Trieste in the mirror
I looked forward to the ECVP99 meeting in Trieste for many reasons, one of them being the fact that the gulf of Trieste is the stage of the closing scene of a novel by John Berger. His novel *G.* was a winner of Britain’s prestigious Booker Prize and makes great reading. I have often used a quotation from the book as illustration of lectures on ecological optics. Here is the passage (Berger 1972, page 316):

“The sun is low in the sky and the sea is calm. Like a mirror as they say. Only it is not like a mirror. The waves which are scarcely waves, for they come and go in many different directions and their rising and falling is barely perceptible, are made up of innumerable tiny surfaces at variegating angles to one another—of these surfaces those which reflect the sunlight straight into one’s eyes, sparkle with a white light during the instant before their angle, relative to oneself and the sun, shifts and they merge again into the blackish blue of the rest of the sea. Each time the light lasts for no longer than a spark stays bright when shot out from a fire. But as the sea recedes towards the sun, the number of sparkling surfaces multiplies until the sea indeed looks somewhat like a silver mirror. But unlike a mirror it is not still. Its granular surface is in continual agitation. The further away the ricocheting grains, of which the mass become silver and the visibly distinct minority a dark leaden colour, the greater is their apparent speed. Uninterruptedly receding towards the sun, the transmission of its reflections becoming ever faster, the sea neither requires nor recognizes any limit. The horizon is the straight bottom edge of a curtain arbitrarily and suddenly lowered upon a performance. Geneva · Paris · Bonnieux 1965–1971”

It is a touching scene indeed, because it describes the last moments of *G.* who drowns after having been sapped and shoved from the quay by two Italian secret policemen on the day of the declaration of what would later be known as WW-I. The scene takes place near the conference location, the railway tracks near the water at the Canal Grande. It is also interesting from the perspective of ecological optics. I have rarely read a better description of sunlight reflected by a rippled water surface (see figure 1).

*Figure 1. Dense glints. Notice how the individual sparks merge and the sea really looks almost ‘like a mirror’.*
Understandably I looked forward to taking photographs of these natural phenomena on location. For reasons I fail to understand, I guess because there are none, one often experiences striking coincidences. That’s how the mental make-up of many of us is. In this case Richard Gregory’s (1999) invited lecture (see figure 2) was also about mirrors! Thus it seemed apt to do an editorial on mirror reflection with illustrations from ECVP99 and its setting.

From the perspective of modern physics, ‘reflection’ is not a fundamental phenomenon at all. In the reflection by a pane of glass, the incident electromagnetic waves are scattered by the glass molecules—the ‘pane’ being nothing but a cloud of these—and when you describe this statistically, you obtain the reflection of old-fashioned phenomenological optics. The point of this is that the scattering is the fundamental phenomenon, whereas the reflection is only a derived overall property (Born and Wolf 1964). Many materials are rough on a macro-scale and the scattering is not by molecules but by macroscopic irregularities (Beckmann and Spizzichino 1963). In such cases one may be able to resolve the individual scattering events individually. Yet, especially for very oblique incidence, the scattered waves may still combine in such a way as to result in phenomenologically mirror-like properties. For instance, you can easily see the reflected image of a candle flame in a piece of writing paper at grazing incidence. Thus mirrors need not necessarily be polished. Remember that John Berger has “Like a mirror as they say. Only it is not like a mirror”. Indeed.

The solar glitter on a ruffled sea is a magnificent example of scattering by rough surfaces. Because the surface also changes in time, the glints move about nervously and new ones are created, existing ones annihilated at a fast rate. The first one to study the structure of this glitter in detail was Longuett-Higgins (1960) (not Christopher, the one generally known to our readers though, but his brother). He showed that the sparkles are created and annihilated in pairs, and that the members of such a pair flee from each other at infinite speed at the moment of their birth. In many cases, though not necessarily, the members of a pair meet again after perhaps complicated wanderings and approach each other at infinite speed at the moment of their mutual annihilation. Once you know these facts it is great fun to watch the sparkles and try to pick out the pairwise birth and death events. You can actually record their full life stories when
you take photographs with an exposure time longer than the average lifetime of pairs (see figure 3). The best vantage points or sun elevations (fewest glints) are high. Indeed, “as the sea recedes towards the sun, the number of sparkling surfaces multiplies until the sea looks indeed somewhat like a silver mirror”, because near the horizon your effective height vanishes.

For rough surfaces with a simple statistical structure one can work out formulas that describe the glint density as a function of the structure of the surface, the elevation of the sun, and the height of the observer above the surface (Beckmann and Spizzichino 1963). The structure of the surface again depends on the speed of the wind that causes the ruffling of the water surface. These elevations are critical, and you can use that fact to change speckle density as you please, at least when you are easily able to adjust your height. Notice that John Berger has “The sun is low in the sky and the sea is calm”, thus specifying the major parameters. During the ECVP, I took photographs from the waterside and from the balcony at the floor at which the conference was held. Moreover, I watched the scene at various elevations of the sun, that is to say, at various times of day. The “surface of glistening points” (Beckmann and Spizzichino 1963) tends to be limited to a “pillar under the sun”, and the density varies a lot (Minnaert 1992) (see figure 4).

It is not particularly difficult to obtain an intuitive understanding of these phenomena. For a given position of the sun and a given vantage point, at any point in the scene there is only a single orientation of a mirror that would indeed send a glint to the eye. If the local water surface happens to be in that particular orientation, you witness a glint. But, of course, this is highly unlikely, since the surface orientation changes continually. John Berger has “The waves ... are made up of innumerable tiny surfaces at variegating angles to one another”. That is why only a few points actually send glints to the eye at any moment. They happen to be oriented exactly right. Notice that orientations can be parameterised by points on a sphere. Since each location on the sea surface has some orientation, you may map the whole surface of the sea on this parameter sphere. Since most orientations are roughly horizontal—thus with a vertical normal direction—the ‘image’ on the sphere will be concentrated near its north pole. From a continuity argument, you conclude that the image will have to be an incredibly
complicated crumpled mess whose exact nature we may know only in some approximate, statistical sense. You may obtain a good grasp of the nature of this image when you take a crumpled piece of writing paper. It is much smaller than the smooth paper because of a dense nexus of criss-crossing folds. So which points will deliver glints? Well, they need to have a certain orientation. Pick any point on your crumpled paper, thus simulating your fiducial orientation, and pierce the mess with a needle at some point. Then spread out the paper flat on your table. You will typically notice a number of needle holes, and this is a good model for the location of glints. The more crumpled the paper, the larger the number of holes you may expect. When you would have pierced at a location very close to the first one, the needle holes would end up at slightly different places, but they could still be identified. However, when you had pierced at a very different position, you would generally obtain a different number of needle holes. Some thinking reveals that pairs of needle holes have to appear or disappear when you select locations at different sides of a single fold that makes up the crumpling. This is indeed how the pair events come about, a ‘fold’ of the image sweeps over the fiducial orientation.

The water surface is flat on the average; this means that places of convexity must alternate with places of concavity. Convex and concave parts are kept apart by parts that are of a saddle-shape nature (Koenderink 1990). Thus you have an array of convex...
and concave mirrors. This can indeed be seen when you study the images of simple shapes in the water, keeping the optical effects of curved mirrors in mind. The water surface is much like the distorting mirrors (Pollock 1903) that people pay for to look into at country fairs (see figure 5). Good objects are masts of ships or horizontal divisions of different lightness, for instance land and sky (see figure 6).

The local shape of the surface at glints co-determines the intensity of the glints. This can most easily be seen when you intercept the scattered waves at close distance. At the ECVP, I simply watched the reflections of the water surface on the hulls of ferries that were regularly moored next to the conference site (see figure 7). Notice the network of bright curves: these are the loci of images of the sun by the local concave

**Figure 5.** Trieste in the mirror: Reflections of boats in the harbour next to the ECVP conference location. The images of the (straight) masts become serpentine, occasionally they even shed loops.

**Figure 6.** Trieste in the mirror: Reflections on the water of the horizontal division between land (dark) and cloudy sky (bright). Notice how the edge is chopped up, with light patches intruding into the dark area and vice versa.
mirrors on the surface (Minnaert 1992), the so-called 'caustics by reflection'. Imagine yourself near the ship's hull. Clearly you will experience a high intensity when you put your eye exactly on such a caustic curve. Since the water is mobile, the caustic network changes all the time. Thus when you would keep your eye stationary, the caustic curves would cause irregular moments of high intensity when they sweep over your eye. For the case of figure 4 you effectively deal with the 'caustic at infinity'—that is to say, with locally almost planar mirrors.

In general, the eye will not be at a caustic—that is to say, the 'focus' will be at some arbitrary point. Since the focus is an image of the sun, it acts as a local point source. The intensity you experience will be proportional to the strength of the source and inversely proportional to the square of its distance. The strength depends on the 'size' of the local mirror and thus on the area over which the surface approximates the ideal mirror closely enough. It is the change of shape with position that limits the size of the local mirrors.

Why do the glints collect to form a “pillar under the sun”? This has to do with the fact that “their rising and falling is barely perceptible”—that is to say, the range of orientations is rather limited. It is only in the forward direction that you have any chance to find suitably oriented local mirrors (Pollock 1903; Minnaert 1992). Notice that the pillar under the sun is not a feature like the white lines painted on a motorway; for instance, it doesn't follow the rules of perspective the way such painted lines do. Consider an example: You will find that—when you hold your camera level—the pillar is always vertical in the photograph whether it happens to be situated in the centre or at the edge of the picture. You might find it amusing to spot paintings which 'correct' this apparently faulty perspective. Examples taken from classical Western painting are certain harbour scenes by Claude. Thus these particular 'laws of ecological optics' are apparently not part of our mental make-up or 'internalised regularities'. We have to learn them in order to perceive right, as Claude—no doubt a keen observer of nature—evidently did not. Indeed, I doubt whether anyone but John Ruskin (1873), who rivals Leonardo (Kemp 1989) in his keen eye for optical phenomena, noticed Claude's nonveridical pillars under the sun before.

Once you have become an accomplished glint watcher you should proceed to detect glints on many materials such as leathers, wood, many cloths or human skin, especially

![Figure 7. Caustics by reflection on a ferry's hull. Notice that the water once again reflects these caustics, thus causing doubly scattered light waves.](image-url)
wet or greasy. All the effects noted here can easily be spotted (Jacobs 1988). The nature of the reflection, its extent and granularity, reveals the microstructure of the surface. It is one of the signs by which we easily distinguish apples from oranges, or the weathered skin of old sailors from that of babies or young women, even without resolving the actual texture. For instance, you can easily change an apple into an orange—or a lemon, depending on the colour—in a painting by simply putting a sprinkling of white dots at the right places (Jacobs 1988).

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