5.1.4 Using shadow volumes to generate soft shadows

Another important extension to the shadow volume algorithm is due to Brotman and Badler [BROT84] who enabled soft shadows caused by distributed light sources to be computed. They combined the algorithm with an enhanced Z-buffer to enable umbra/penumbra effects to be generated by a superposition process. Soft shadows are computed by modelling distributed light sources as a series of points, stochastically chosen, each of which has its own shadow volume. Thus a point in the image can be enclosed by a number of shadow volumes and a 'darkness level' computed by linear superposition. An enhanced Z-buffer is used to store an entire record of information, rather than just the depth. In particular a counter is maintained that stores the number of shadow volumes which surround a pixel – the darkness level counter. As each shadow volume is processed, the value of the darkness level counter gives the current number of points in the array approximation to a distributed light source that does not illuminate the pixel. An attenuated intensity is calculated from:

$$I_{att} = \frac{I}{n}(n - dl)$$

where:

I_{att} is the intensity at a pixel due to a distributed light source
I is the total intensity of the light source
n is the number of points in the light source
dl is the darkness level at the pixel

Yet another extension for umbra/penumbra calculation is given by Nishita and Nakamae [NISH85]. This technique eschews the approximation of a distributed

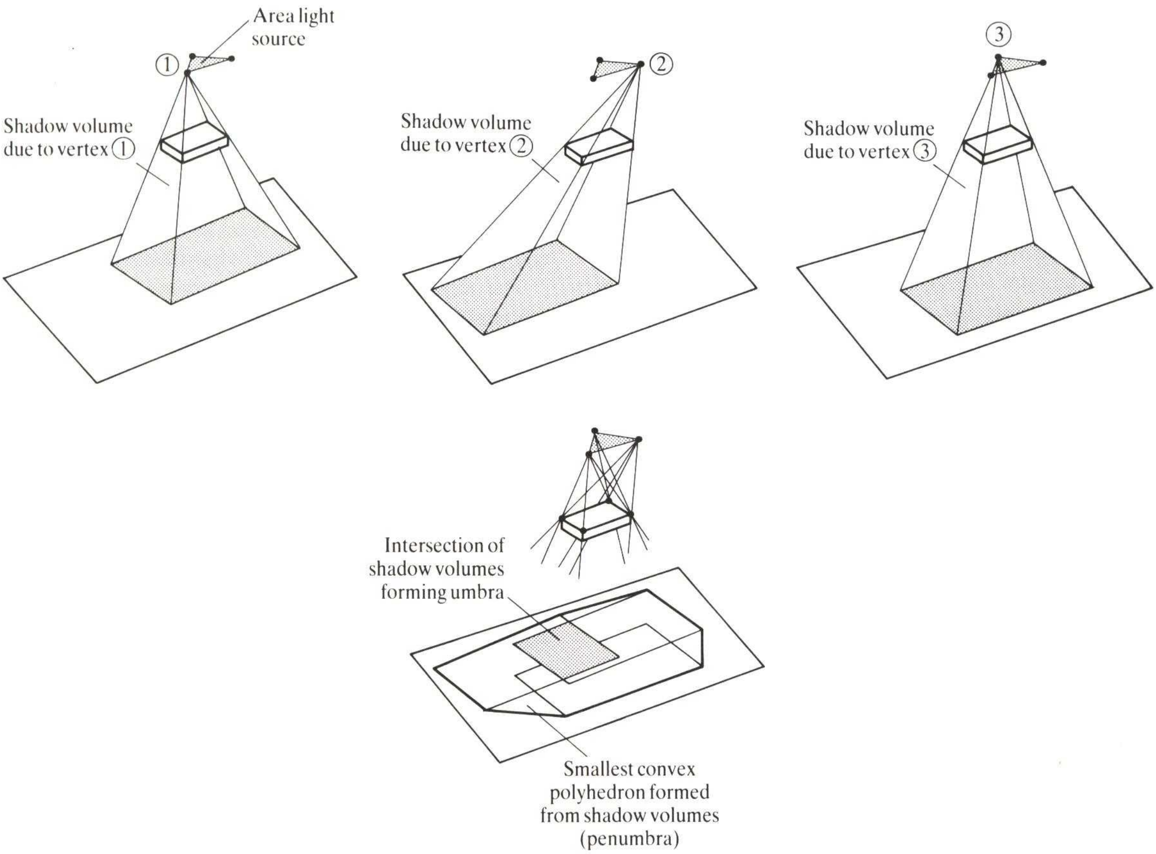

Figure 5.11 Penumbra/umbra derivations due to an area light source (from an illustration in [NISH85]).

light source as an array of points and treats it as an exact geometric entity (with a Lambertian distribution). Each vertex of the source is treated as a point light source that has an associated shadow volume (Figure 5.11). A penumbra and an umbra shadow volume is then computed. The penumbra shadow volume is the smallest convex polyhedron that can be found from the vertex shadow volumes and the umbra shadow volume is the intersection of these volumes.

5.1.5 Using shadow volumes as light volumes

If we invert the sense of the shadow volume, and say that a point on a surface inside the volume is in light and a point outside is in shadow, then the volume becomes a light volume. Apart from this inversion, light volumes differ slightly from shadow volumes in that the light volume, unlike the shadow volume, can itself be rendered in order to simulate the scattering of light by a participating medium usually caused by minute impurities suspended within the medium itself, for example, dust particles in air. The rendering of the light volume is usually done in conjunction with a ray tracer. The section of the ray inside the light volume is calculated and a scattering function is integrated along the illuminated length of this ray. Typically the scattering function, involving inverse square laws and exponential attenuation, is computationally intensive making images of light volumes expensive to produce.

Max [MAX86a] used the shadow volume idea to model the effect of atmospheric illumination and shadows. In particular, he considered the complex case of beams of sunlight passing through the leaves of trees. In order to exploit coherency to its full, Max rejected the traditional horizontal scan line approach, restructuring the rendering to work on radial scan lines in polar coordinates. These radial lines were aligned along the direction of light propagation greatly simplifying the sorting of the shadow polygons. Nishita [NISH87] also took the light volume approach generating both light volumes and shadow volumes off objects falling within the light volumes. Nishita considered light sources with various variable angular intensity distributions of luminosity in order to simulate the effect of spotlights, searchlights and car headlights.

Finally, we refer the reader to a description of another variation of the light volume approach in order to simulate the effect of light, after having been refracted at the surface of water, then being scattered due to impurities in the water - see Section 10.1.