
- Implemented by per-pixel memory buffer
- Buffering requires:
    - careful shielding
    - better micro-lenses and larger sensor to compensate for reduced fill-factor
- More expensive than ERS, but competitive in the same markets as CCD sensors

Global vs. rolling shutter

- Image rows are read sequentially



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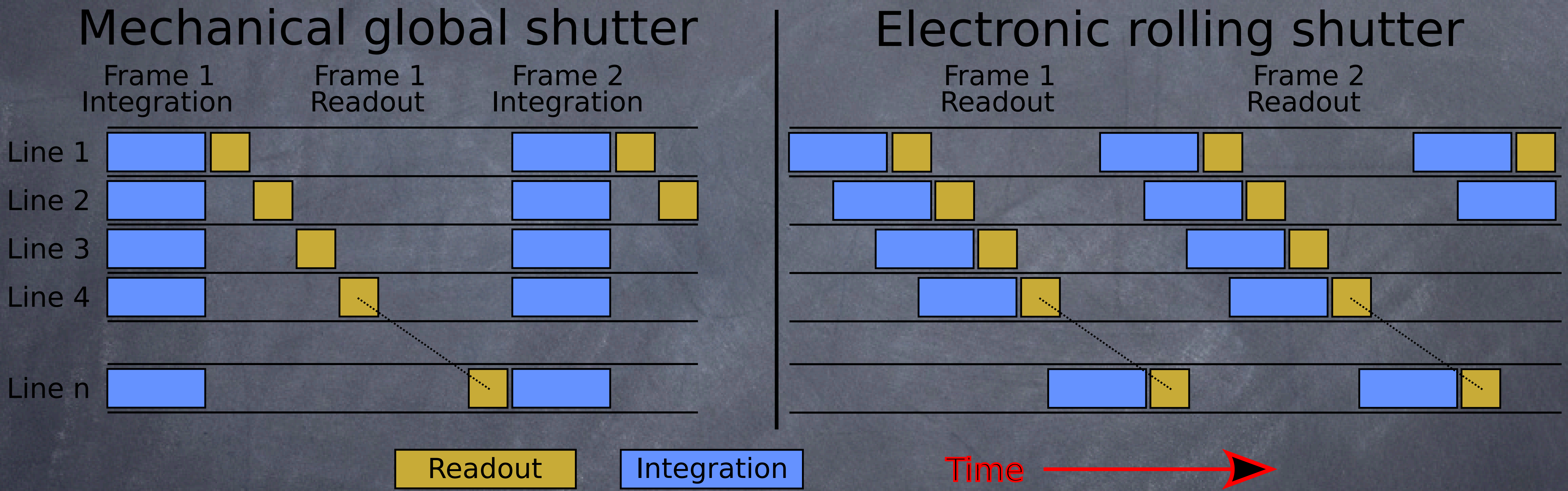

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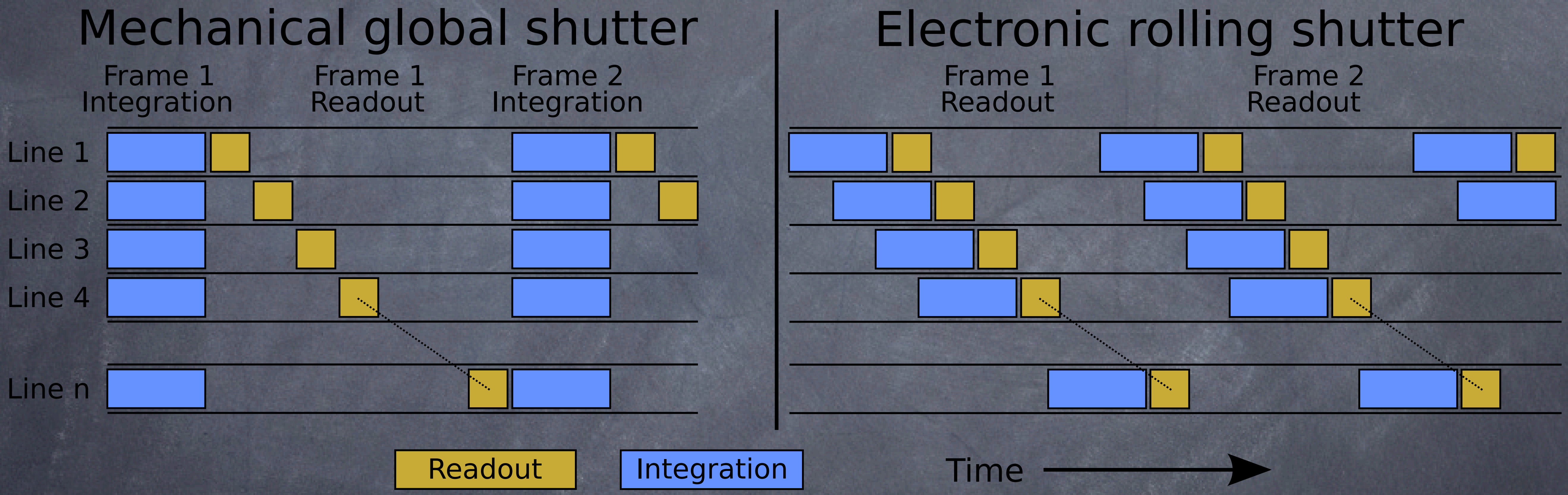

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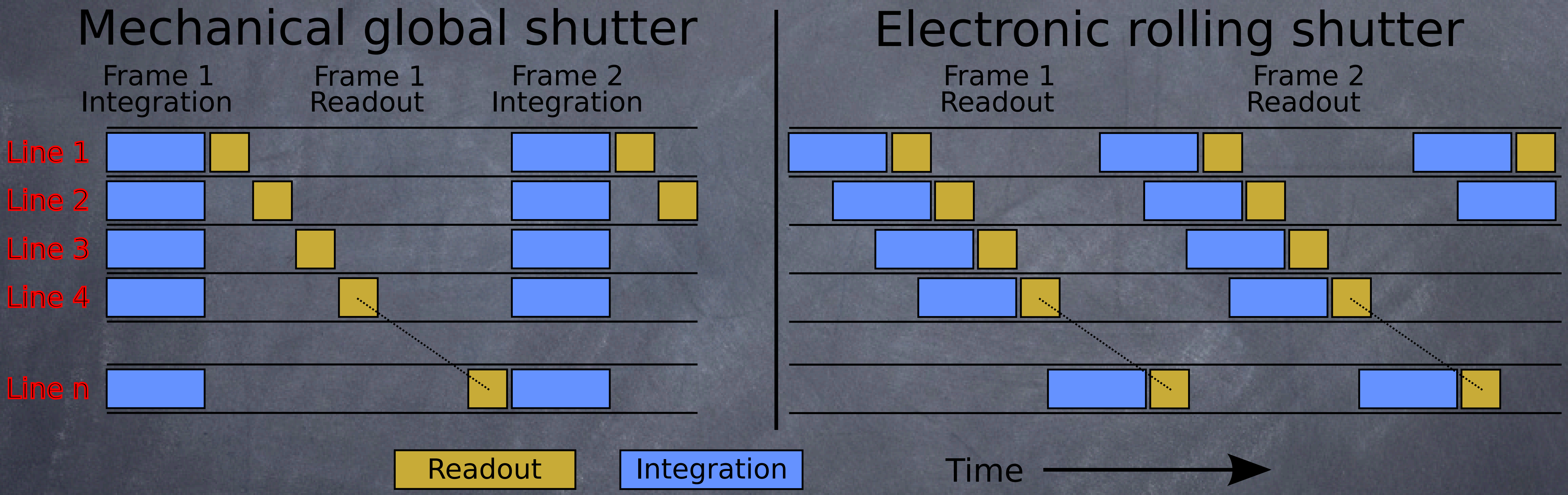

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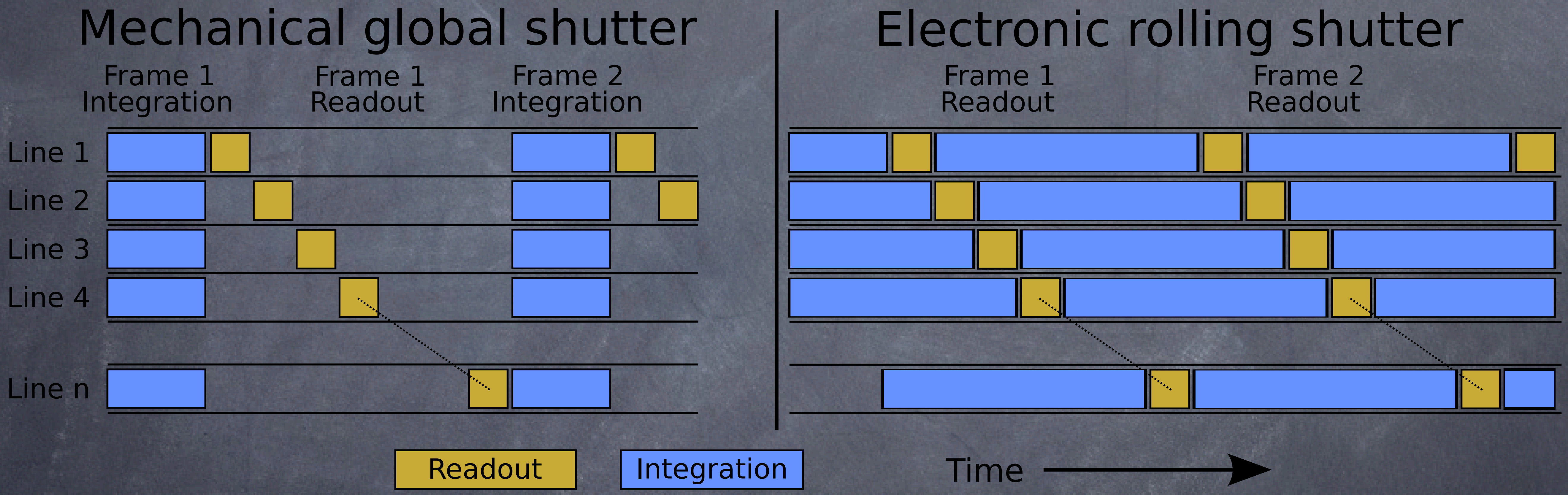

- Rolling shutter allows for longer integration
- No mechanical shutter or on-chip buffer needed

Rolling shutter artifacts

- motion:
  - wobble (vibrating motion)
  - skew (panning motion)
- varying illumination:
  - camera flash
  - fluorescent lamps

Slowed down to 2Hz

Hardware fixes

- Mechanical shutters
- Good for still images
- Used only in motion-picture video cameras (cumbersome)

Sony F65 Cinealta
CMOS motion-picture camera

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Rotating mirror shutter
from ALEXA

Sony F65 Cinealta
CMOS motion-picture camera

Hardware fixes

- Mechanical image stabilization
- Assumption: Small camera rotations
- Solution: Tilt lens/move sensor to counteract motion
- Failure cases:

Camera pan

Image plane rotation

Object motion

Hardware fixes

- Steadicam rigs, dollys and rails
- Failure cases: same as for MIS.

+ also generates smooth trajectories

- cumbersome

Steadicam smoothee for cellphones

Naming controversy

- Some authors use the term CMOS distortion or CMOS motion distortion instead of rolling shutter
- Some even (incorrectly) use the term motion blur
- We prefer the term rolling shutter because:
  - The problem is not confined to CMOS sensors
  - There are global shutter CMOS sensors

Focal-plane shutters

- Slow focal-plane shutters also cause rolling-shutter artifacts
- The fastest focal-plane shutters have rates near 0.1 msec/frame.

Grand Prix de Circuit de la Seine', June 26th 1912, photographed by Jacques Henri Lartigue

Early TV cameras

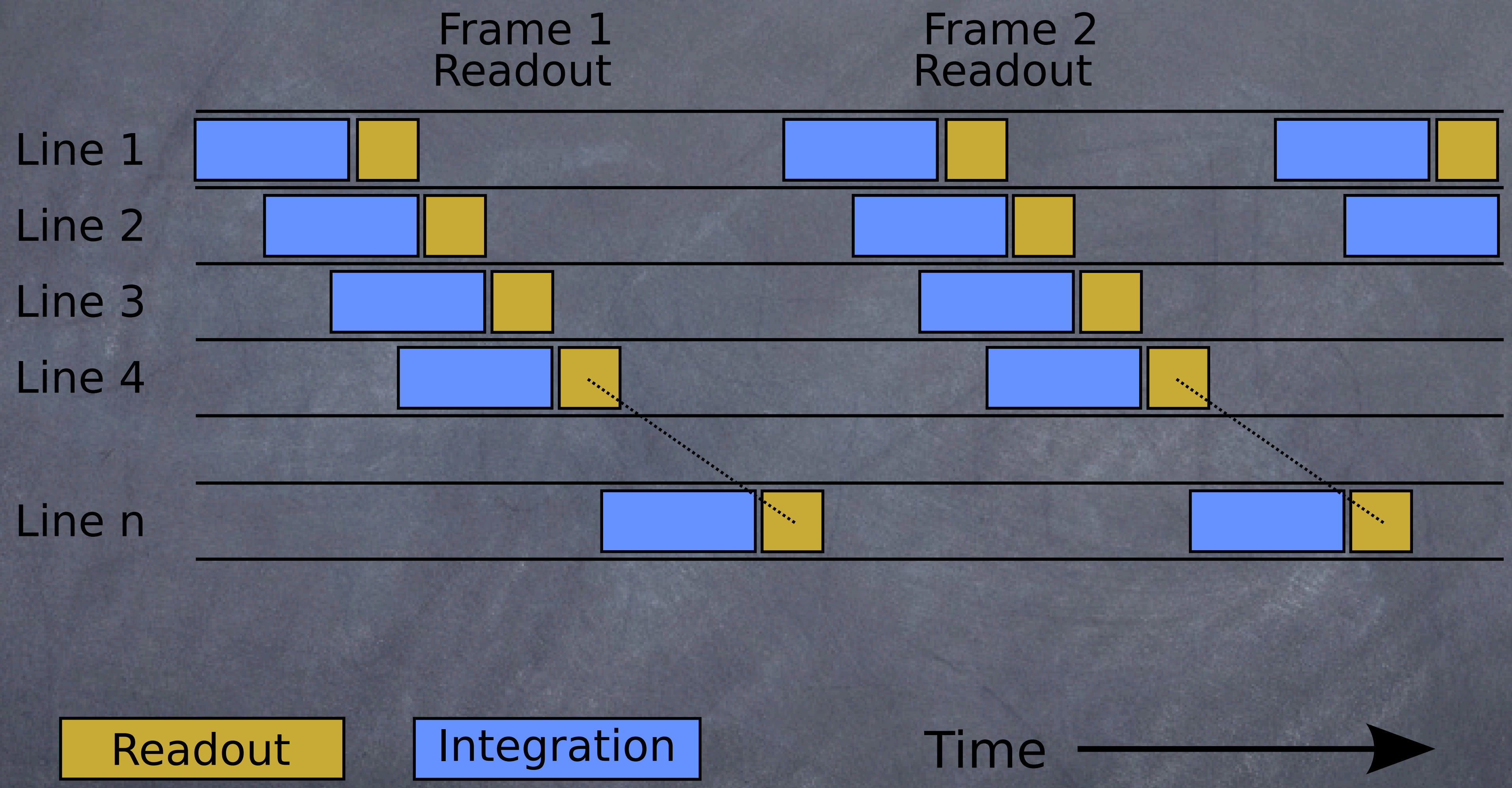
- Vidicon

- Used line scanning (thus rolling shutters) of the live scene to generate the serially transmitted TV signal (NTSC or PAL)

Sensor readout times

- How fast are modern rolling shutters?
- sensor readout times (milliseconds)

Sensor readout times



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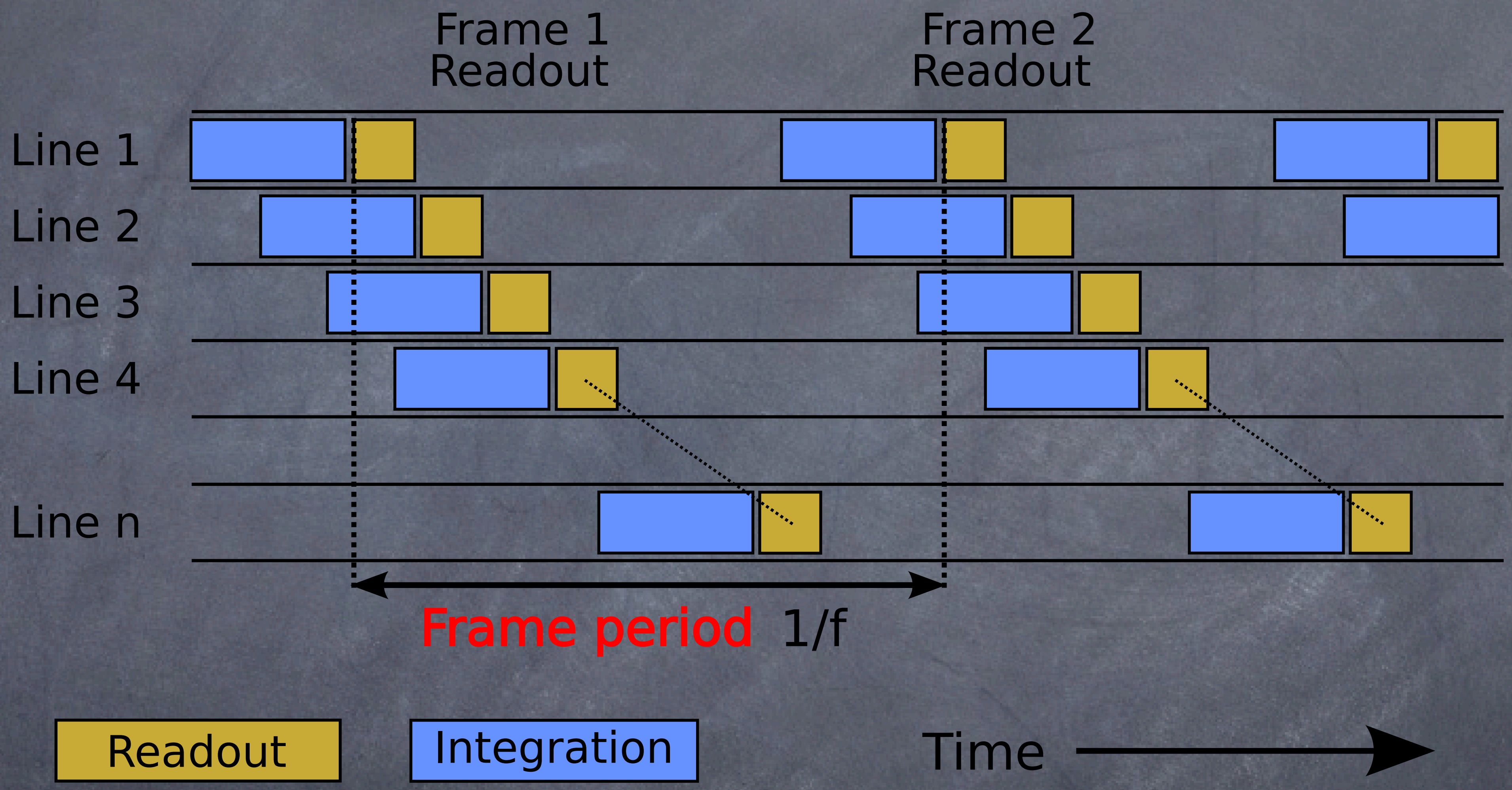

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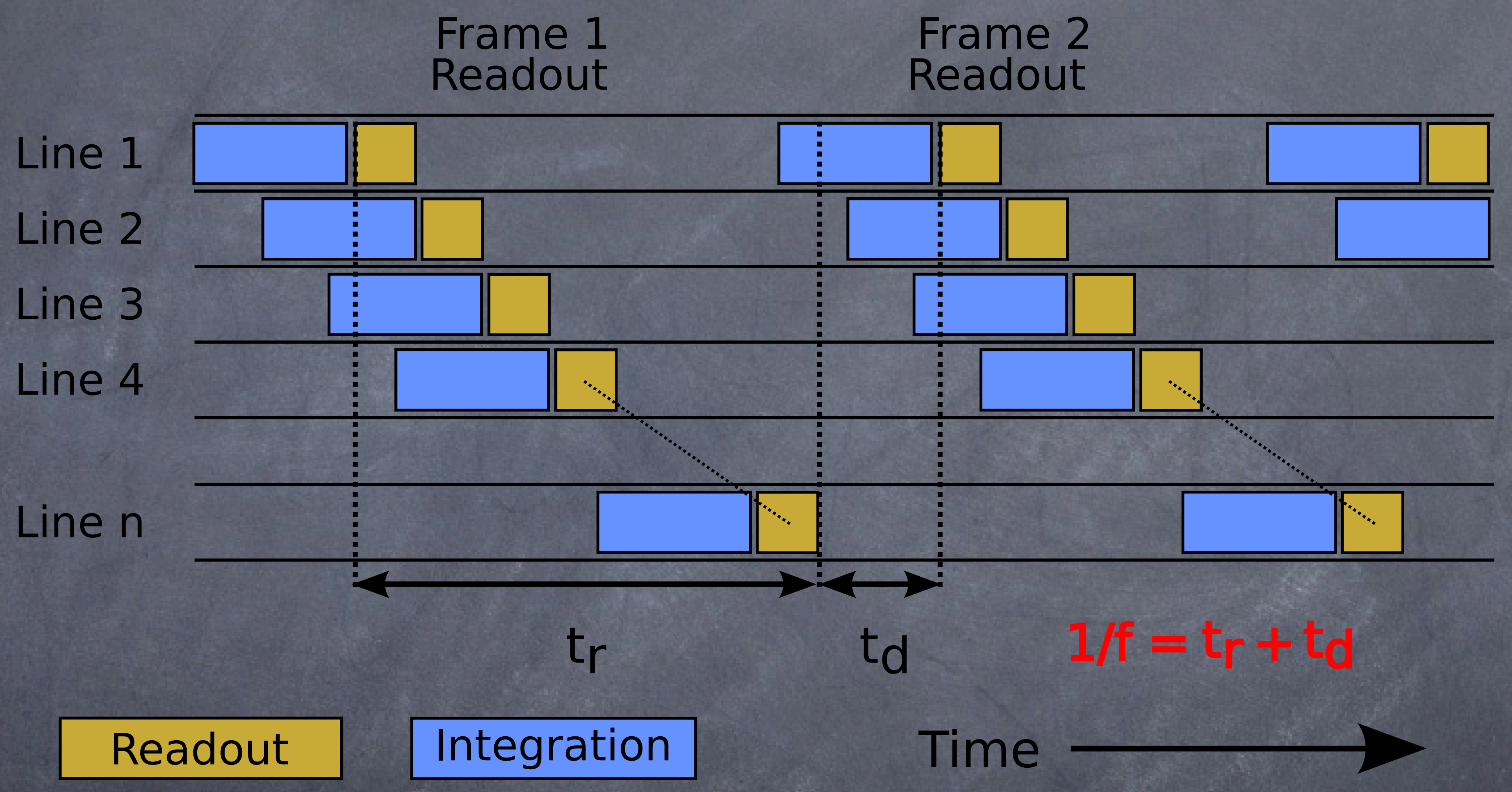

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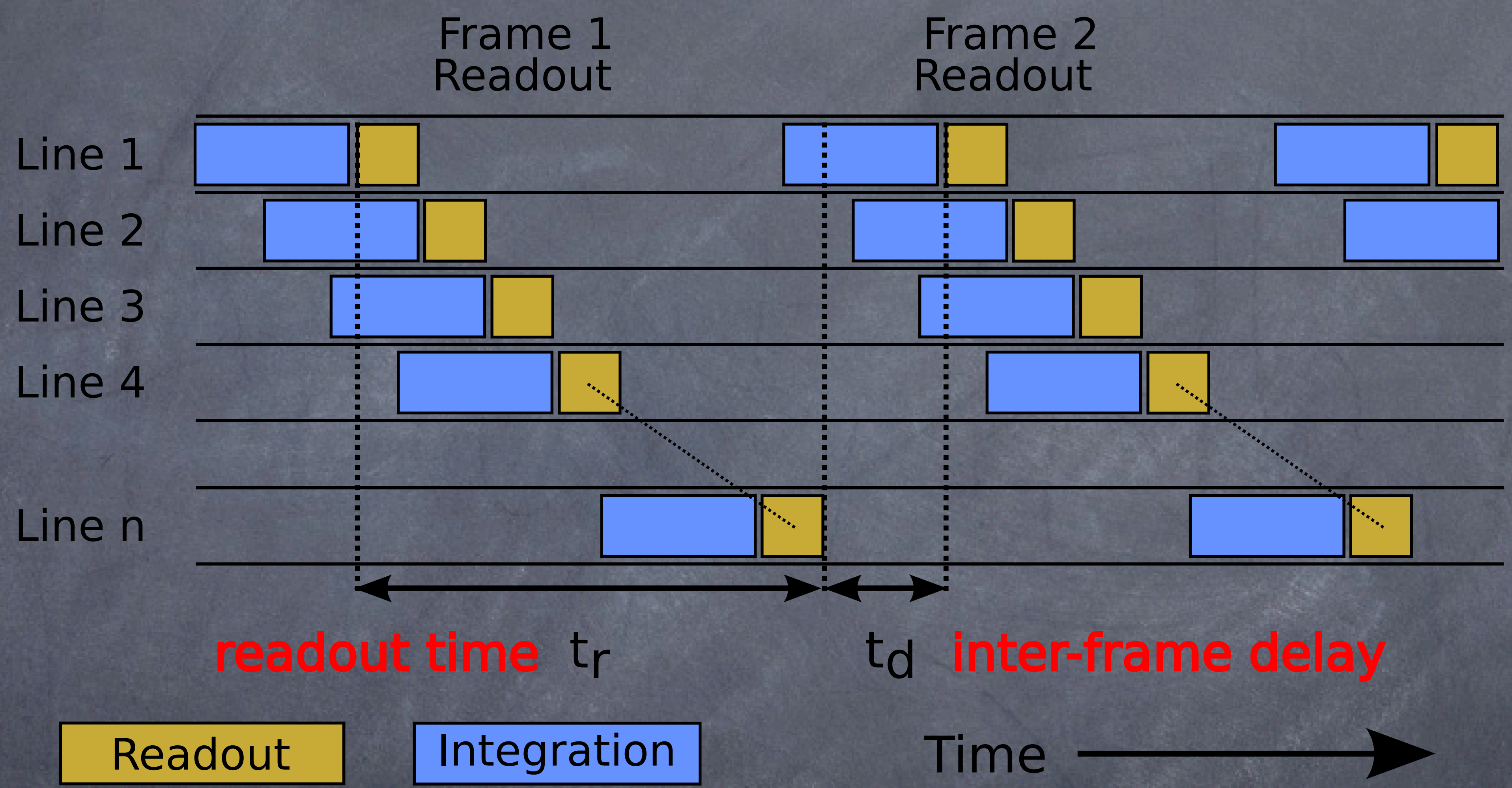
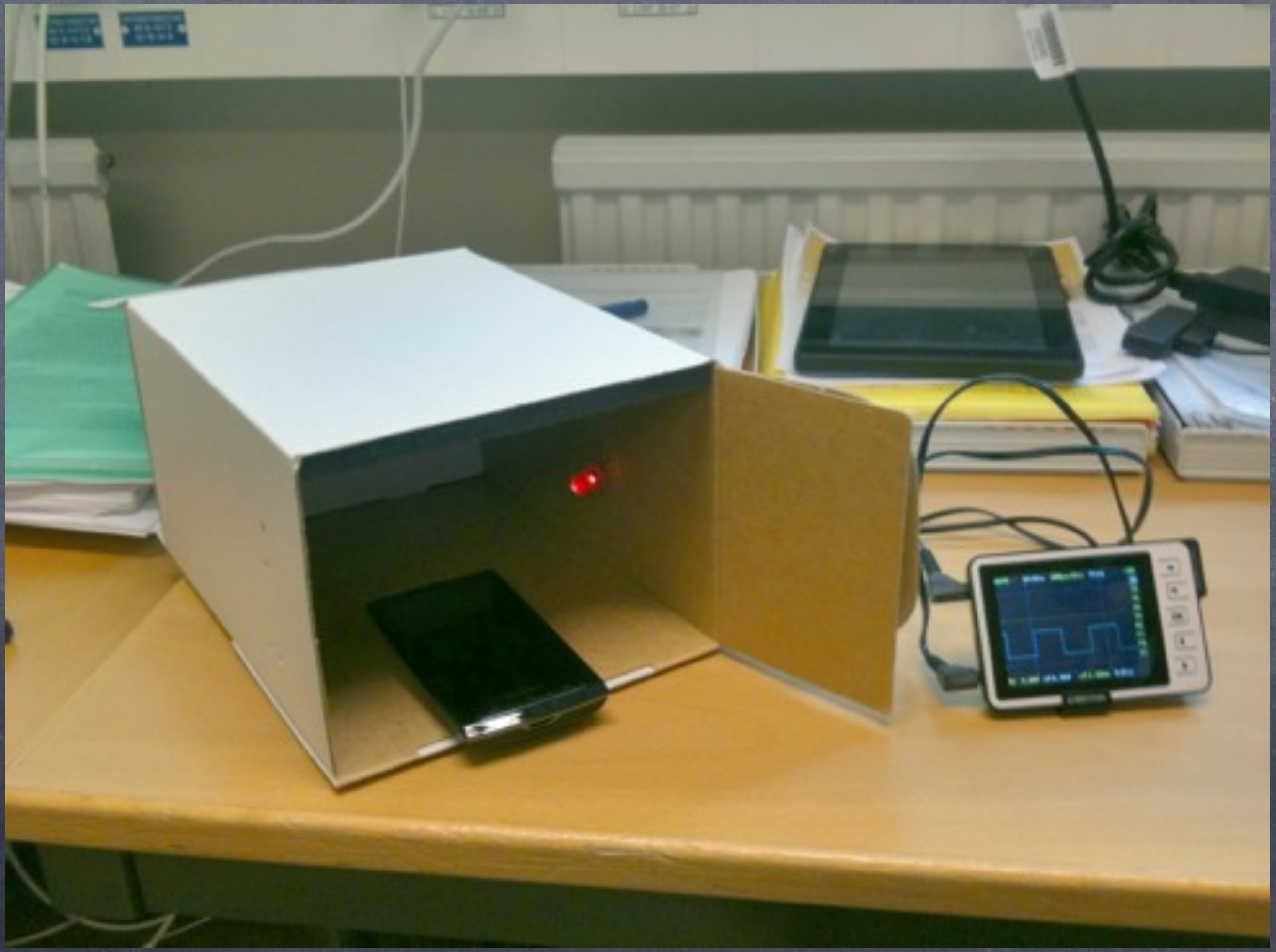


Sensor readout times

- We obtain the readout time as $t_r = N_r/(T f_o)$ by imaging a flashing LED with known frequency f_o and measuring the imaged period T [Geyer et al. OmniVis 2005]



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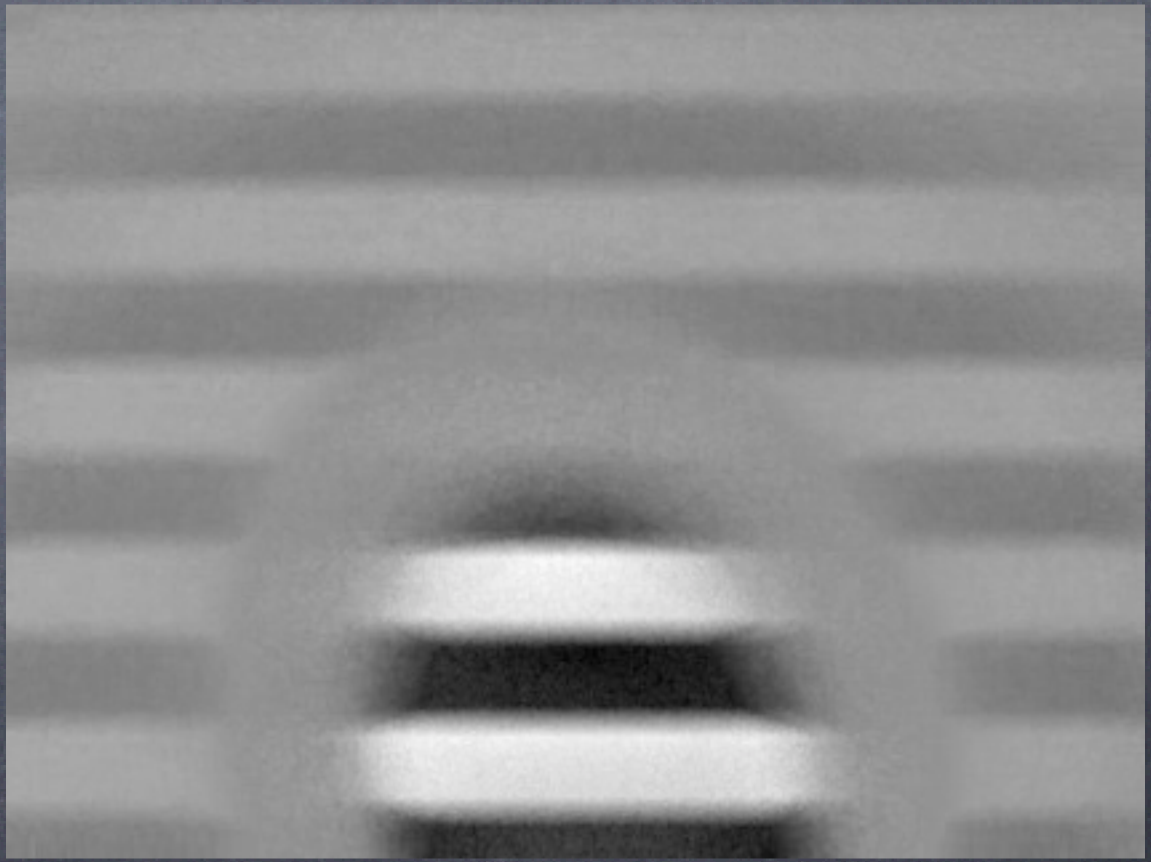

Sensor readout times

Device	framerate	Released	readout
GoProHD Hero	59.94fps	Fall 2009	16.22 msec
Kinect RGB	30fps	Nov 2010	26.11 msec
Kinect NIR	29.97fps	Nov 2010	30.55 msec
iPhone 4s	30fps	Oct 2011	22.08 msec
AR drone v2	30fps	June 2012	24 msec

Summary

- Rolling shutter cameras are everywhere
- CMOS image sensors designed for the mass market have electronic rolling shutter (ERS) readout
- A rolling shutter degrades all kinds of geometric computer vision
- A mechanical shutter solves the RS problem
- The readout time can be measured accurately by imaging a flashing light with known rate.