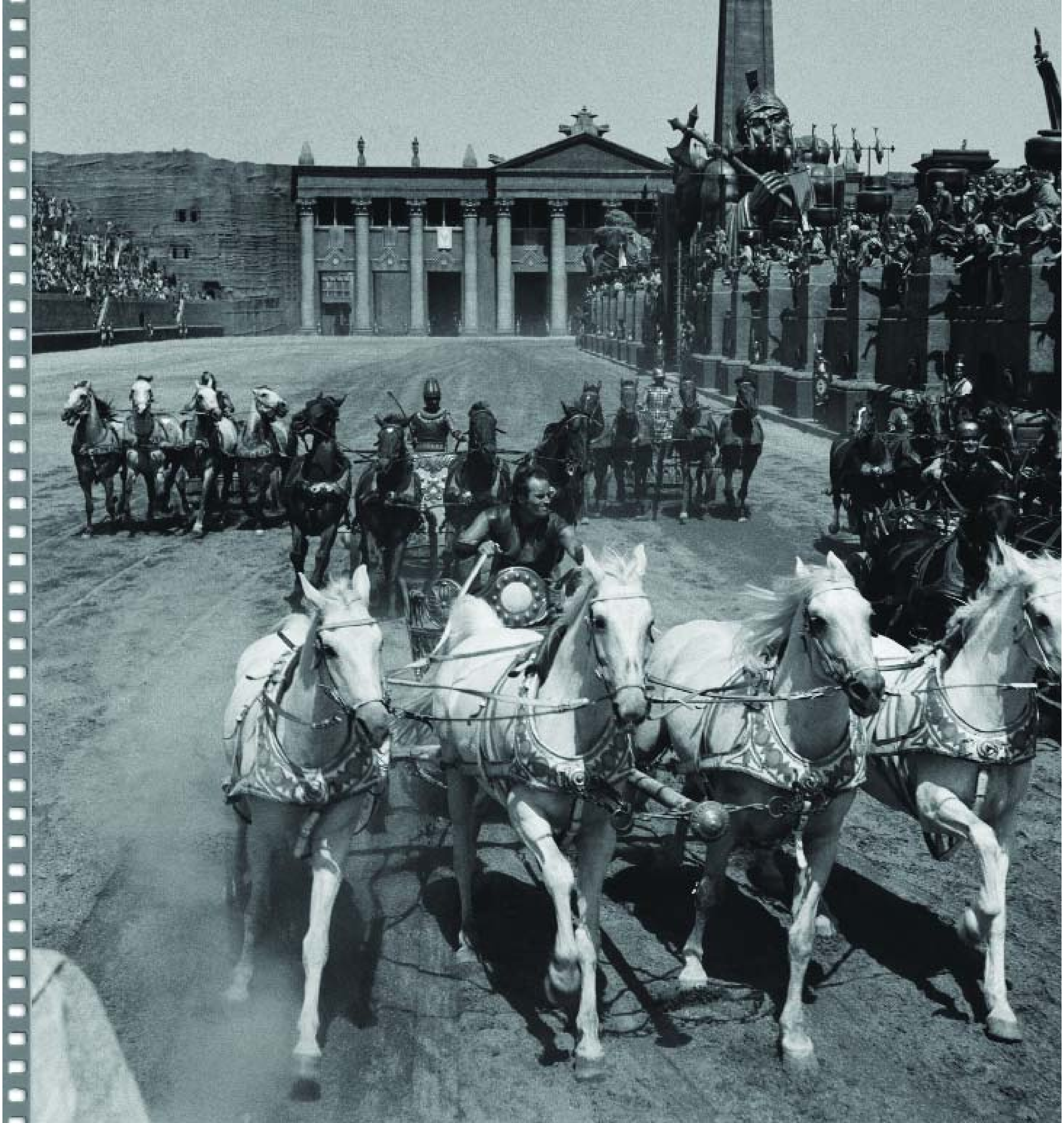

Lenses In Cinematography

Iain A. Neil

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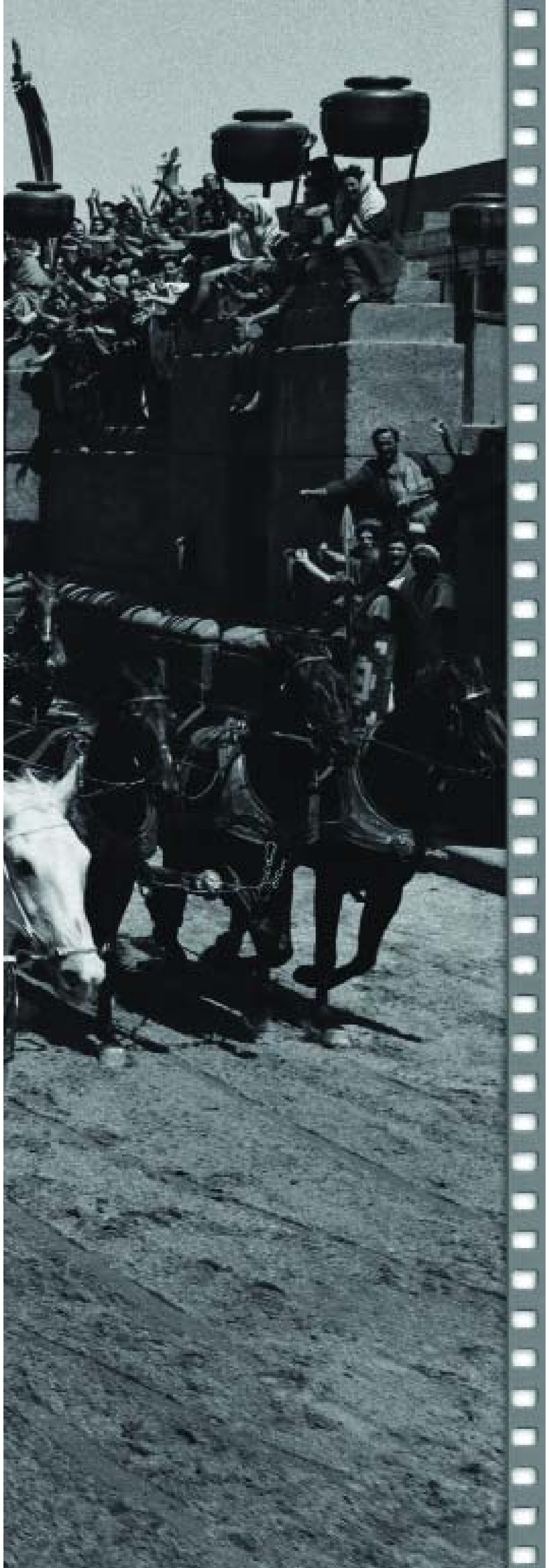

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Actor Charlton Heston drives a chariot down the streets of Rome in the Camera 65/Ultra Panavision film *Ben Hur*, released by MGM in 1959. The film was shot by Robert Surtees of the American Society of Cinematographers (ASC) using early Panavision anamorphic prototype lenses designed to eliminate the lens-induced aberration known as "anamorphic mumps." The famous chariot race sequence took three months to film.

The performance characteristics of specific types of cinematographic lenses are appreciated by movie industry professionals. The development and application of modern "cine" lenses—which comprise high technology glasses, coatings and mechanical components and can house up to 25 elements—are heavily dependent on computers. The author, the recipient of 11 Academy Awards for Technical Achievement and other scientific and movie industry honors, describes the performance characteristics—technical, artistic and aesthetic—of a number of "cine" lenses via movie examples that outline their purpose, versatility and limitations.

All past and present camera systems rely on the lens, the image-forming device that predates film and will probably outlast current silicon electronics. Yet the cinematographic, or "cine" lens, with its centuries of history, is generally not well understood. Indeed, the pedigrees of contemporary cine lenses are usually descriptive titles that are meaningless to anyone but the lens designer and that have become, in essence, a marketing tool. In a similar vein, "techno" terms—such as modulation transfer function (MTF), which is common in describing military lenses, electronic and optical system performance—are now used to describe the overall performance of cine lenses. Yet MTF is only one criteria for measuring cine lens performance and its real value lies in the lens design and manufacturing domain. In the field of cinematography, lens performance characteristics—technical, artistic, aesthetic—are well known and appreciated, particularly by experienced professionals.

Characteristics of cine lenses

All cine lenses may be classified as objective lenses which collect visible light from a real object in front of the lens (anywhere from close to the lens to infinity distance) and form a real image of the light somewhere after the lens. Lens systems may be refractive, reflective or a combination of the two. Systems that are either partly or totally reflective—quite popular in long focal length, still photography lenses and astronomical telescopes because of their compactness and efficiency at collecting light—are uncommon in cine lenses for one major reason. A reflective or partly reflective system (with coaxial optics) depends on at least two mirrors to change or reverse direction of the light from object space before it reaches a real image. To achieve this result, such an optical system, with mirrors aligned on a common optical axis, must involve a central obscuration so that, in the central portion of light beams, light is vignetted and not transmitted to the final image. At first, this condition might not seem important, but the aesthetic result can be quite unacceptable. Imagine for example a night scene with two street lamps, one at six feet and in focus, one at 20 feet and considerably out of focus. With a refractive lens system, the result is as expected: one lamp sharp and one soft with a blurred image. However, in the case of a reflective or partly reflective system, one lamp is sharp and the other is soft, but in the form of a blurred, donut-shaped image that does not look realistic (see Fig. 1). Sometimes such a result is visually acceptable, even appealing. However, for the majority of filming situations, this effect of reflective (or catadioptric) lens systems makes them unappealing to cinematographers.

Glasses are the predominant refractive medium or substrate, mainly because their optical and mechanical characteristics are superior and consistently precise, a factor that is extremely important in the field of cinematography, where lens-performance requirements are very demanding. For this reason, cine lenses are almost always made of glass elements, although occasionally (e.g., long focal length telephoto Canon primes) they are made of calcium fluoride.

History of cine lenses

In the "old days," say the first half of the 20th century, all lens designs had to be kept simple, employing up to five lens elements or five doublet components. This was because anti-reflection coatings did not exist and a great deal of light was lost through the lens. For example, a 50 mm f2.8 focal length lens containing five single lens elements and 10 refractive surfaces would typically experience a 5 percent loss per surface (i.e., 95 percent transmission or 0.95 normalized transmission), meaning that, for 10 surfaces, the overall transmission might be 60 percent (i.e., 0.95^{10}). Since T-stop = f-stop ÷ √(normalized transmission), this 50 mm f2.8 lens would have a T-stop = 3.6. An f2.8 lens working at T3.6 does not sound too bad, but consider a 10 or even 20 element f2.8 lens with corresponding T-stops of 4.7 and 7.8!

Fortunately, cine lenses of this era had one major advantage over later lenses: the film cameras they were attached to were predominantly non-reflex. The lens could therefore be placed quite close to the film, which made the lens design task easier and the lenses less complicated. It is interesting to note that in the case of old wide angle, short focal length lenses, the back focal length was normally smaller than the focal length, which would make such lenses incompatible with modern reflex cameras. And since all the light that is lost has to go somewhere, even in the best lens designs some of it would, by successive lens element surface reflections, head toward the film, causing ghosting and/or veiling glare. To aggravate matters, these slow lenses of T3.6–T5.6 full aperture, coupled with the insensitivity of film stock, say ASA 50, meant that huge amounts of light were required to illuminate a scene: good for lighting suppliers but trouble for cinematographers. Still, the early cinematographers benefited from one big advantage: a larger depth of field than cinematographers are accustomed to now. So these early cine lenses got close to the film, were necessarily simple in construction (no coatings), and because of their lack of speed (aperture) performed well (because of good aberration correction at their full aperture, albeit with careful lighting).

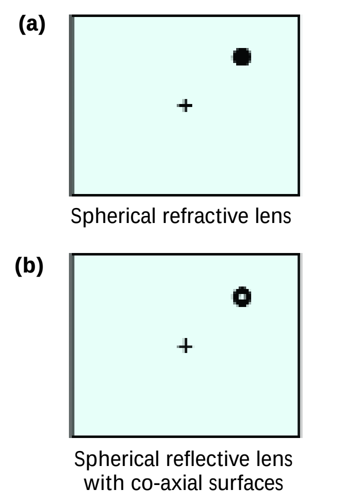

Figure 1. With a refractive lens system (a), the result is as expected: one lamp sharp and one soft with a blurred image. In the case of a reflective or partly reflective system (b), one lamp is sharp and the other is soft, but in the form of a blurred, donut-shaped image that does not look normal or realistic. (*Only the blurred images are shown here*.)

Of course, modern cine cameras are virtually all reflex because of the need to provide continuous line-of-sight, through-the-lens viewing to the camera operator. What this means is that the rear element of the lens must be located some distance in front of the film as predicated by the reflex mirror design of the camera. Fortunately, by the 1950s the transmission problem had been remedied by the introduction of thin film technology, which ushered in anti-reflection coatings. More complex lens configurations, containing anywhere from 10 to 20 elements, were now considered practical, and the fixed focal length lens (or prime) suddenly had a partner: the zoom lens. Both lens types still had to deal with a large back focal length distance, but this issue was now easily managed because complex lens arrangements were feasible. Even those troublesome wide angle lenses, now sitting at a film distance mostly exceeding their focal lengths, could be relatively easily constructed.

Even though post-1950s cine lenses were substantially better than their predecessors, an additional demand had been placed on them: faster speed, i.e., greater aperture. Although film stock sensitivity had gradually improved, the number of low-light filming situations had increased, a factor which made necessary cine lenses of full aperture T1.3–T1.4 and sometimes T1.0 or less. Fortunately, glass technology started to improve substantially in the 1960s. The first major effect on cine lenses was the realization that fast-aperture lenses were now possible thanks to the advent of high refractive index glasses of various dispersions. However, aberration correction was still limited, especially at T1.3–T1.9 apertures. By the early 1980s, glass technology had improved so much that aberration correction, even in lenses of T1.9 full aperture and, to a lesser extent, T1.3, was approaching the maximum theoretical limit, even after allowing for all other lens design constraints such as length, diameter, weight and cost.

Perhaps more significantly, zoom lenses could be designed to perform as well as prime lenses, although they were still of greater size, weight and cost. Of course, it is easy to draw comparisons with the still photography market, but this would be misleading because its performance requirements are normally inferior to those of the cine market. Nevertheless, advances in the still photography lens market are a good indication of where cine lenses might go. One important area of distinction between still and cine lenses is mechanical design. Whereas still lenses are intended for a consumer market, cine lenses address an industrial market. The mechanical requirements placed on the latter dictate greater accuracy and reliability, as well as higher cost. Precision lead screws (or threaded, mated parts) have for some time been the norm in prime cine lenses, but they are slowly being supplanted by nonlinear cams and linear-bearing technology in some primes and many zooms. Zooms are the main benefactor of linear-bearing technology because they have at least two moving zoom groups and one focus group, all of high optical power requiring precision alignment and maintenance. Just as in the still photography market, the cost of all the technologies described means that in the field of cine lenses, zooms are likely to eventually dominate over primes, except in extreme applications such as very wide angle, fisheye or long focal length lenses.

Another optical technology in its infancy is the design and manufacture of cine lenses that use aspherical surfaces. These axially rotational, symmetrical, non-spherical surfaces, which have been used in infrared waveband military systems (e.g., thermal imagers) since the 1970s, are only now being introduced in cine lenses.

Manufacturing, testing and assembly techniques have improved to the extent that several cine zoom lenses employing one aspherical surface, and even one cine zoom lens employing two aspherical surfaces, are now available. The aspheric technology used in cine lenses should not be confused with that used in inferior performance still photography lenses. Extremely high precision, ground and polished glass aspherical surfaces are needed for cine lenses to achieve the high performance imaging expected, while the much advertised, aspherically surfaced still photography lenses depend essentially on low quality, low cost, molded and replicated lens elements. Many other optical technologies that are relevant to cine lenses could be described, such as gradient index glasses, diffractive or binary surfaces and holographic elements, but for the time being aspherical surface technology is the most promising. Figure 2 illustrates several modern cine lens optical designs.

The modern cine lens, be it prime or zoom, houses up to 25 lens elements and comprises high technology glasses, coatings and mechanical components. Focal lengths from 6 mm to 1,000 mm at working apertures from about T1-32 are available. All of these lenses fit onto reflex camera systems and generally perform admirably given the physical constraints (length, diameter, weight) and cost constraints imposed on their designs. Derivatives of these technology driven lenses are available today in many forms.

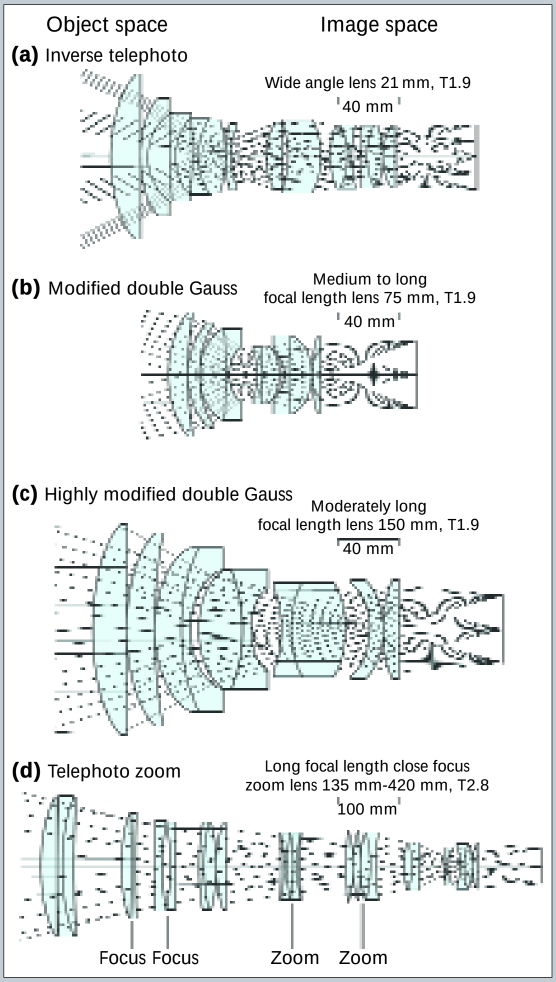

Figure 2. Several modern cine lens optical designs: (a) wide angle; (b) medium angle; (c) narrow angle; (d) long focal length, slightly telephoto zoom containing 24 elements.

Types of lenses

Three kinds of lenses are commonly used in cinematography to provide wide, medium or narrow fields of view. For the dominant spherical (or so-called flat) format, 1.85:1, wide lenses have focal lengths from 10 mm (or less) to 35 mm, medium lenses have focal lengths from 35 mm to 100 mm, and narrow lenses have focal lengths from 100 mm to 1,000 mm (or more). Although this categorization is somewhat arbitrary, it encompasses the preferred fields of view as well as the majority of lens constructional forms currently employed.

For the wide angle lenses (as for the others), the exact constructional form varies depending on the source (designer, manufacturer or supplier). However, the form is almost always based on an inverse telephoto (i.e., retrofocus) arrangement of lens elements, which means that the front grouping overall is negatively powered and the rear grouping overall is positively powered. This arrangement is a prerequisite for obtaining the necessary back focal length or lens-to-film interface distance. Many variations within this power arrangement have been derived, but all effectively do the same thing: suitably increase the back focal length while ensuring image quality. A modern wide angle lens design is shown in Fig. 2(a).

For medium angle lenses, the constructional form may vary from an inverse telephoto to a double Gauss and even a weak telephoto construction. This means that the power groupings may be quite different depending on the exact focal length, size, weight, full aperture, cost and so forth. Figure 2(b) shows a modern, medium angle, double Gauss derivative lens design.

Narrow angle lenses are dependent on “stretched” double Gauss and telephoto lens power constructional forms, with the latter dominating focal length designs of 200 mm or longer. Figure 2(c) gives an example of the former and Fig. 2(d) gives a zoom lens example of the latter.

Anamorphic lenses contain a hybrid construction comprising either a spherical prime or zoom lens and either a front- or rear-integrated anamorphic lens that usually contains mostly cylindrically surfaced lens elements.

Zoom lenses usually have upwards of 15 elements. They may be telephoto or inverse telephoto in constructional form; many times, however, their form is not distinguishable. Figure 2(d) shows a modern, long focal length, slightly telephoto zoom lens containing 24 elements. An even more complex inverse telephoto, macro-focus zoom lens is illustrated in Fig. 4.

Spherical vs. anamorphic

"What happened to the original Cinemascope anamorphic lenses?" is an often asked question. Interestingly, the word "scope" has survived to this day, even though the terms spherical (i.e., flat) and anamorphic (i.e., widescreen) are best suited to describe the format difference. There are many reasons, mostly economic, that Cinemascope lenses had disappeared by the mid-1960s. Some aspects of the early lenses also had technical deficiencies, and these are worth expanding upon.

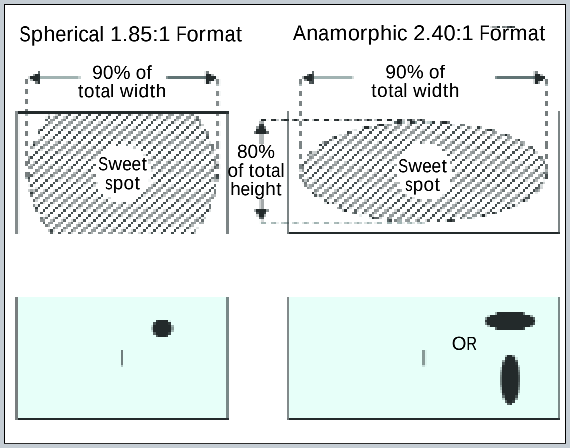

Figure 3. (a) Sweet spots of spherical and anamorphic lenses. (b) In a spherical movie, the defocused lamp will be blurred and circular in shape, but in an anamorphic movie the defocused lamp will be blurred and elliptical in shape.

Early anamorphic lenses produced a disconcerting, focus-related image characteristic known as anamorphic lens breathing or, more familiarly, "anamorphic mumps." Consider an actress speaking her lines, walking from, say, 20 feet to five feet (i.e., full body to facial shot) while the camera does a "follow focus" to keep her in focus at all times. Assuming a high quality anamorphic prime lens was used (Cinemascope circa 1955-65), the face of the actress would increase in size as she approached the camera. Because of lens breathing through focus (explained on p. 32), and more specifically, anamorphic lens breathing, not only did the face of the actress seem to increase in size at close focus, it also seemed to become fatter. The breathing effect—or increase in size of the object—is in fact much greater in the horizontal direction than in the vertical. Since actors were unhappy about this phenomenon, to alleviate it early anamorphic pictures had close-up shots at 10 feet instead of five feet. Production companies and camera crews did not like this, because with the old, slow film stocks, a tremendous amount of lighting was required, and the perspective of the shot was not as it should be. Heat from the extensive lighting setup produced problems, including sweat on the actors' faces and makeup meltdown. In 1958, a U.S. patent was issued for an anamorphic lens design that virtually eliminated the problem, and anamorphic lenses based on the patented invention have been used continuously for more than 40 years. They are the same lenses used to shoot the majority of widescreen movies today. The importance of the new anamorphic lenses was exemplified by the fact that Frank Sinatra, the main actor in the movie *Von Ryan's Express*, shot by ASC member William H. Daniels, supposedly demanded that this type of lens be used. Before leaving this subject, an interesting piece of historical information. The first prototype anamorphic prime lenses with reduced "anamorphic mumps" were used in the 65 mm format film *Ben Hur*, released in 1959 by MGM and shot by ASC member Robert Surtees. A little known anecdote about anti-anamorphic mumps lenses is that they can be specially designed to squeeze, or thin, an actor's face in close-ups; indeed, use of this technique was requested by a particular actress, who shall remain nameless, after her face had begun to fatten with age.

In terms of absolute or theoretical image quality and overall aberration correction, there is no doubt that spherical lenses are capable of superior performance over anamorphic lenses. However, in terms of what will be eventually viewed on movie screens or smaller presentation mediums such as TV, both easily provide adequate performance. For theatrical presentation on a fixed-width cinema screen, the anamorphic format will have a distinct advantage over the spherical format because there is more depth of focus at the film print in the projector, which means that constancy of film print position in the projector is less critical. Another consideration relating to image quality or residual aberration correction differences in spherical as opposed to anamorphic lenses is integration of visual effects (optical and computer-generated). Part of the reason the Super 35 format (spherical-lens origination, anamorphic release) has recently become popular, even though the film negative is small—65 percent smaller than pure anamorphic, 2.40:1—is because the low residual aberrations can aid the special effects community. Considering various aspects of spherical- versus anamorphic-lens residual aberrations, the latter lens tends to produce more field curvature, astigmatism and distortion. Because of this, the spherical lens has a sweet spot (i.e., excellent image quality) with a diameter roughly equal to 90 percent of the width of the format. In comparison, the anamorphic lens has an elliptical sweet-spot area bounded vertically within 80 percent of the format and bounded horizontally within 90 percent of the format [see Fig. 3(a)]. What this means for the cinematographer in practical terms is that objects of principal importance are best kept within these sweet spots (at lens apertures approaching full aperture). It should also be noted that all lenses, spherical and anamorphic, tend to perform best beginning at an aperture stopped down by at least one from their maximum aperture opening and up to, say, an aperture of T11 to T32 depending on lens focal length (i.e., T11 for very short focal length lenses, T32 for very long focal length lenses).

Until quite recently, a problem associated with anamorphic prime lenses has been their limited ability to provide good quality imaging at close focus distances. In fact, all lenses, spherical and anamorphic, are usually designed to perform best at one distance and gradually lose image quality performance toward infinity, and especially at close focus. Modern zoom lenses, spherical and anamorphic, are less afflicted by this problem because they incorporate complex, usually multiple, internal focus lens groups. In the case of anamorphic prime lenses (as opposed to spherical prime lenses, which do quite well in this respect), there has always been a trade-off with regard to lens size, weight and image quality at close focus (6 feet to 3 feet). Indeed, compact, lightweight close-focusing anamorphic lenses of fairly low image quality have been around since the 1960s, but until recently no anamorphic lenses, large or small, could provide good image quality over a focus range from infinity to 2–3 feet with low veiling glare characteristics. In the mid-1980s, technological advances in lens coatings and fabrication techniques brought spherical prime lenses with the above attributes to the marketplace. Later, ASC member (now director) Jan DeBont suggested that the combination of these spherical prime lenses with the best anamorphic optics might produce anamorphic prime lenses of high image quality and low veiling glare that would compete favorably with the best available spherical prime lenses. Such anamorphic lenses were produced and first used on the movie *Flatliners*, shot by DeBont. Still, the close-focus anamorphic lens image quality problem had to be solved. The solution turned out to be developments in spherical zoom lens cam technology. Using precision nonlinear cams in modern anamorphic lenses, still based around that 1958 anamorphic lens patent invention, high-quality-imaging anamorphic prime lenses with substantially reduced veiling glare and close focusing down to 2½ feet or less were produced. They are still somewhat large and heavy, but provide the image quality characteristics required for modern filmmaking.

Since anamorphic (widescreen) and spherical (flat) movies are no longer identified when shown in theaters, and many times are not even presented in their full format ratio, how can one tell them apart? Depth of field differences can be looked for. Streaking of hot (bright) objects, especially point objects such as a kick of sunlight off the chrome trim of a car, is usually more pronounced when anamorphic lenses have been used. Two good examples of films which purposefully use this characteristic to intensify the action are: *Close Encounters of the Third Kind*, shot by ASC member Vilmos Zsigmond, in which the small alien spaceships with bright lights fly low along a twisty road at night; and *Speed*, shot by ASC member Andrezej Bartkowiak, where the underground runaway train with bright headlights hurtles along the tracks just before crashing. In both of these scenes, the streaking can be seen as bright blue, red, purple and white lines, mainly horizontally spread across the picture but also at other angles. Perhaps the definitive giveaway of an anamorphically lensed movie appears in a scene shot at night with a streetlamp well out of focus: in a spherical movie the lamp will be blurred and circular in shape, but in an anamorphic movie the lamp will be blurred and elliptical in shape. [See Fig. 3(b).]

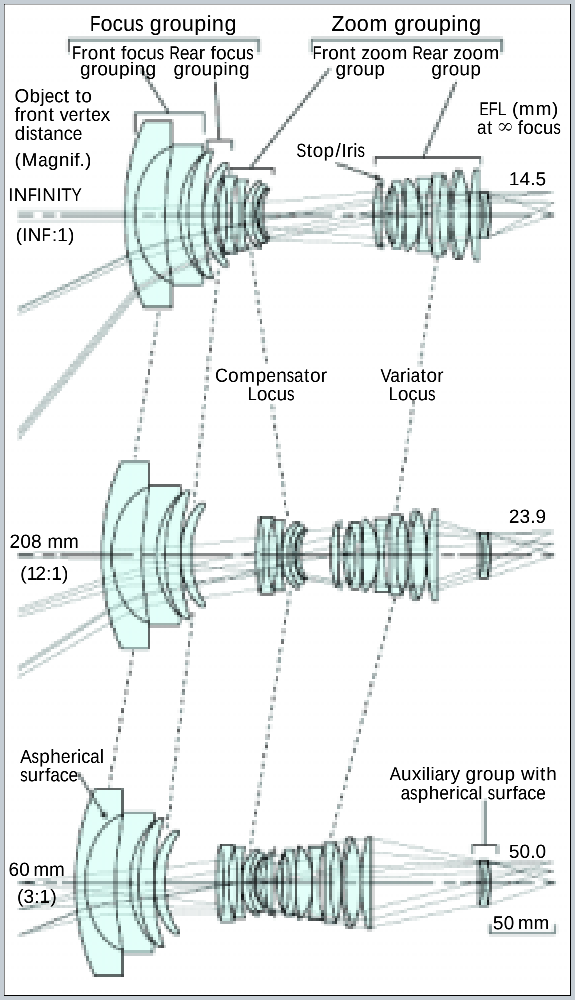

Figure 4. Recently introduced compact, wide angle, macro-focus (continuously focusable from infinity down to almost the front lens element), constant aperture (through focus and zoom) cine zoom. This lens employs two aspherical surfaces, some of the most exotic glasses ever produced, five cams, two movable focus groups, two movable zoom groups, a movable iris and 23 lens elements.

In summary, the pace of development in spherical versus anamorphic prime lenses has been greatest in the former, yet the latter has benefited greatly from some of the former's developments. The image quality performance differences and depth of field considerations have been reduced from a technical level to that of aesthetic preference, which is good, because it involves interpretation of the storyline. To elaborate, it is worth considering a movie example. ASC member Dean Semler shot the feature film *Dead Calm* in the anamorphic format. Given the confined, if not claustrophobic, circumstances of filming—almost entirely on a yacht on the open sea with many close focus distances—one might question his choice of the anamorphic format. However, Semler had good reason: he wanted to emphasize what was happening on the yacht and not distract the viewer by drawing attention to things in the distance that were not relevant to the scenes being enacted.

Prime vs. zoom

All the technological developments discussed above and others have been instrumental in bringing zoom lenses to the point at which they rival or exceed prime lenses in virtually every aspect, be it cost, performance or versatility; their only drawbacks are still size and weight, but even those are being gradually eroded. In cinematography, where optical and mechanical performance requirements and expectations are traditionally higher, zoom lenses have seen a much slower acceptance than in other applications such as still photography, photocopiers and video camcorders. In the late 1950s to early 1960s, zoom lenses gained popularity with cinematographers mainly for their intrinsic zooming capability. Today, the most technologically advanced cine zoom lenses have become popular above all for their performance and versatility. They are used equally for zooming and as variable focal length primes.

Prime cine lenses, having a huge range of discrete focal lengths from about 6 mm (fisheye) to 1,000 mm, full apertures starting at about T1.2 and close focusing to 1 or 2 feet, are commonplace. The overall performance of modern prime cine lenses is usually excellent. In general, if you want more from a prime lens you can get it; you just have to pay more. The performance that can be achieved now closely approaches limits set by the laws of physics. Primarily due to their greater cost but far better return on investment, as well as their greater overall complexity, zoom lenses can readily incorporate advanced features, such as close-to-macro focusing (with virtually constant aperture throughout focus and zoom) and reduced breathing at short focal lengths.

Optical breathing is a phenomenon peculiar to cameras that continually record images over time. It is not present in still photography. Breathing is well illustrated by considering a scene containing two persons talking intermittently with each other, one at 6 feet and one at 20 feet focus. Let's say the person at 20 feet (in focus and at the edge of the scene) first talks to the person at 6 feet (slightly out of focus but quite discernible, centered in the scene). Then let's say that during the conversation, the person at 6 feet (now in focus by refocusing the lens) starts talking to the person at 20 feet (now slightly out of focus), but the person at 20 feet, due to refocusing the lens, moves out of the scene. This means that the person at 6 feet is talking to nobody in the scene, which ruins the take. Breathing, through change in field of view during focusing, has moved objects at the edge of the scene into and out of the scene. Patents of zoom-lens inventions dating back to the late 1950s have addressed this problem, and several modern cine zoom lenses, sometimes using complex internal focusing arrangements, have successfully minimized this effect—especially at short focal lengths, where the larger depths of field make it more noticeable.

The Kenworthy snorkel, a periscopic specialty lens, was used to film the introduction to the public television series *Masterpiece Theatre*. The point of view has the lens working its way through the memorabilia on a table in a Victorian drawing room ...

Prime and zoom lenses complement each other in the field of cinematography. Virtually all movies now feature prime lenses and one zoom lens. Many movies use prime lenses and more than one zoom lens. Some movies use only a few prime lenses and are shot almost entirely with zooms.

Specialty lenses and systems

In addition to prime and zoom lenses, the cinematographer has at his or her disposal a variety of other lenses or lens systems (which contain primes or zooms) that provide different imaging characteristics or other features: specialty lenses. Some specialty lenses may be just prime lenses with unusual features, and some may involve an optical system that accepts attachment of a variety of primes or zooms. Some specialty lenses are dependent on folded optical configurations that use mirrors or prisms. By far the most significant aspect of these lenses and optical systems is their ability to achieve in-camera real-time shots not possible with regular primes and zoom lenses. Other advantages include large depth of field, extreme close or even macro focusing, and maneuvering among objects (e.g., miniatures, models, forced perspective).

There are some good examples of their shot-making capability. In *Titanic*, ASC member Russell Carpenter and visual effects supervisor Erik Nash used a Panavision/Frazier lens system and camera, each under motion control, to shoot the beginning of the last sequence in the movie. Shortly after the woman drops the gem into the ocean from the back of the research ship, a dry-for-wet scene commences with the camera system approaching a model of the sunken Titanic hulk (in dark blue lighting), then traversing the bow of the ship toward the port side, then entering and traveling through a covered outside walkway, and eventually slowing to a halt after turning left to see two doors with unlit glass windows, which then are lit and open to reveal a congregation of people collected to toast the lead actor and actress. In this shot, which is far too complicated to describe fully, the large depth of field, image rotation control and pointing capability of the Frazier lens system are used to the point at which the doors open. Another movie, *The Rock*, shot by ASC member John Schwartzman, exemplifies the variety of shots that can be accomplished with the Frazier lens system and some other specialty lenses. Many of the shots are seen toward the end of the movie, when Nicolas Cage is being chased on the Alcatraz prison walkways carrying the deadly green marbles and accidentally dropping, then grabbing, them on the parapet of the lighthouse tower. This shot clearly illustrates the macro focus (close-up of Cage's feet) to the infinity focus (distant skyline) carry of focus (i.e., huge depth of field with no follow focus). A good example of a periscopic specialty lens can be seen in the introduction to public television's *Masterpiece Theatre* series, where the point of view has the lens working its way through table-top memorabilia in a Victorian era drawing room, eventually halting in front of a hardbound book with the title of the play about to be presented on its cover. This shot combines the maneuvering, pointing and close focus capabilities of the Kenworthy snorkel.

Special applications

Special applications fall into the category of special effects, which include visual effects, computer graphics imaging, digital effects and animation. Most of these applications have one thing in common: they require principal photography with lenses and film to achieve about 2,000 pixels of usable information (and more recently up to 4,000 pixels) across the film format. Today, the best and most-used cine lenses—even anamorphic ones, which have gotten a bad name—can meet this requirement. In fact, until quite recently, in the realization of special effects, film stocks—because of their chemical image processing for enhanced contrast in the negative—have proved to be more problematic than lenses, especially in blue or green matte screen applications.

Although modern cine lenses are precision optical instruments that are designed, manufactured, tested and calibrated in a highly scientific manner, many of their characteristics, features and specific properties have not been made available to the public by the manufacturers. As an example, we can take the case of *Titanic*, which featured many special effects. When camera equipment was supplied, the crew requested certain lens information. Topics that kept arising were variations of distortion and field of view through focus and zoom, and lens repeatability. Eventually, this information was released so that the desired special effects could be realized.

Future lenses

From conception to use, all modern cine lenses are heavily dependent on computers. The complexity of modern cine lenses, whether optical, mechanical, electronic or some combination thereof, is so great that computers are fundamental to producing them. The advances made by zoom lenses in many fields are a testament to the importance of the computer in the whole design process, from idea to application.

Figure 5. Primo macro zoom lens. [Photo by Christina Peters, courtesy of Panavision Inc.]

A full series of prime lenses will continue to be available for some time, but increasingly, the prime lens will become more complex, with features such as continuous focusing from infinity to close or even macro object distances; internal, optically generated filtration effects; and so on, so that their design and manufacturing costs (i.e., return on investment), remain economically attractive. Individual prime lenses do offer one valuable advantage over zooms: they fill niche or special lens requirements better (e.g., very wide angle and fisheye field of view, very long focal lengths, slant focus, bellows). In the future, cine lens complements will thus include primes as well as zooms and specialty lenses, but the mix will undoubtedly change.

Technological advances in raw glasses, aspherical surfaces, thin films, diffractive optics and other aspects of lenses will continue to fuel lens development. A recently introduced compact, wide angle, macro focus (continuously focusable from infinity down to almost the front lens element), constant aperture (through focus and zoom) cine zoom lens indicates what is to come. This lens, which employs two aspherical surfaces, some of the most exotic glasses ever produced, five cams, two movable focus groups, two movable zoom groups, a movable iris and 23 lens elements, is a good example of what is already possible (see Figs. 4 and 5). Given the high performance level achievable by such a zoom, whether it be image quality, breathing control, macro focusing or many other features, it is easy to understand why zoom lenses will gain ground over traditional primes.

Iain A. Neil is executive vice president, research & development and optics and chief technical officer at Panavision Inc. He is the recipient of 11 Academy Awards for Scientific and Technical Achievement, two Emmy Statuette Engineering Awards and the 1999 Fuji Gold Medal Award.

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