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Unlocking the full potential of mobile video:

HOW MUCH RESOLUTION IS ENOUGH?

(why my 4K picture still looks fake)

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Agenda

- Pixelworks Overview
- How much resolution is enough?
- Impact of video processing
- Motion
- Pixelworks True Clarity™
- Pixelworks Iris

Pixelworks overview

Pure-play
Video Display Processing™
Semiconductor Company

North America
Silicon Valley-Headquarters
Portland

>250 people worldwide

Korea
Seoul

Japan
Tokyo

China
Shanghai
Shenzhen

Taiwan
Taipei
Hsinchu

Founded in 1997
IPO May 2000
NASDAQ: PXLW

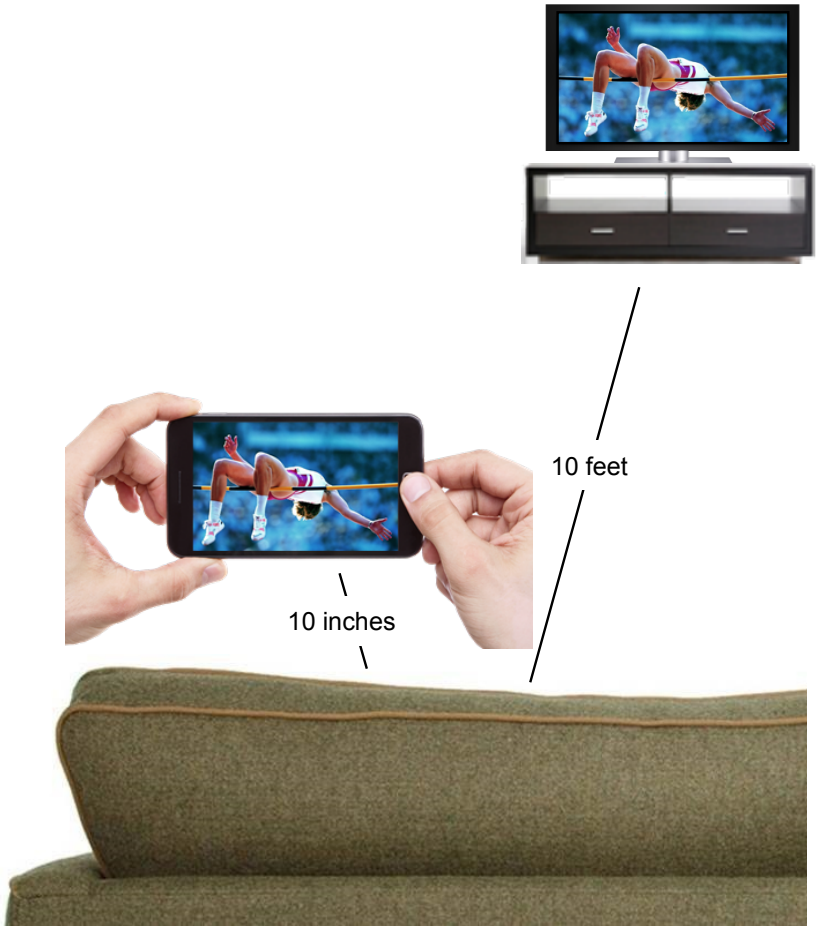
Focused on maximizing the visual experience for all screens

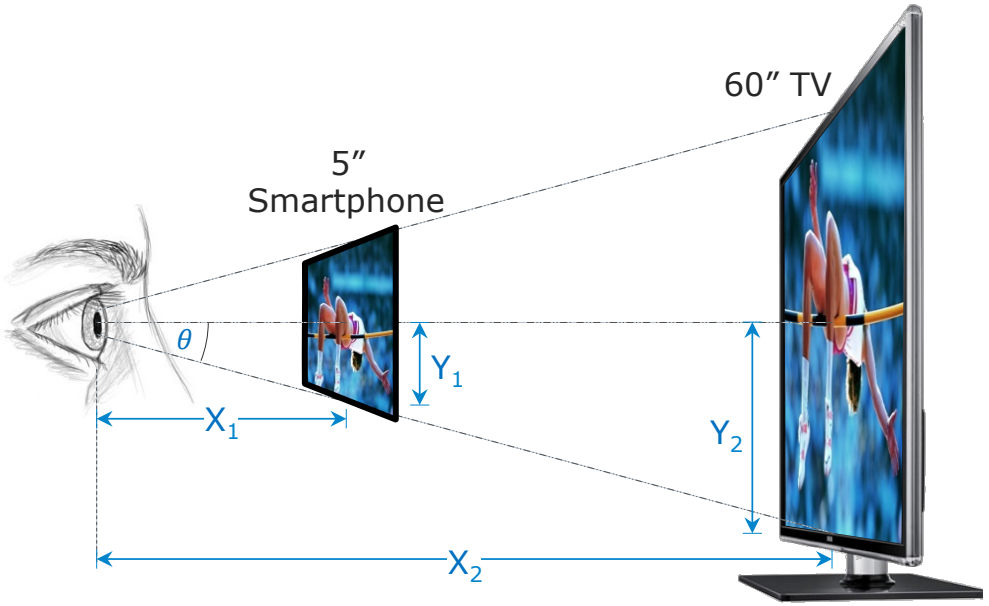
The move to higher resolutions

- The common term ‘Retina’ was coined by Apple in reference to the high resolution display of the iPhone 4 in June 2010
  - iPhone 4 resolution was 326 pixels per inch (ppi)
  - .. or 57 pixels per degree (ppd) viewed at 10”
- Basis was the ‘Snellen Chart’
  - Created by Dr. Hermann Snellen
  - Commonly used for eye tests by opticians
- Snellen criteria
  - With 20/20 vision, details smaller than 60 ppd cannot be perceived
  - However, youths with well corrected vision cab have 20/10
- Improved readability of static images

PPI vs. Viewing Distance

60” TV at 10 feet ***looks the same size as*** 5” smartphone at 10”





$$\tan\theta = Y1/X1 = Y2/X2$$

Device resolutions

	Viewing Distance	Screen Size	Horizontal Resolution	Vertical Resolution	Pixels Per Inch	Pixel Per Degree
iPhone 6 plus	10''	5.5''	1920	1080	401	70
Galaxy 6	10''	5.1''	2560	1440	576	101
HTC one M9	10''	5''	1920	1080	441	77
iPAD	15''	10.1''	1024	768	127	33
iPAD Retina	15''	10.1''	2048	1536	253	66
Kindle Fire HDX	15''	8.9''	2560	1600	339	89
MacBook Pro	20''	13.3''	2560	1600	227	79
Sony Fit 14	20''	14''	1600	900	131	46
MacBook Pro	20''	15.4''	2880	1800	221	77
FHD @ THX dist	67''	56''	1920	1080	39	46
FHD @ SMPTE dist	90''	56''	1920	1080	39	62
FHD @ Man dist	140''	56''	1920	1080	39	96
4K @ THX dist	67''	56''	3840	2160	79	92
4K @ SMPTE dist	90''	56''	3840	2160	79	124

60 ppd, video, and digital displays

- 60 ppd limit is based upon:
  - Average eyesight
  - Black letters or objects on a White background
  - No motion
  - 'Analog' charts

- Video on digital displays:
  - Complex textures
  - Moving
  - Pixels are discrete, quantized, not analog
    - Both at capture and display

Static acuity

- Pixel density (pixels/degree) where you can no longer recognize
  - small objects (eg 5 pixel high letters) or
  - High frequencies (grill pattern) indistinguishable from solid gray

1 arc sec
= 1 pixel

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Fixed pixel static acuity

- 60ppd resolution is good enough
  - Even for 3D
- But what about moving images?
  - What happens as content moves from pixel to pixel?

	Grating	Letter	Point	Vernier*	Stereo*
Accepted Values	2′	5′	1′	10″	5″
60ppd Display	2′	5′	N/A	5″	5″

* Assuming no aliasing at capture or generation

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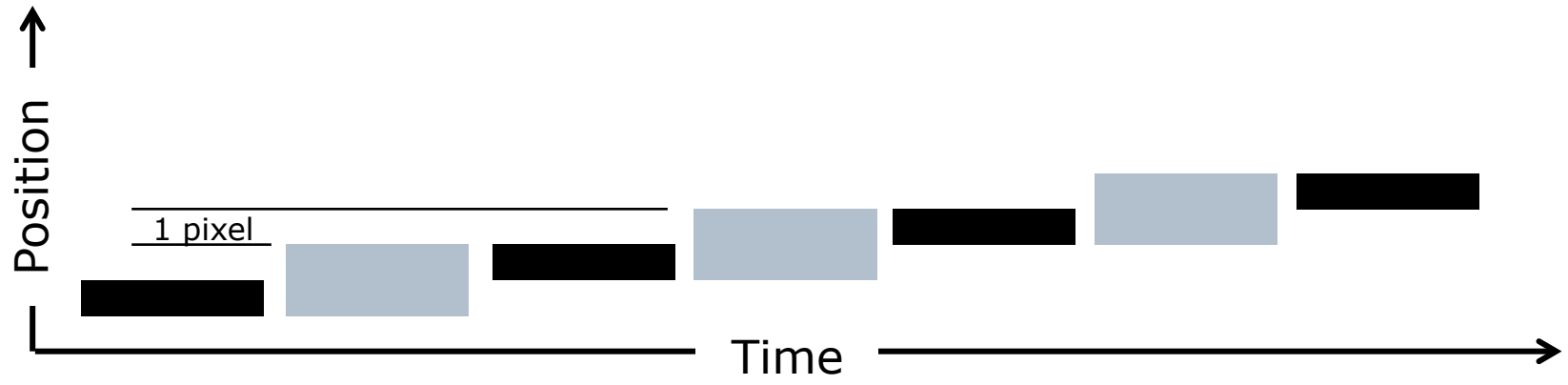
Dynamic acuity

- Pixel density where you can no longer notice changes to content caused by sub pixel motion
  - E.g. does a moving line flicker in brightness or appears to vary in sharpness?



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Moving test images

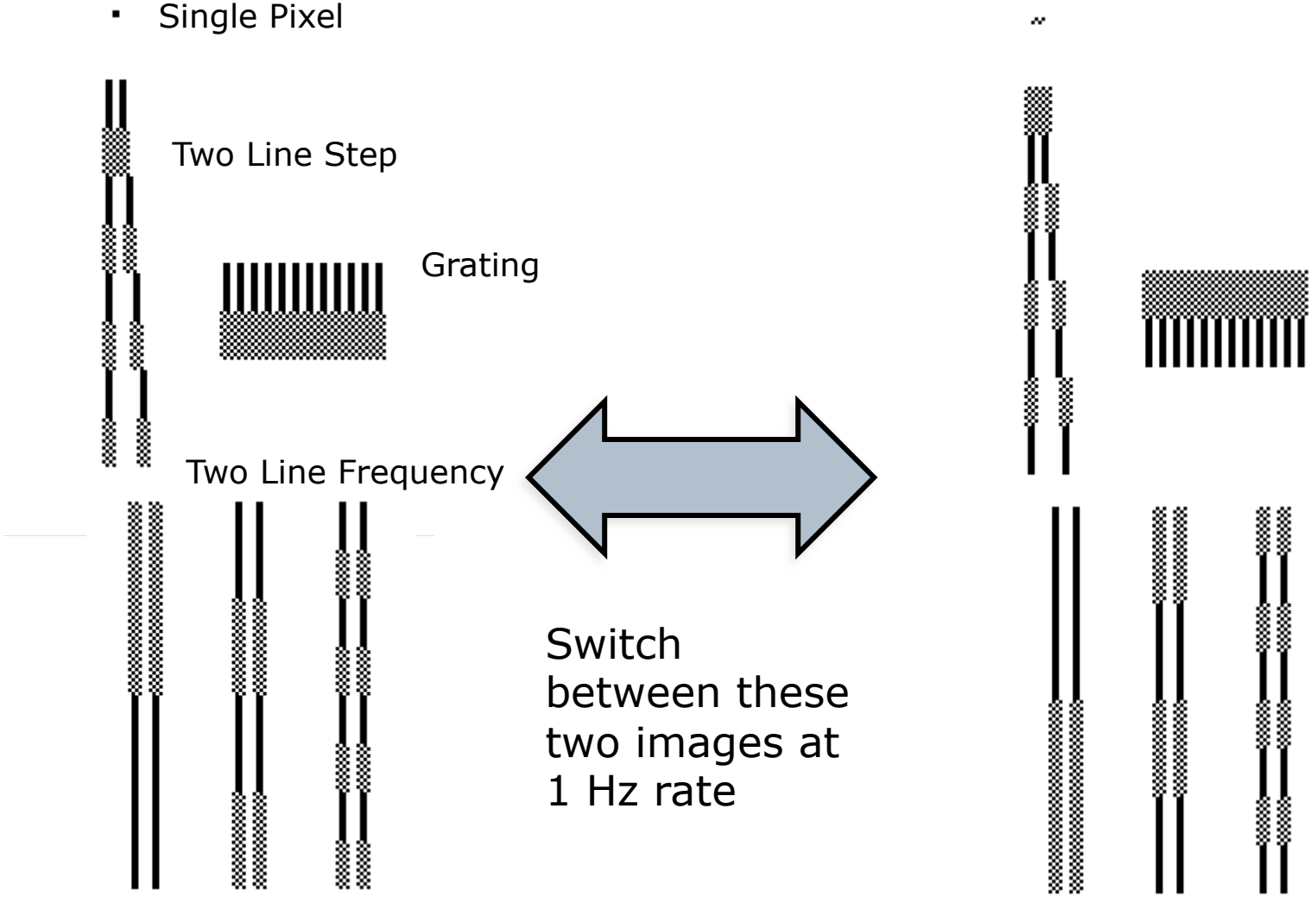
- Sensitivity to temporal frequencies have been measured
- Not directly applicable to moving objects on a display
  - Spatial-Temporal frequency response uses a fixed grating pattern
  - Does not capture impact of sampling and finite size of pixels
- New test pattern required to estimate

Moving video pattern

- Vertical bars with different distance between 1 pixel wide bars
- Half the pattern is the equivalent of being offset ½ a pixel at capture
  - 2 pixels wide at ½ the amplitude
- Task is to recognize which portion is "sharper" when the ½ pixel offset position is changed
  - Pattern doesn't "move" to avoid display interactions
- Frames switched at 1Hz rate
  - Fast frame rates would be better, but LCD response time starts to impact the results
- 2x size was used and half tone used instead of 50% gray to eliminate gamma matching problems

Point, grating & 2 line patterns

- Single Pixel



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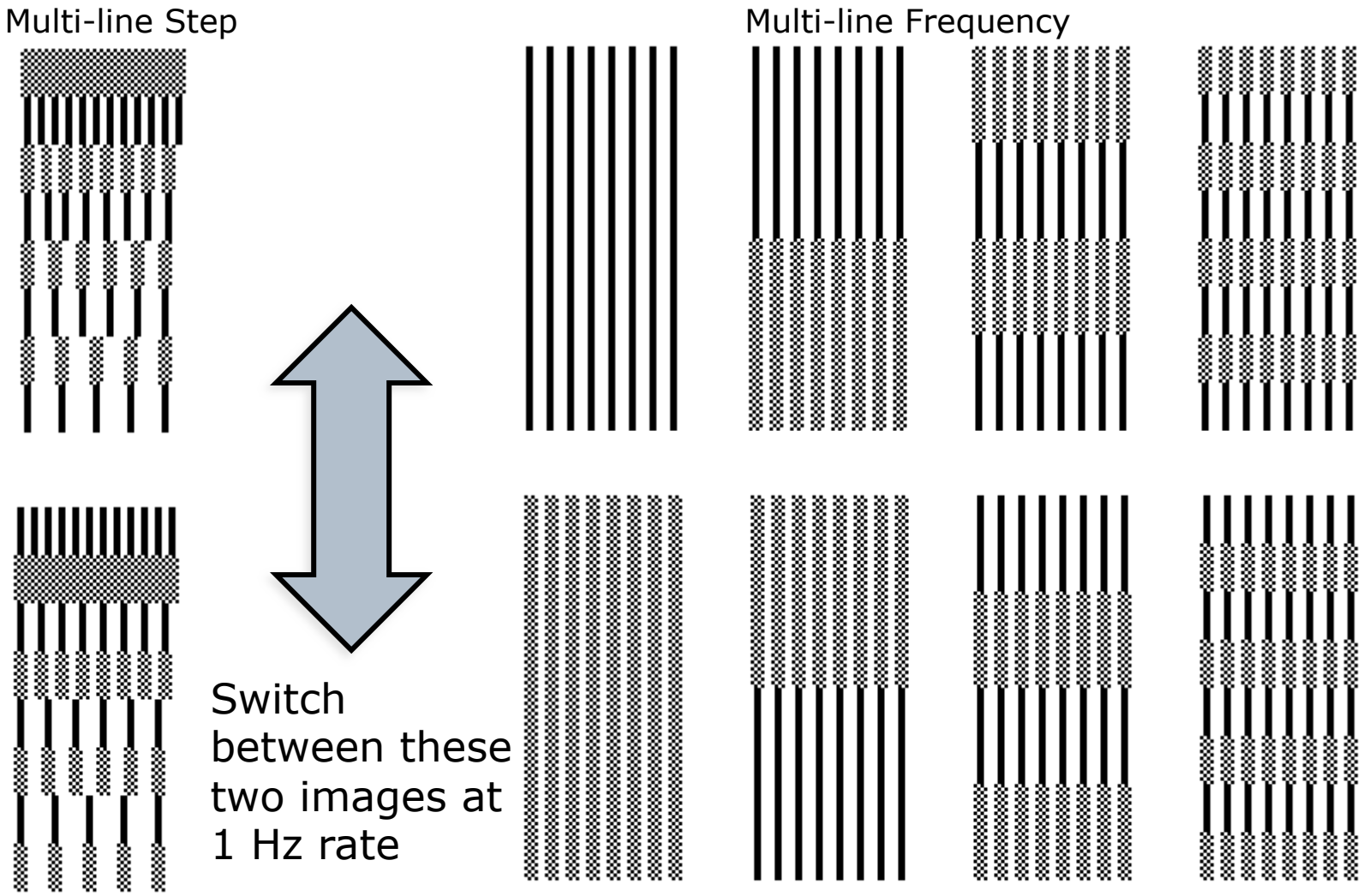
Multi-line acuity test pattern



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Moving video test results

- Acuity depends on size of pattern
  - Two line step ~ letter on eye chart
- Test patterns with 1 pixel on and 2 pixels off between lines are most visible
- 50% increase over 60 ppd resolution observed
- Other studies have shown a noticeable impact at even higher pixel density*

	Average (pixels/deg)	std dev
Single Pixel	48	9.2
Grating	78	7.9
Two Step	61	8.7
Two Line Vert. Freq.	81	15.1
Multi-line Step	88	8.7
Multi-line Vert. Freq.	90	6.1

* http://www.eetasia.com/STATIC/PDF/201312/EEOL_2013JAN03_OPT_TA_01.pdf?SOURCES=DOWNLOAD

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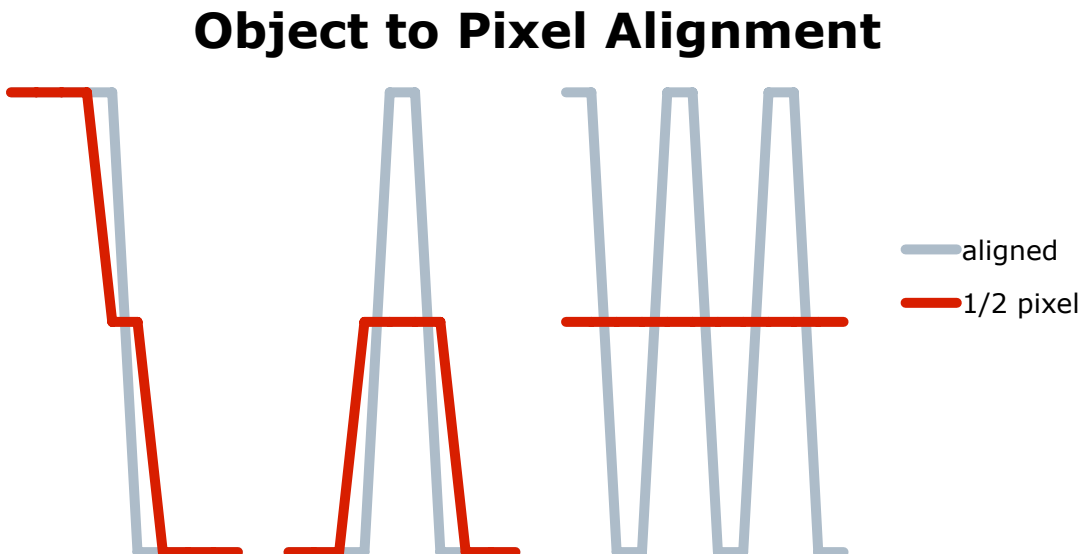
Impact of video processing

- What's the impact on the picture quality as the sampling phase changes
- If you can't see the pixels, the sampling phase shouldn't matter



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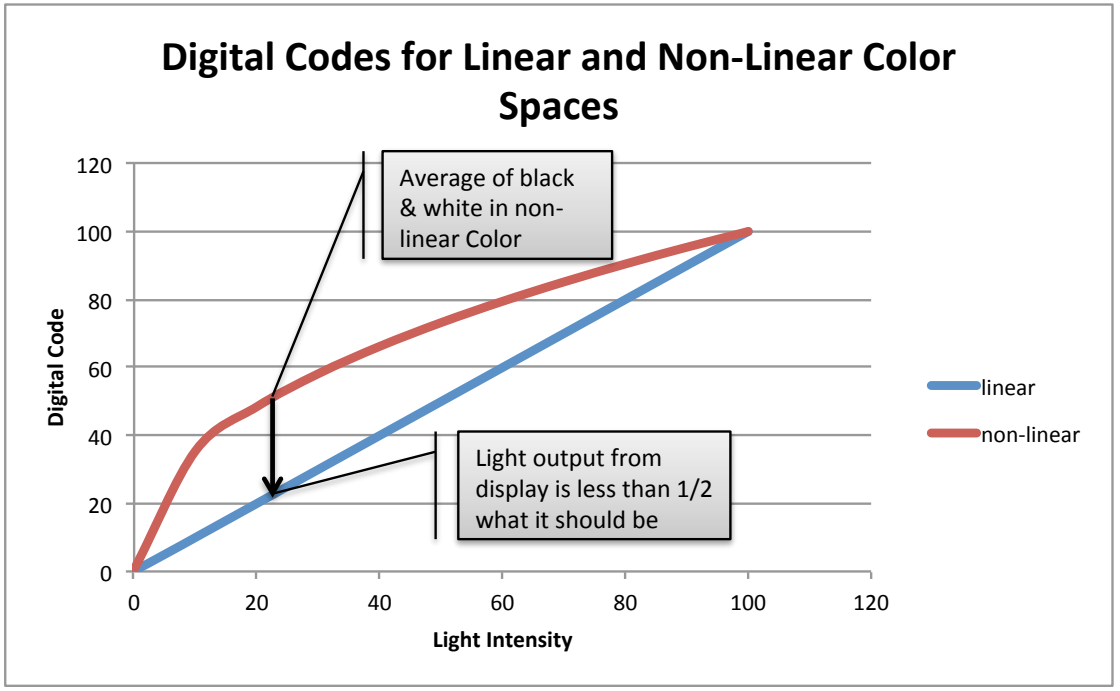
Color space makes a difference

- Averaging two pixels can change the brightness level in non-linear space

- Pixels are averaged in scaling, up or down
- Pixels are averaged in compression
- High frequency details are blurred during capture



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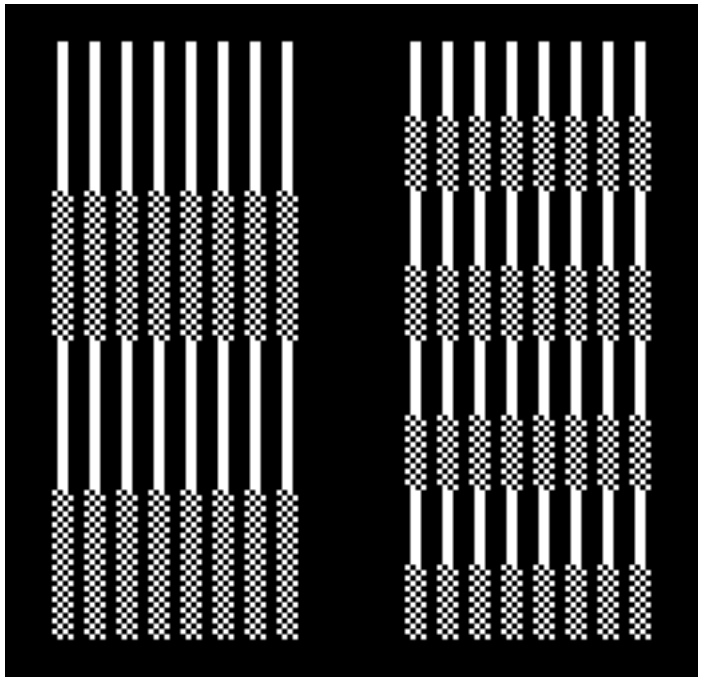
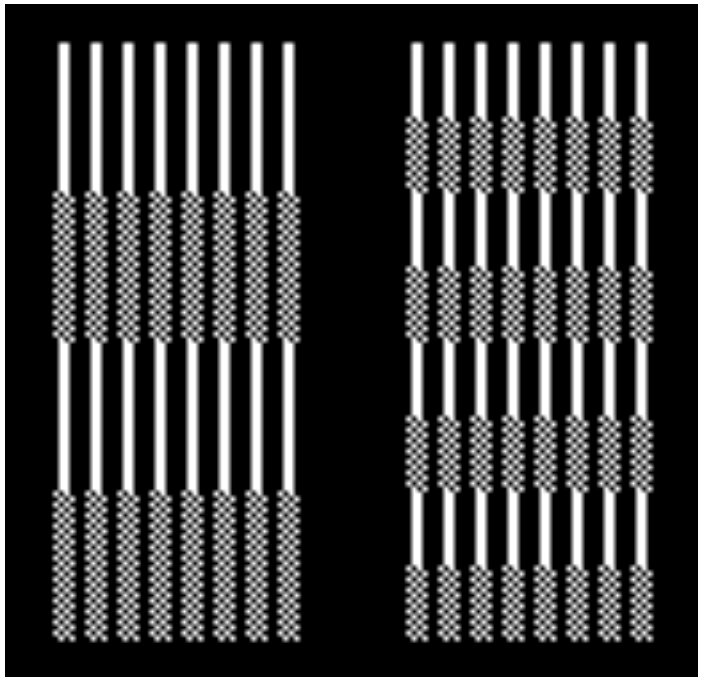
Scaling

- Interpolated pixels are a weighted average of adjacent pixels
  - More detail areas become darker

2x Pixel Duplication



2x Bicubic



Real World Video

- From SNL 40th anniversary
  - Adjacent frames
  - May or may not look different at a distance (squint and blur it out)
  - Compression has blurred out part of the picture
  - https://www.youtube.com/watch?v=ImaYMoTi2g8

Impact of averaging

- Causes larger change in average brightness to areas with more texture

Wow, that picture looks digital

- But most add some peaking to the picture…
  - ImageJ unsharp mask sigma = 1, weight = 0.5

- Peaking causes average picture level changes based detail causing it to look unnatural

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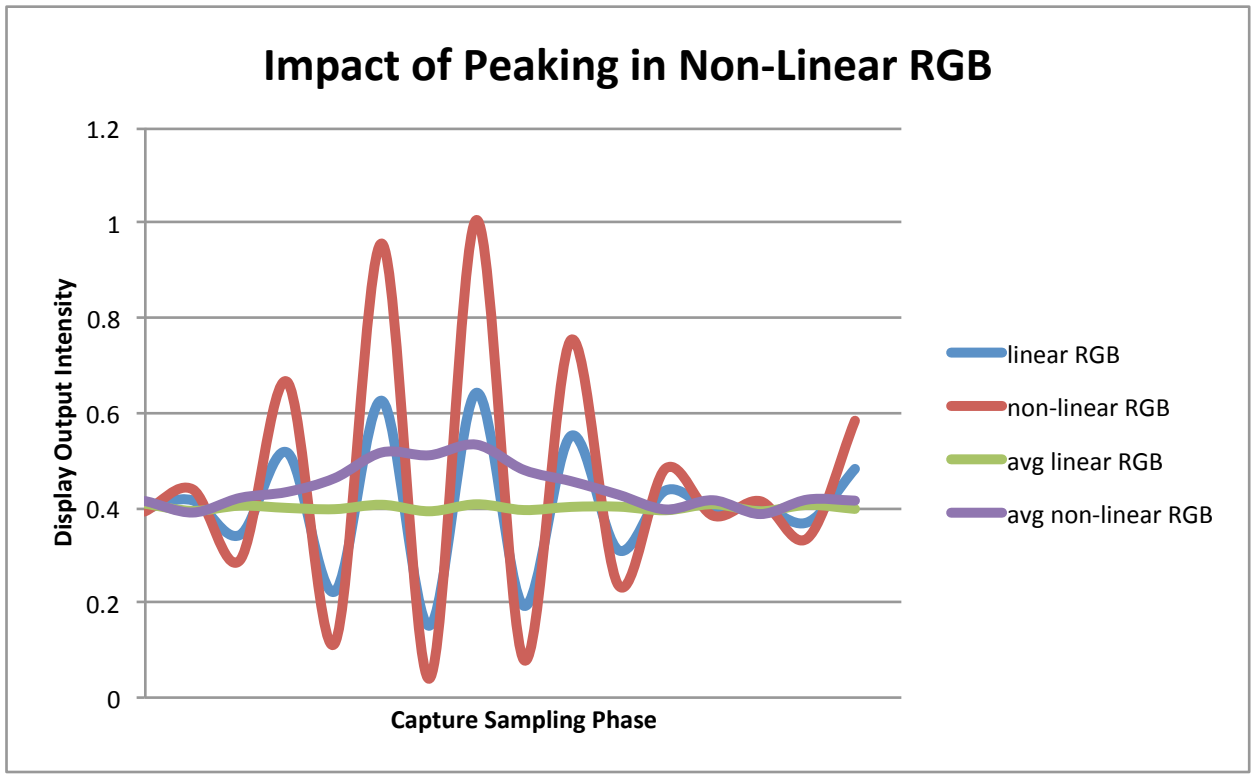
What happened?

- Peaking applied to non-linear RGB data
  - Increases average picture level based on amplitude



Tone mapping

- Changing sampling phase at capture causes amplitude modulation of texture
- If gamma of display doesn't match encoded gamma then flashing artifacts can occur
  - Gamma changed from 2.2 to 2.8
  - Contrast changed to fill dynamic range

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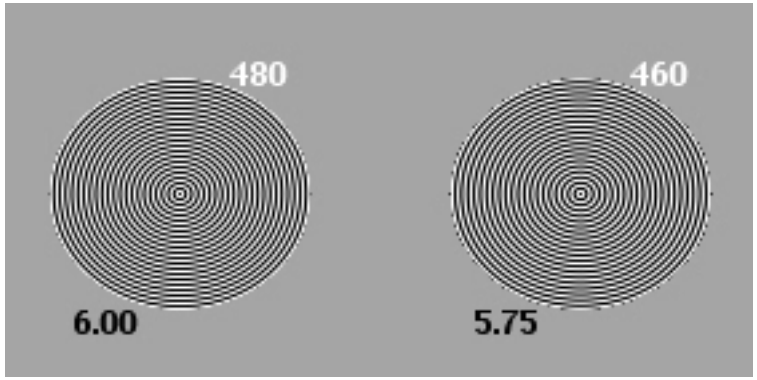
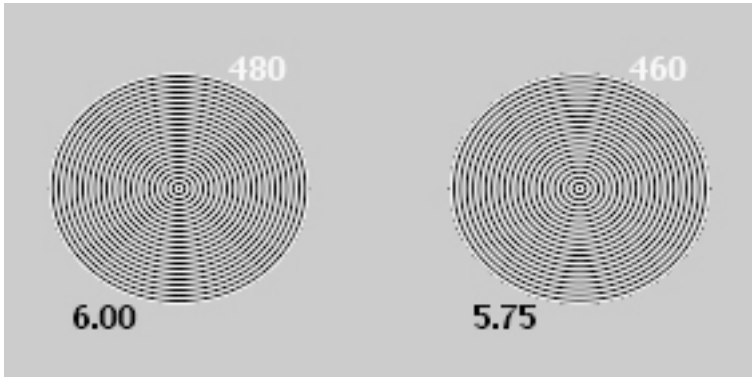
Static Impact of Tone Mapping

- If not done correctly, artifacts are visible at any distance, even on static objects*
- Resolution test pattern from Video Essentials
  - Gamma = 1 is the original
  - Gamma = 2.2 is the corrected version



Gamma = 1

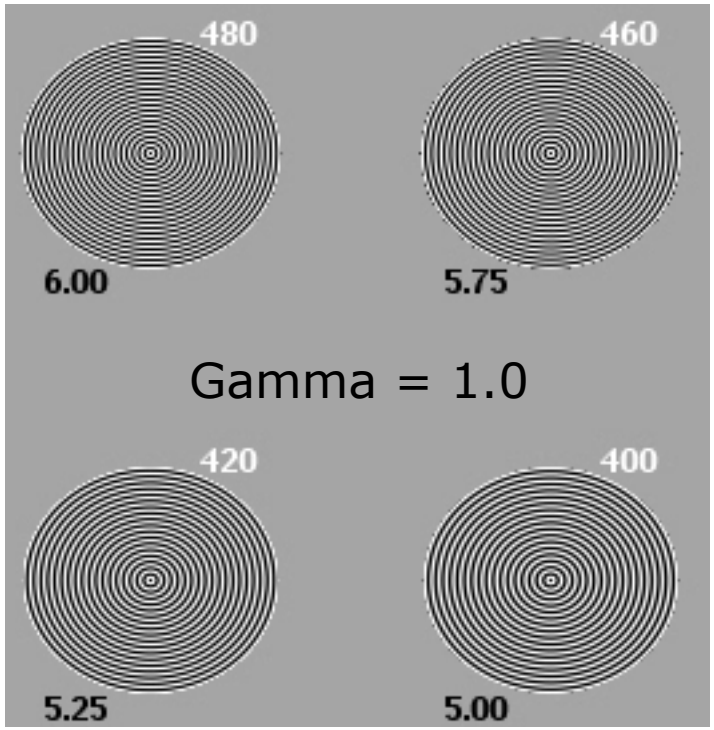


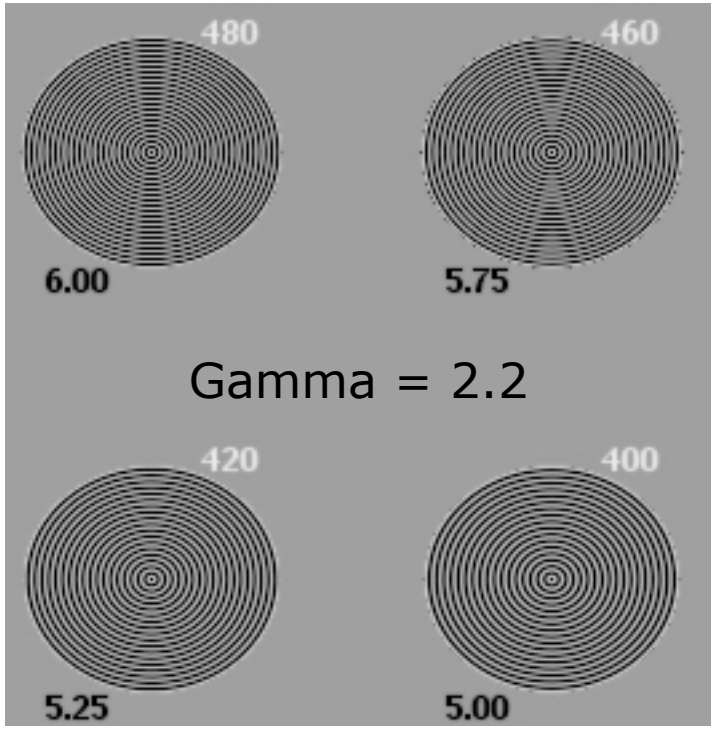
Gamma = 2.2

* Can also be impacted by display and software resulting in incorrect reproduction in this document

Tone mapping

- Tone mapping is required
  - Changing ambient light
  - Dynamic range of the display (e.g. HDR)
- Pixelworks' method avoids the flashing artifact and moiré

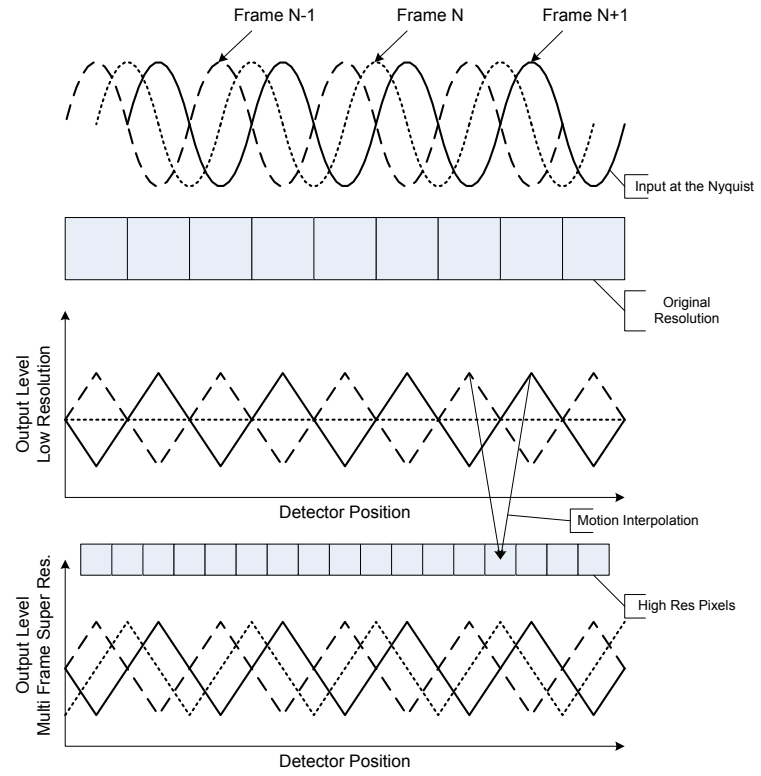




Super resolution

- Single-frame SR the same issues with respect to peaking if done in non-linear space
- Multi-frame SR can reduce flashing by reducing the impact of sampling phase

Multi-Frame Super Resolution



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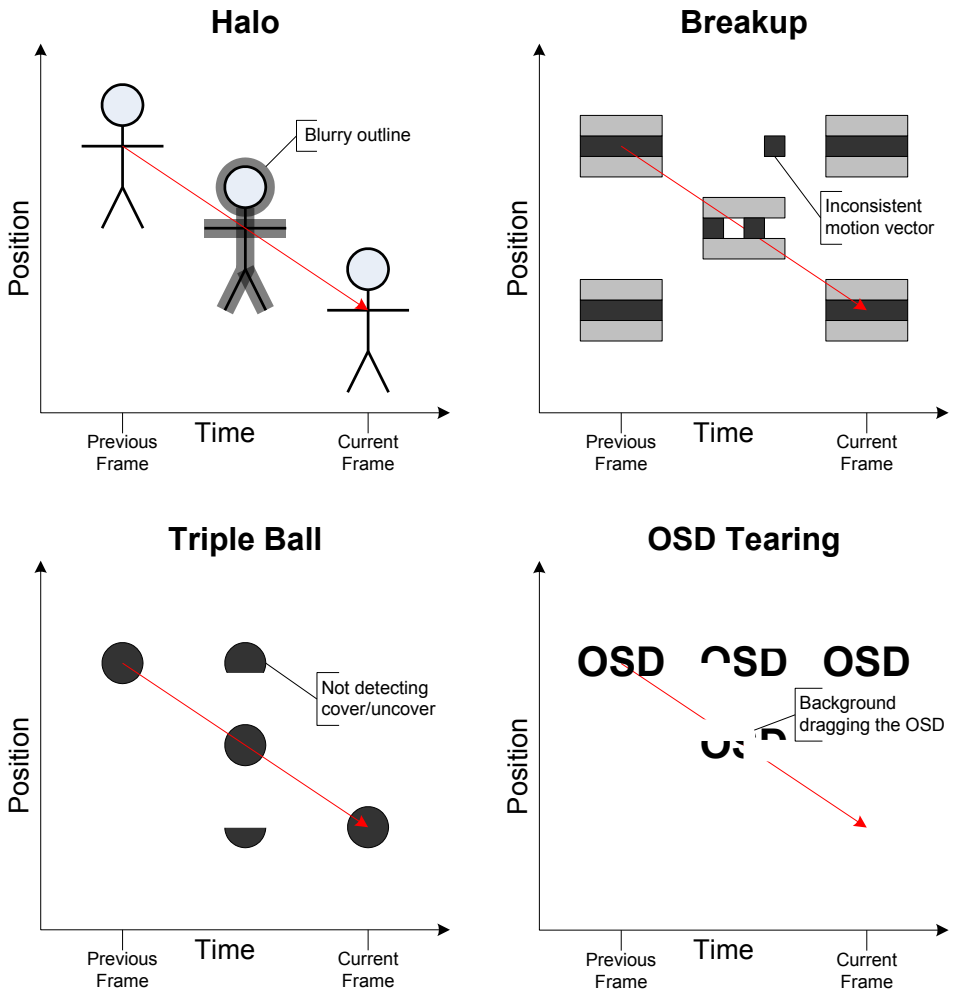
Motion

- Almost all TV's have some form of motion compensated frame rate conversion
- As resolution and contrast ratios increase, judder becomes more noticeable
  - Judder destroys the realism of the picture
  - Actually considered an Artifact by cinematographers
- FRC can also cause artifacts that impact picture quality

Types of FRC artifacts

- Basic Types
  - Halo
  - Breakup
  - Triple Ball
  - OSD Tearing
- Avoiding artifacts by turning off FRC makes judder more noticeable
- Better FRC results in a more natural looking picture



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TV vs. Mobile video experience

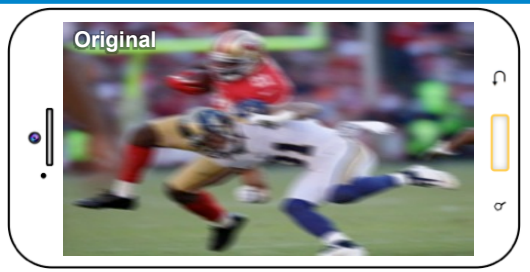
Today's TV Experience

Video Display Processing

- MEMC FRC
- Judder reduction
- Motion blur reduction
- Advanced scaling
- Gamut mapping with 3D LUT
- 6-axis correction
- 2D peaking
- Noise reduction
- Simple scaling
- Basic color management
- Contrast Management
- Backlight control

vs.

Today's Mobile Experience



Video Display Processing

- MEMC FRC
- Judder reduction
- Motion blur reduction
- Advanced scaling
- Gamut mapping with 3D LUT
- 6-axis correction
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- Basic color management
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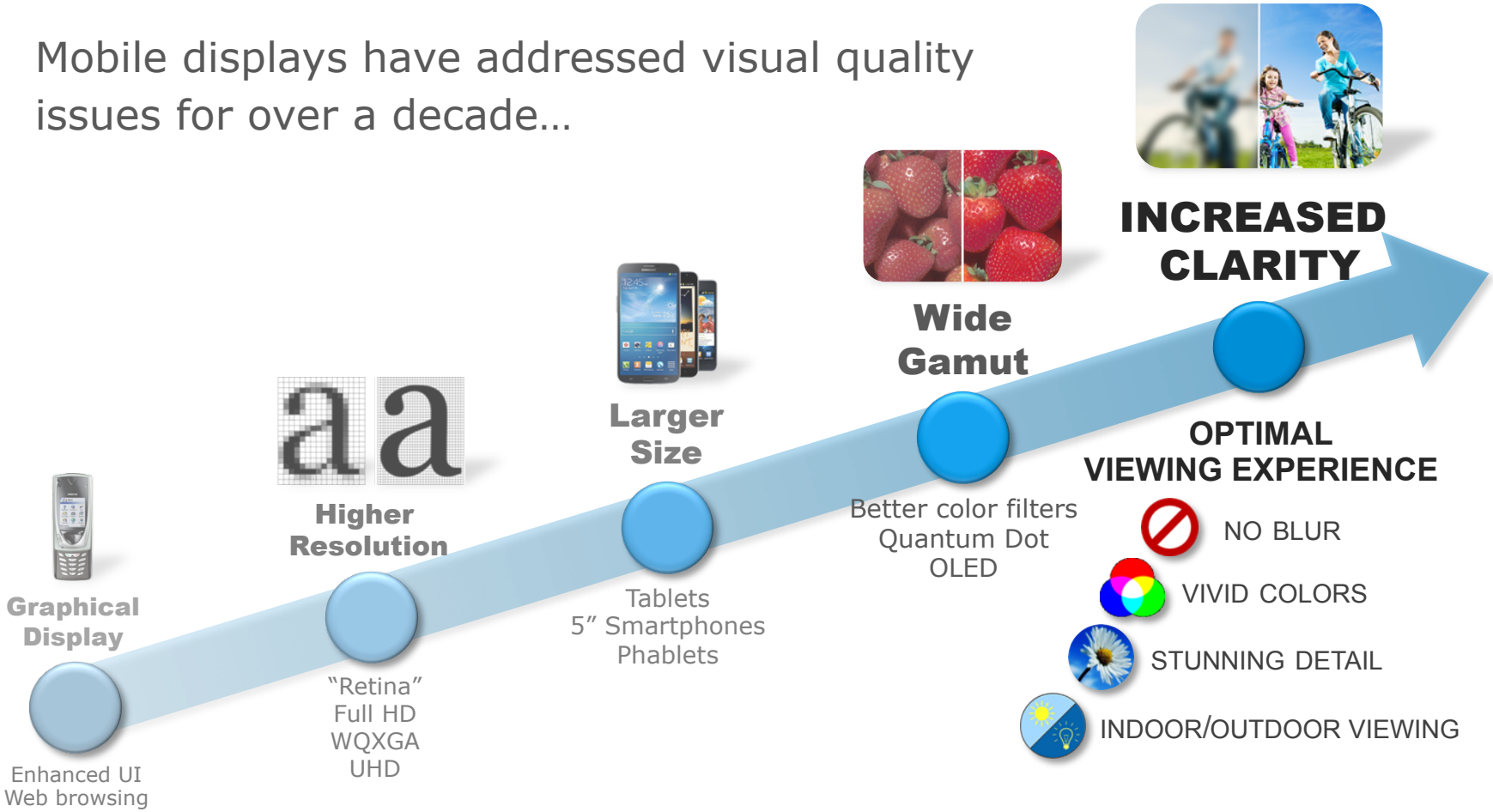
- Backlight control

True Clarity™

Mobile displays have addressed visual quality issues for over a decade…



…the next issue they must address is **CLARITY**

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Pixelworks Iris

Resolution Clarity

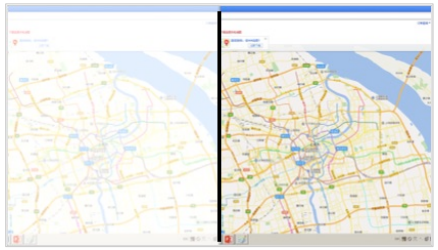
Gaming Clarity

Motion Clarity

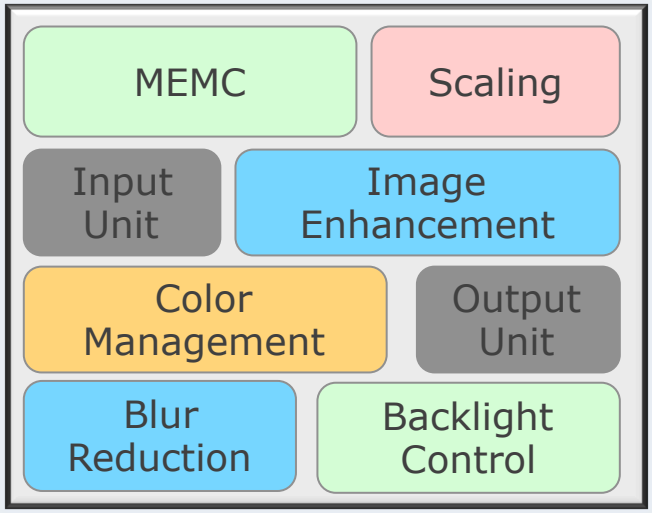
Color Clarity

Detail Clarity

Dynamic Range Clarity



Daylight Clarity



Iris

World's First Mobile Display Processor

Conclusion

- High resolution displays need to be above 90 ppd for average eyesight
- High resolution displays need correct video processing
  - Typical image processing algorithms can still result in a “digital” picture
- The change to HDR content and displays is likely to make the problem worse
- FRC is needed to reduce the impact judder on brighter displays