How Small Should Pixel Size Be?

Ting Chen[1], Peter B. Catrysse[1], Abbas El Gamal[1] and Brian A. Wandell[2]

[1]Information Systems Laboratory

Department of Electrical Engineering, Stanford University, CA 94305, USA

[2]Department of Psychology, Stanford University, CA 94305, USA

Pixel Design

- **Pixel design is crucial in image sensor design**
  - **Selection of pixel architecture**
  - **Selection of photodetector type**
  - **Selection of pixel layout and size**
- **Pixel size tradeoff**
  - **Small pixel size/large pixel count improves spatial resolution and MTF**
  - **Large pixel size improves DR and SNR**

$$\Longrightarrow$$ **an optimal pixel size may exist**

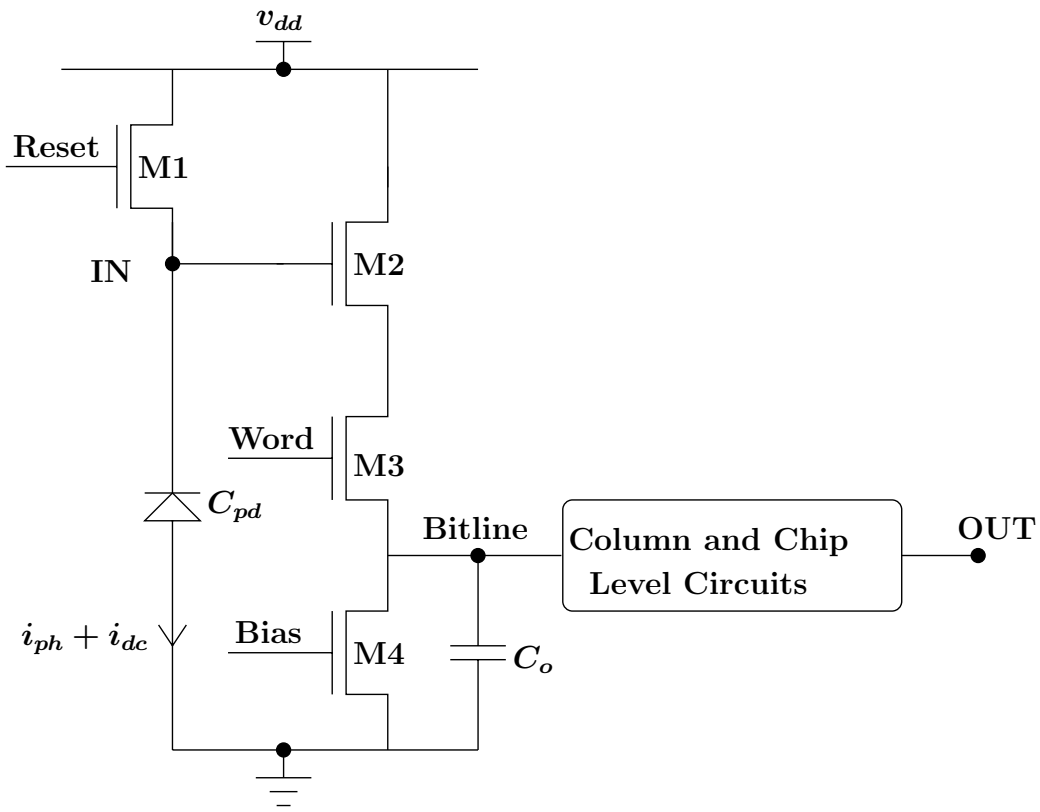
Pixel Size Selection

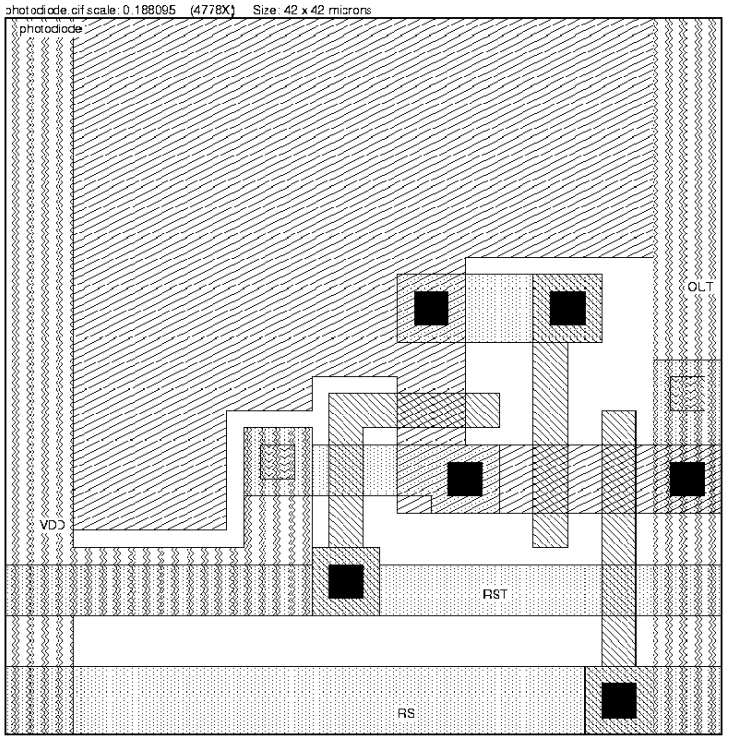
- **Difficult to determine the optimal pixel size analytically, depends on**
  - **Sensor parameters**
  - **Imaging optics**
  - **Human perception of image quality**
- **We describe a methodology using**
  - **Camera simulator (Catrysse *et al.* 1999)**
  - **Image quality metric S-CIELAB (Zhang *et al.* 1997)**

Outline

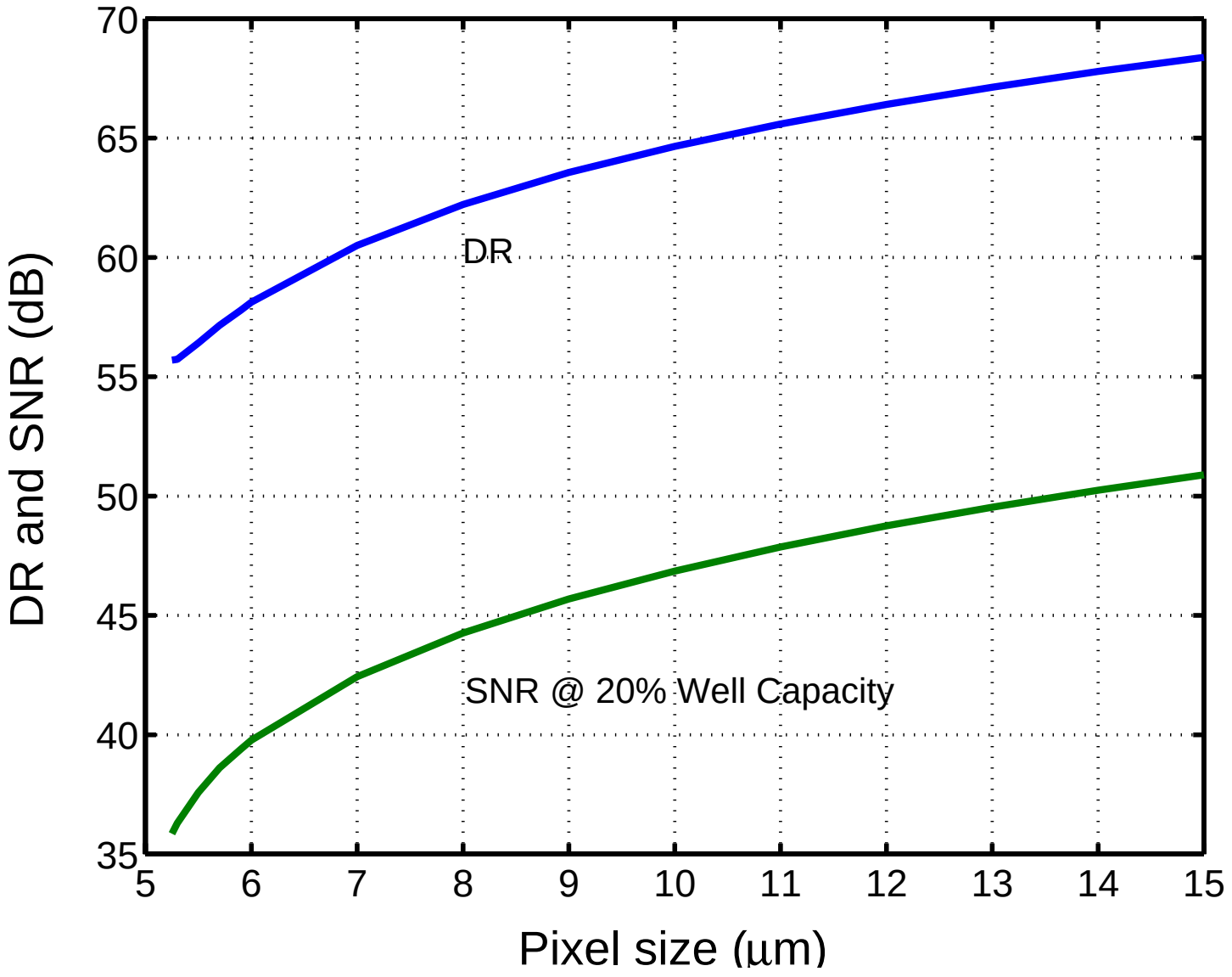
- APS pixel circuit and layout
- Pixel size tradeoff
  - DR and SNR
  - Spatial Resolution and System MTF
- Methodology for determining optimal pixel size
- Simulation results
- Conclusion

APS Pixel Circuit and Layout Topology

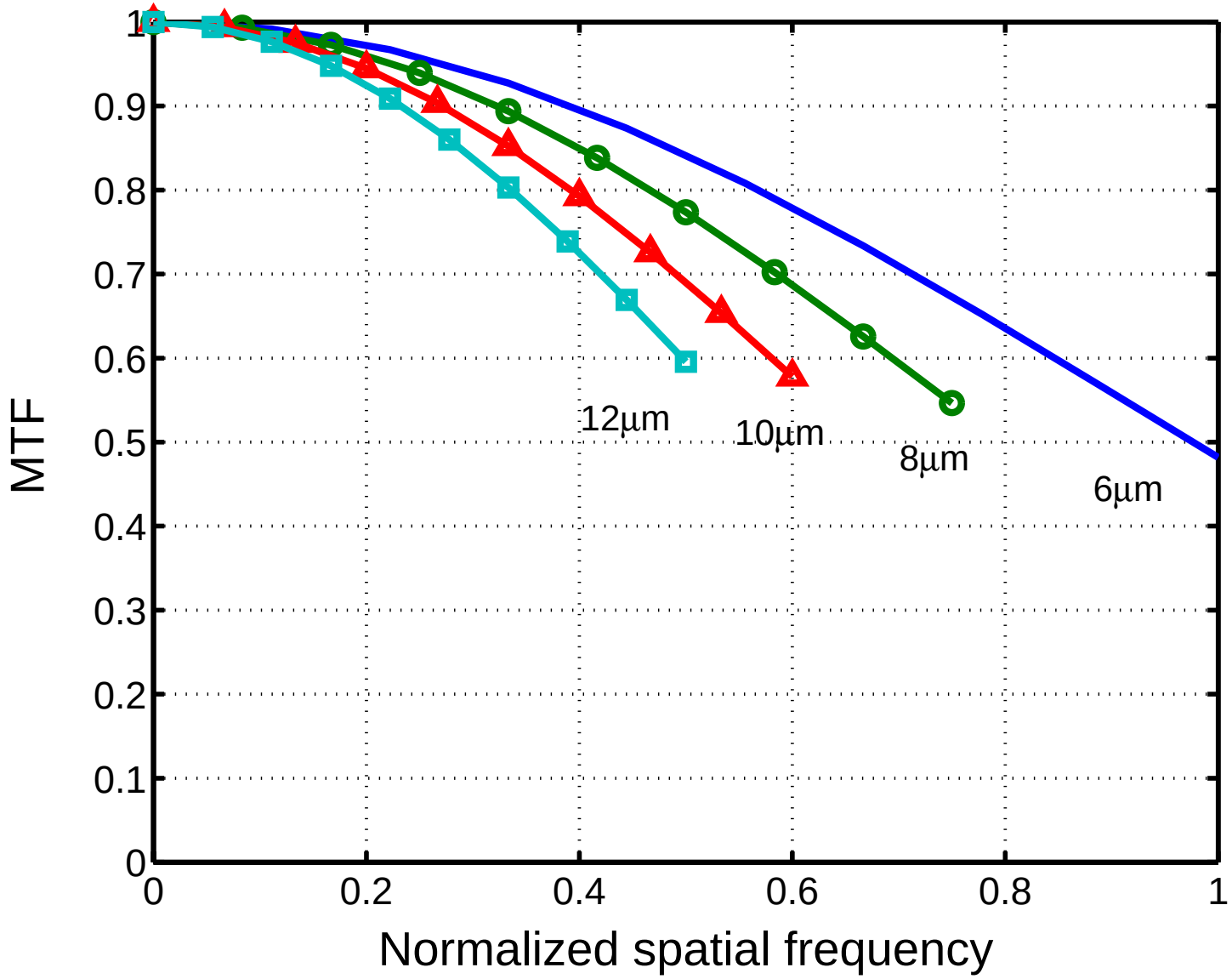




DR and SNR versus Pixel Size



Spatial Resolution and System MTF versus Pixel Size



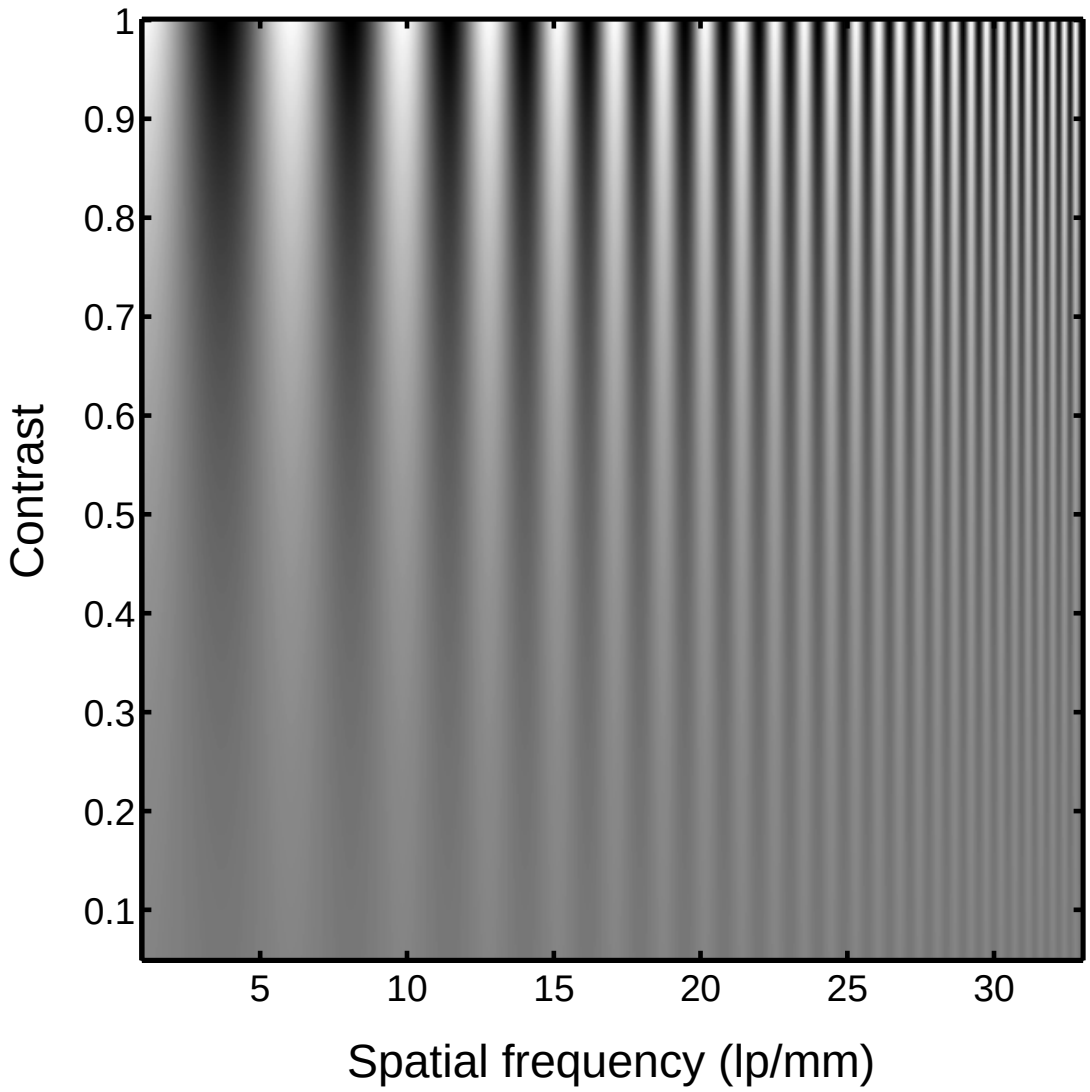
Methodology for Determining Optimal Pixel Size

- **Given :**
  - **Process information**
  - **Fixed die size**
  - **Imaging optics parameters**
  - **Scene luminance range**
  - **Highest spatial frequency in the scene**
  - **Maximum exposure time**

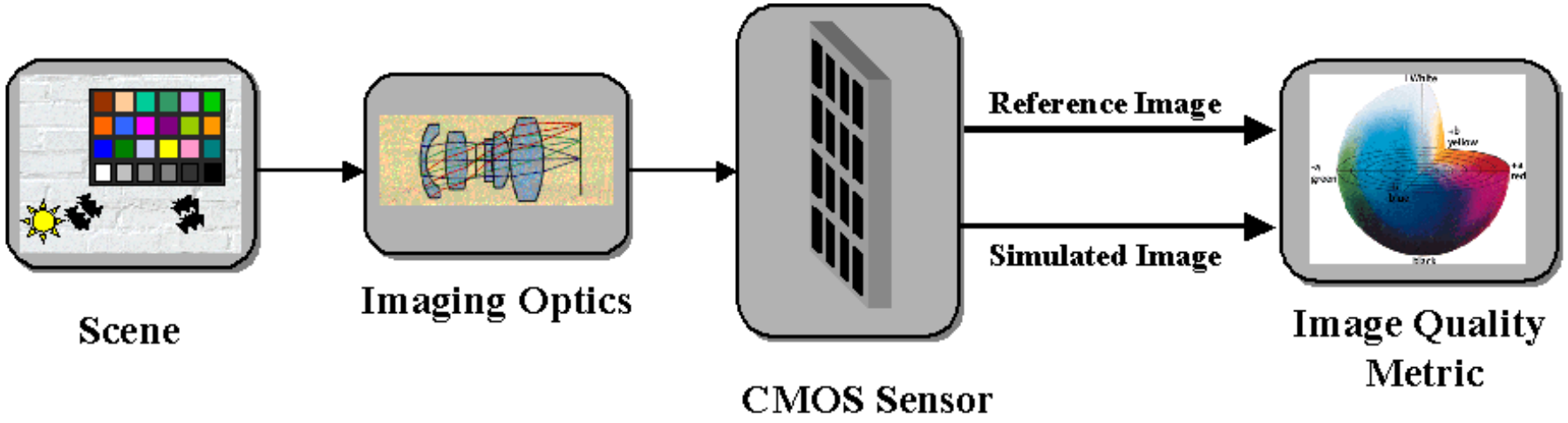
Procedure for Determining Optimal Pixel Size

- Vary pixel size (pixel count) for the given die size
- For each pixel size
  - Use the camera simulator with a synthetic Contrast Sensitivity Function (CSF) scene to estimate the resulting image
  - Determine rendered image quality in S-CIELAB
- Select optimal pixel size to achieve highest image quality

Synthetic Contrast Sensitivity Function Scene



Simulation Flow



Camera Simulator

S-CIELAB ΔE Metric

- Radiometric or photometric scene parameters
- f/#
- Focal length
- Diffraction-only
- Wavelength-dependent MTF
- Off-axis irradiance
- Spectral response
- Fill factor
- Dark current density
- Geometric MTF
- Temporal noise
- Fixed pattern noise
- Perceptual difference
- Spatial sensitivity
- Threshold = one unit

Example : 0.35μ CMOS Process

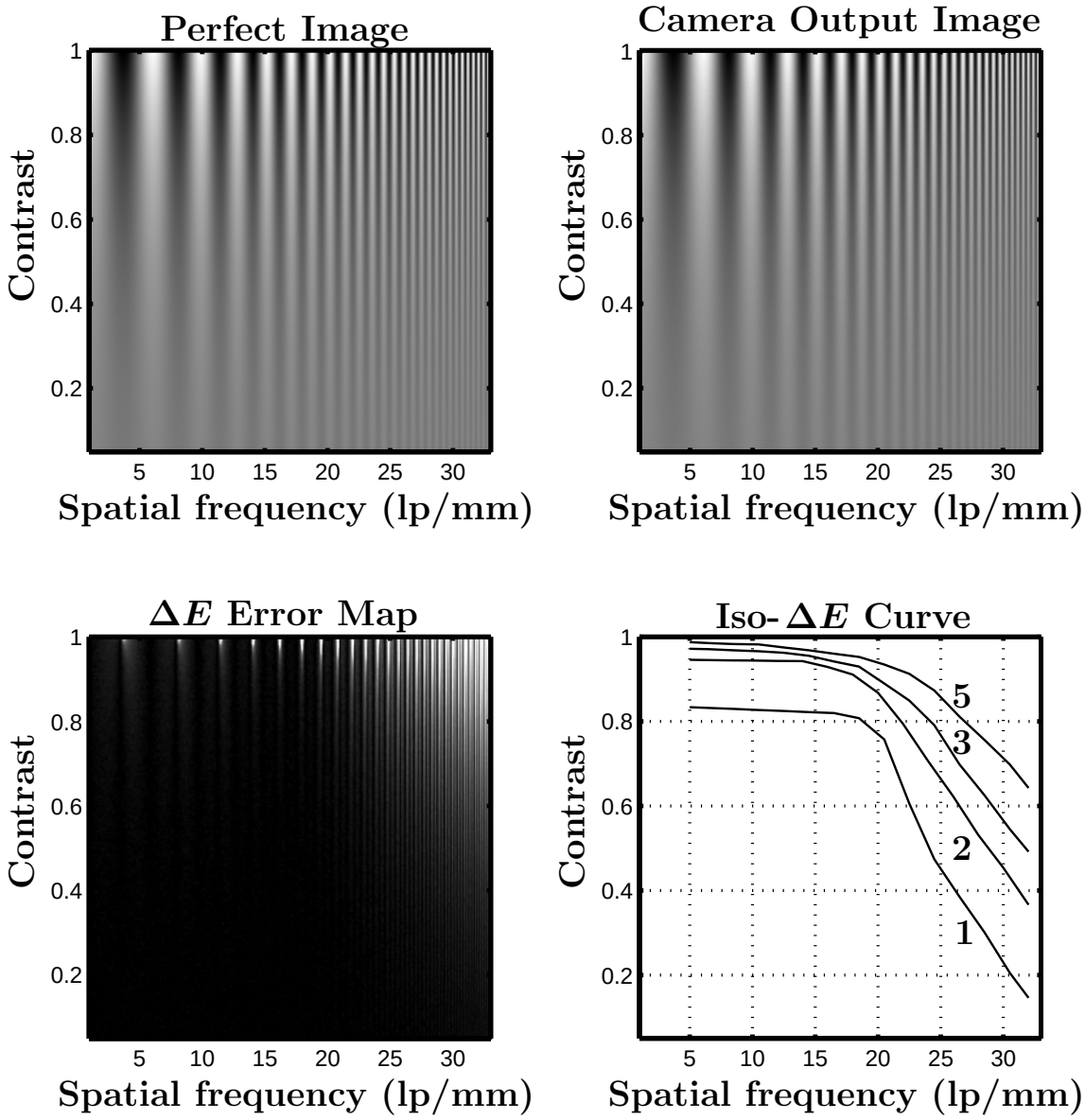
pixel size : 8μm

L_{scene} : 25 - 1000 cd/m^2

t_{max} : 100 ms

f_{max} : 33 lp/mm

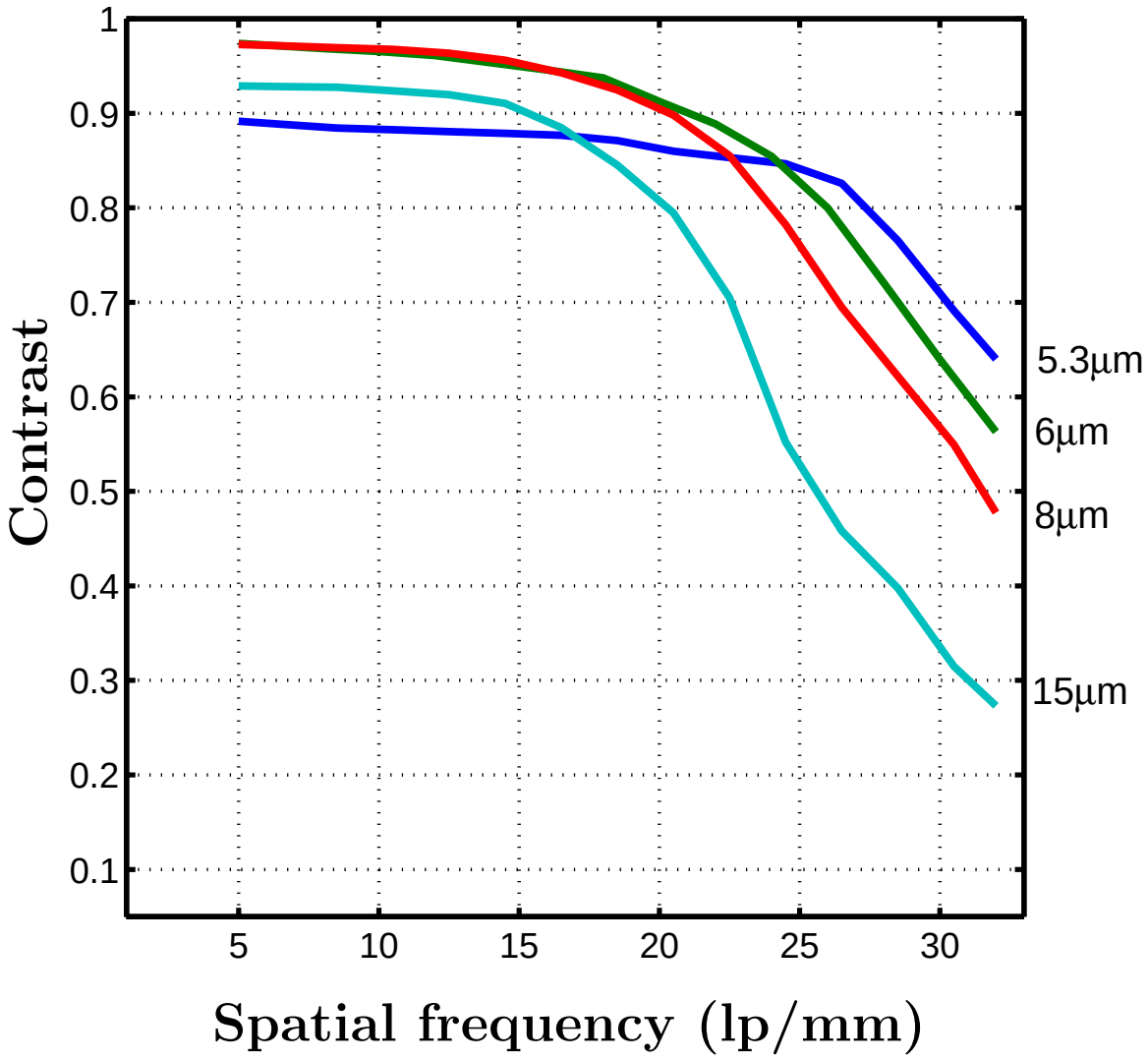
optics f/# : 1.2



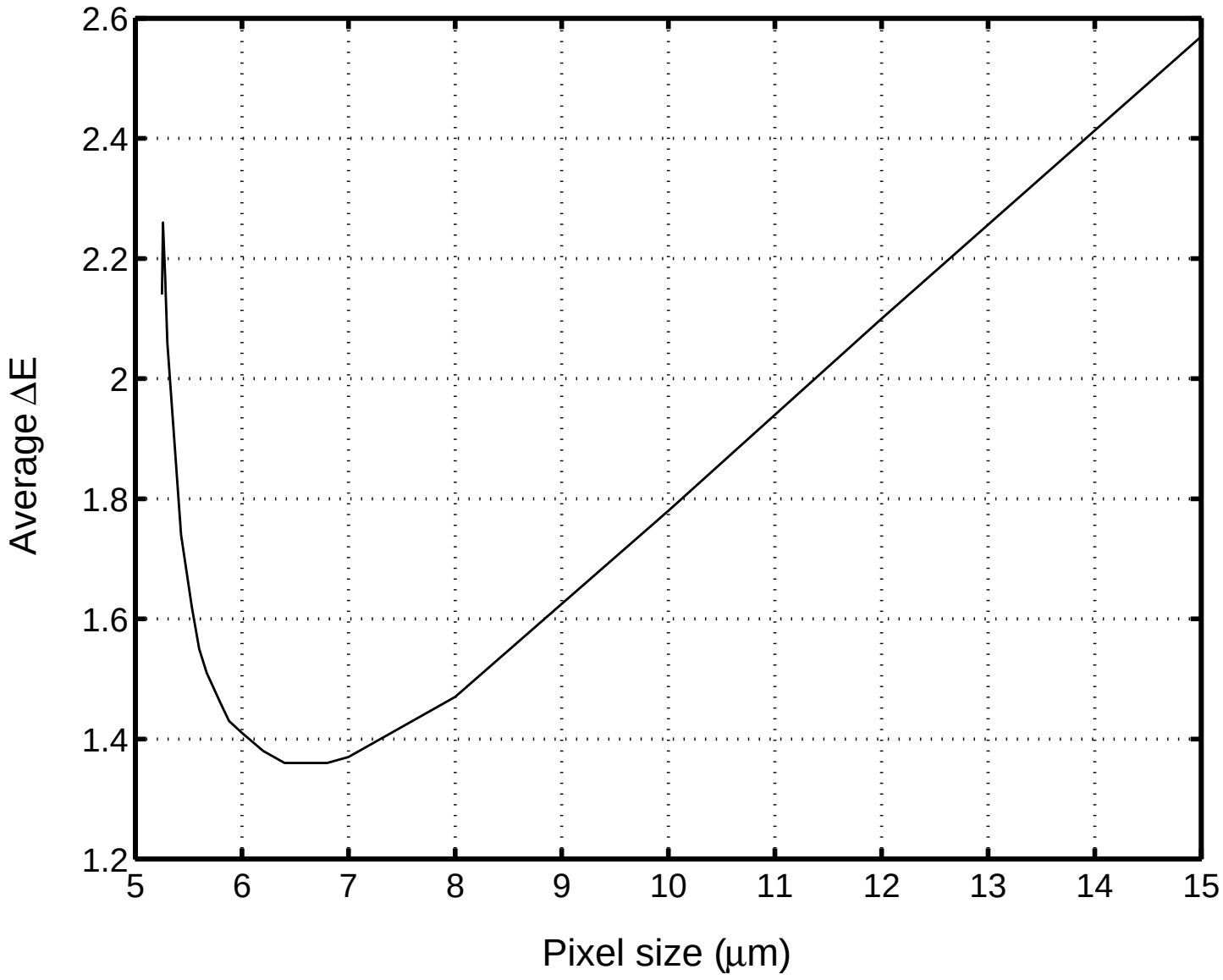
Determining the Optimal Pixel Size

- **0.35μ process**
- **fixed die size**
- **variable pixel size : 5.3 - 15 μm**
- **scene luminance range : 25 - 1000 cd/m^2**
- **maximum integration time : 100 ms**
- **highest spatial frequency in the scene : 33 lp/mm**
- **examine iso-ΔE curves for different pixel sizes**
- **imaging optics f/# : 1.2**

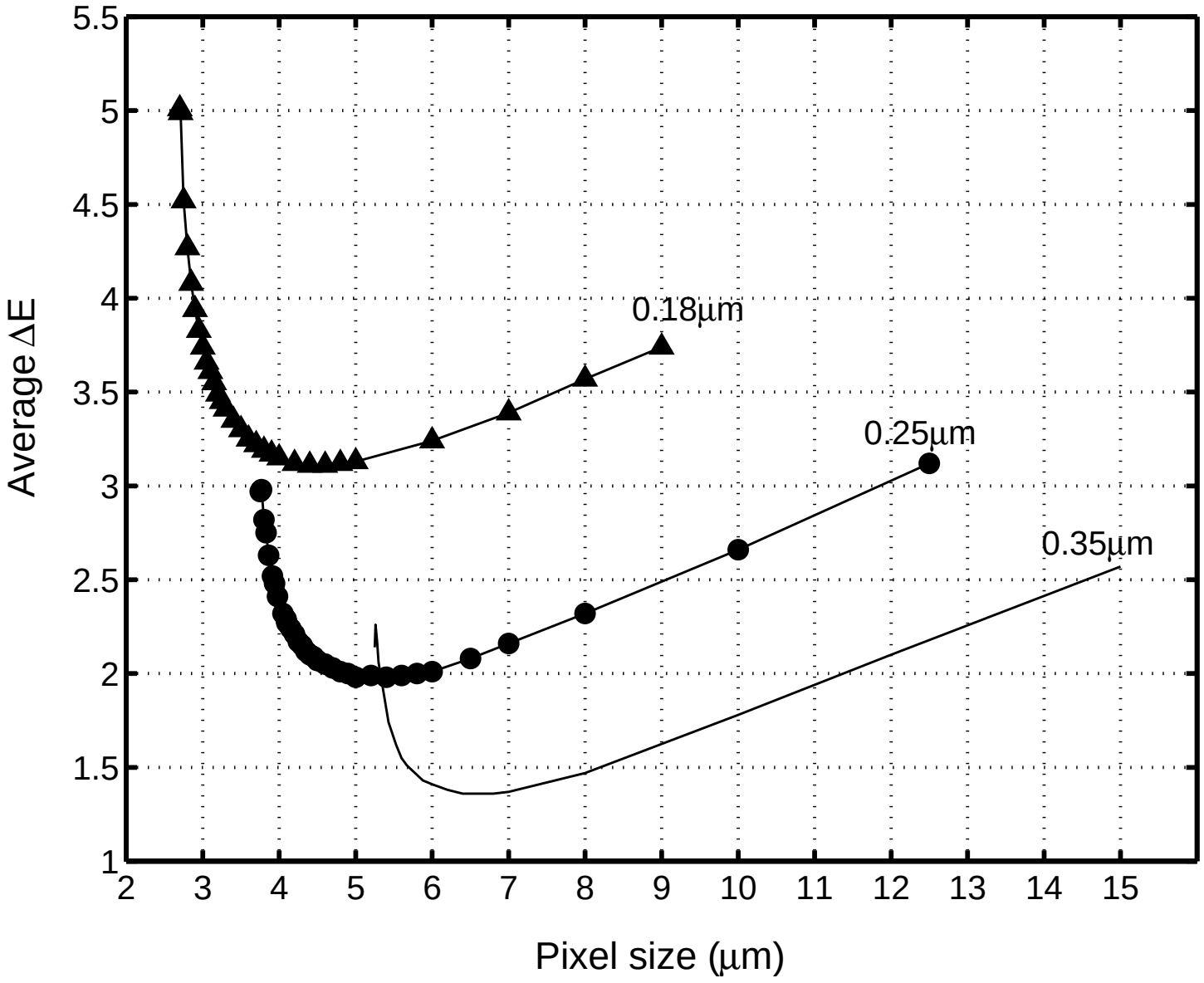
Iso-$\Delta E = 3$ curves for different pixel sizes



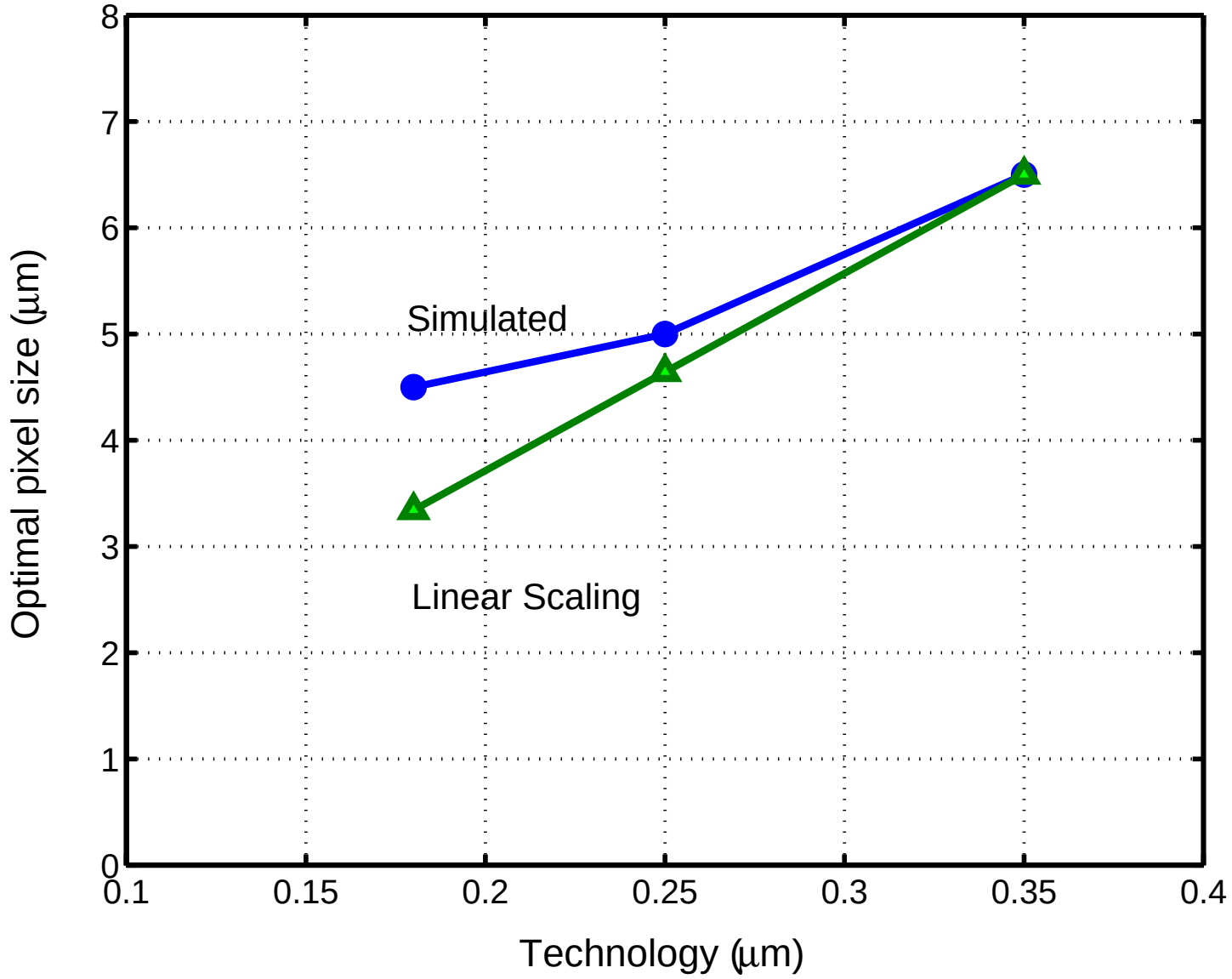
Average ΔE versus pixel size



Effect of Technology Scaling on Pixel Size



Optimal pixel size versus technology



Conclusion

- **Proposed a methodology using a camera simulator, synthetic CSF scenes, and S-CIELAB for selecting the optimal pixel size**
- **Applied the methodology to photodiode APS implemented in CMOS technologies down to 0.18μ**
- **For a 0.35μ process, the optimal pixel size is found to be around 6.5μm with fill factor 30%**
- **The optimal pixel size scales with technology, albeit at slower rate than the technology**