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)
  - $ADCBR = DCBR \times NDP = 1.9768E+10 \times 4 = 7.907E+10$

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)
  - $RDR = ADCBR \times RDR = 7.907E+10 \times 80$
    $= 6.32586E+12$
Accounting for number of eyes

• Two eyes constitute separate channels to the brain (NE)
• Total data rate required (TDR) = RDR \times NE
  \[ = 6.32586 \times 10^{12} \times 2 = \]
  \[1.26517 \times 10^{13}\] 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 $1.26517 \times 10^{13}$ 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 $6000/80=9.49\times10^{14}$ 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 $9.49\times10^{16}$ bits/sec.