# Calculating data rate needed for ideal virtual visual display

# Pixels per resolution element

- One cycle of one dimensional spatial information requires _two_ picture elements to describe
- Therefore, one cycle of two dimensional spatial information requires _four_ picture elements of describe
- Pixels per resolution element (PRE) = 4

## instantaneous visual field required

- each eye subtends a visual angle of approximately 180 degrees horiz X 180 degrees vertical
  - E.g. right eye (85 up, 95 down, 110 rt, 60 lf)
- Eyes can look off axis by 40 degrees in horizontal & vertical directions (note: in horizontal direction limited by nose)
- Assuming a static visual field that does not track the eyes, the total visual field that must be represented by the display (DFOV) is approx. 220 X 260 degrees

## Resolution elements for instantaneous visual field

- Limits of human vision ~ 1 minute-of-arc
- Display field-of-view (DFOV) = 220 X 260 sq degrees
  - = (220 X 60) X (290 X 60) sq. minutes-of-arc
  - =2.06E+08 square minutes-of-arc or resolution elements required
- Number of pixels required (NPR) = (DFOV x PRE) = 8.24E+08 pixels

## Accounting for color

- Three primary color channels (red, green, blue) = 3
- Color pixels required (CPR) = NPR X 3
  - = (8.24E+08) X 3
  - =2.471E+09

## Accounting for dynamic range

- Dynamic range (DR) is the range of the brightest brights to the darkest darks of any hue.
- Human can perceive approximate 14-16 $\sqrt{2}$ shades of gray (instantaneously) =
  - (1.414**16)= 255:1 ratio
  - DR Binary representation = $2^n$
  - DR (n=8) = $2^8$ = 256
- Dynamic color bits required (DCBR) = CPR * DR
  - = 2.471E+09 X 8 =1.9768E+10

# Accounting for monocular accommodation

- Accommodation = ability of eyes to focus at various depth planes
  - Depending on the entrance aperture (pupil) of the eye, some of the visual field may be out of focus on the retina
  - The display to each eye must provide for accommodation cues
  - Say sensitivity of accommodation response is 12 depth planes (NDP)
  - NDP of 12 requires $2^4$ = 16 or 4 bits to describe
- Accommodated dynamic color bit rate (ADCBR)
  - ADCBR = DCBR X NDP = 1.9768E+10X 4 =7.907E+10

# Accounting for refresh rate of display

- Must take into account the persistence of the eye
  - Function of luminance & persistence of phosphor on screen
  - Refresh rate is the number of times per unit time the display image is repainted on the screen
  - Typical CRT display refresh = 60-80 Hz
- Required refreshed data rate (RDR)
  - RDR = ADCBR X RDR = 7.907E+10* 80 =6.32586E+12

## Accounting for number of eyes

- Two eyes constitute separate channels to the brain (NE)
- Total data rate required (TDR) = RDR X NE
  - = 6.32586E+12 X 2 =

$\boxed{\text{1.26517E+13 bits/s}}$

## But…

- Accounting for dynamic vision (vernier acuity)
- Positional information
- Head rotation rates
- Eye movement saccades
- Etc.

## Accounting for dynamic head movement

- If assume 100 degrees/sec head rotational rate in azimuth axis (horizontal)
- Then the head would move 6000 minutes of arc per sec.
- In order to stabilize an occluded scene within the one minute of arc limiting acuity of the eye, it would have to updated and refreshed at 6000 times per sec.
- Therefore the head orientation would have to be sampled at 6000 times/sec and used to refresh the display with zero latency (delay)

## Correcting data flow for head movement

- The data flow for a static scene was 1.26517E+13 bits/s.
- Since the sampling/update/refresh rate needs to be 6000/sec instead of 80/sec. The data flow above is corrected by multiplying by 6000/80= 9.49E+14 bits/sec.
- But this answer is for an immersive/occluded virtual presentation (no overlay) so can use minimum separable acuity of 1.0 minute of arc.
- For the superimposition or augmented vision case, the overlay must be 10 times better (or 100 times for a 2 dimensional picture element) or 9.49E+16 bits/sec.