*Resolution as a Measure of Interpretability**†

DUNCAN E. MACDONALD,
Dean of Graduate School, Boston University

ABSTRACT: *Empirical data have been used to establish the relation between scale and resolution that provide equal levels of interpretability. It has been found that for a given photographic emulsion the level of interpretability of a photograph of resolution R at scale $1:n$ is the same as that of a photograph at resolution 2R at a scale of $1:\sqrt{2n}$. Results have shown that area (rather than a linear dimension) of just detectable objects on the negative is inversely proportional to the resolution.*

GIVEN a print from an unexposed negative, a photo interpreter can make neither photogrammetric measurements nor analysis. If on the other hand, there is a single star (or point image) recorded on the negative, the interpreter may measure the location of the point with respect to the optical axis and, if given the camera orientation, can determine the direction, in space, of the source.

The interpretation process cannot start until the interpreter detects something. In practice, interpretation grows in complexity from this simple starting point to involve the detection of many, many somethings, until finally a sufficient number of clues are revealed to enable the highly sophisticated processes of recognition and analysis to occur. Recognition is based on human experience (e.g., recall, reasoning, etc.) and is derived, in the visual case, from the detection of many somethings, built up to reveal shape, contour, texture, relative brightness, etc., neither separately nor in any combination. All visual clues are derived from the simple detection of elementary somethings.

Let us examine the nature of the factors that are involved in this basic aspect of interpretation. First, there must be something in the object space; second, this something must be rendered detectable to the interpreter of the photograph.

In the object space, in the plan perspective which the emulsion sees, there are only two characteristics which influence the recording, one is the dimension of length, the other is actinic brightness.

Specifications of length are employed to depict the size (or area) and shape of the object. Specifications of actinic brightness are employed to depict (absolute) exposure level and relative contrast of the object with respect to the surroundings. These two characteristics may be used to completely describe the object space of the photographic system.

The image factors, which influence the interpretability of the recording of these two object space characteristics, are far more complex. There are three broad classes of factors: 1) physical, 2) psychological, 3) psychophysical; as noted in Table I. Under each of these categories are many factors, some independent, some interdependent, some cross-related. In this listing of factors that effect interpretability, the degradations of image caused by the intervening atmosphere are purposefully avoided. Also, in this listing there has been no attempt to achieve completeness, but rather only to show the complexity of the interrelationships between the interpreter and his physical subject, the picture.

In a previous paper introducing the concept of interpretability[1] the photo-interpretation process was described as involving 1) the identification of the object and 2) the deduction of its significance. The

[1] Macdonald, Duncan E., "Interpretability," PHOTOGRAMMETRIC ENGINEERING, vol. XIX, No. 1, pp. 102–107, March 1953.

* The work presented here has been performed for Headquarters, USAF, under Air Force Contract No. AF 49(638)-199.

† Presented at the Society's Semi-Annual Convention, St. Louis, Mo., Oct. 3, 1957.

TABLE I

FACTORS INVOLVED IN INTERPRETATION

Object Space Factors	*Factors that Affect Interpretability*		
LENGTH: SHAPE; SIZE (AREA)	PHYSICAL (Inherent limits set by the physical characteristics)	IMAGING FACTORS	Sharpness focus aberrations image motion Scale grain/detail grain/shape transfer function
ACTINIC BRIGHTNESS: EXPOSURE LEVEL; CONTRAST		PHOTOGRAPHIC FACTORS	Gamma Exposure Transfer function Latitude Granularity Turbidity Printing and projection losses
	PSYCHOPHYSICAL (Inherent limits set by the viewing process)		Sharpness of image Contrast of image Scale of image Scale of viewing Graininess Shape of object Illumination in viewing Conditions of viewing projection vs. direct binocular vs. monocular stereo vs. non-stereo Observer comfort
	PSYCHOLOGICAL (Inherent limits set by the human being)		Acuity Experience Motivation Set Skill Intelligence A priori knowledge Environment

former was held as primarily related to the physical and psychophysical aspects, the latter to the psychological. The paper went on to describe the problem of evaluation of interpretability and generalized on some approaches.

Today we are examining one specific aspect of the physical-psychophysical problem, the relationship between resolution and interpretability. Resolution is an often time objective measure. It assesses the degree of fineness to which a specific type of recorded detail can be observed. With this we are all familiar. Interpretability, on the other hand, is subjective, and must be considered as a measure of the degree to which an interpreter, using a photograph, is able to accomplish observations, descriptions, measurements, and analysis of the object space.

Clearly an evaluation of such a complex process is most difficult. On the other hand, if the psychological factors are excluded from consideration, comparisons of relative interpretability are straightforward. By exclusion of the psychological factors, one no longer seeks to evaluate the degree to which an interpreter is able to accomplish . . . rather one now seeks to evaluate the varying combinations of physical and psychophysical criteria that will provide the average interpreter with a constant level of information. Thus this paper proceeds to consider combinations of physical stimuli (resolution, scale, contrast, emulsion) that will provide the average interpreter a constant level of interpretability or information yield.

Considerable emphasis has been placed on resolution measures for judging quality improvements, for depicting research and development goals, for establishing performance specifications for equipment and operations. In this there has always been an intuitive awareness that more information would be available with higher resolution systems.

It is important to call attention to the fact that while this is a correct awareness, perhaps the failure to recognize the interrelationship of the many other factors that bear upon interpretability has placed undue emphasis on resolution as *the* quality measure. As a pure aside, this comment applies equally well to all imaging systems, i.e., radar, infrared, etc.

Figure 1 shows an image *A*. If observation or experience establishes that one resolution line per object is required to render this image detectable, one would expect a trace of the resolving power target at the limiting condition to appear as shown (somewhat exaggerated) directly above this image. For example, assume that this shows an image 1/10 mm. across, just detectable with a 10 line per mm. resolution.

With this same system, if the resolution can be improved to 50 lines per mm., may one not expect to detect an image 1/50 mm. across? This case is shown as image *B* and again the corresponding target trace is drawn above. If it were the case that *A* and *B* would both be detected with the same number of resolution lines per object, doubling resolution would enable halving the photographic scale and accomplishing the same job. The interpretability of pictures *A* and *B* would remain the same for the case of picture *B* taken at 1/5 the scale of picture *A* and at 5 times the resolution of picture *A*. One suspects that intuitively this may have been expected, but it is not true.

Image *B* is smaller than image *A*. Because of this it is clear that image *B* is closer to the grain size of the emulsion, and the grain, therefore, introduces more interference to the detection of the image. Also, the transfer function (the loss of contrast with decreasing detail size) indicates that a larger percentage of the inherent contrast is lost in the rendition of image *B* than in image *A*. The magnification required to bring image *B* to comparable viewing conditions with image *A* introduces an increased graininess effect.

All these factors tend to lead one to a more sophisticated view, viz., that more resolution lines per object are required to detect the image, the smaller the scale of the image. A corollary of this statement is less likely to be accepted intuitively, but with rigorous logic it is, that high resolution systems require more resolution lines per object in order to detect the image at the limit of the system than do low resolution systems. Resolution and scale are not interchangeable at parity.

The results of previously described experiments[2] on the detectability of isolated

[2] Macdonald, Duncan E. and Watson, John T., "Detection and Recognition of Photographic Detail" . . . *Journal of the Optical Society of America*, Vol. 46, pp. 715–720, 1956.

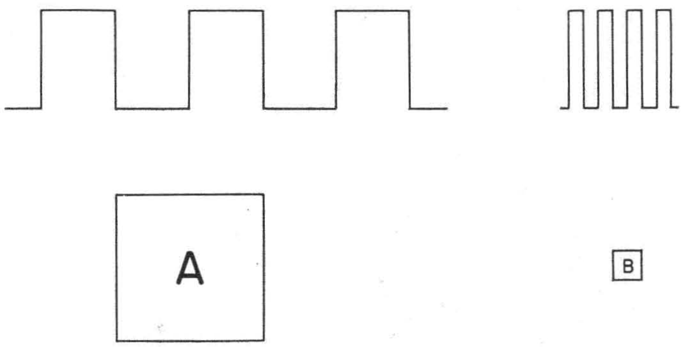
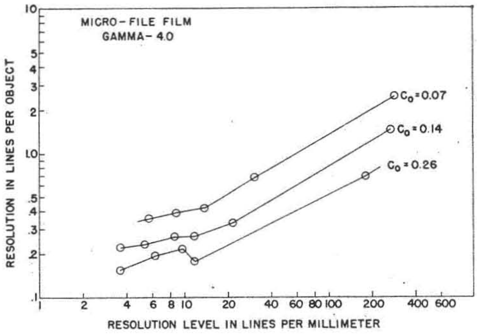
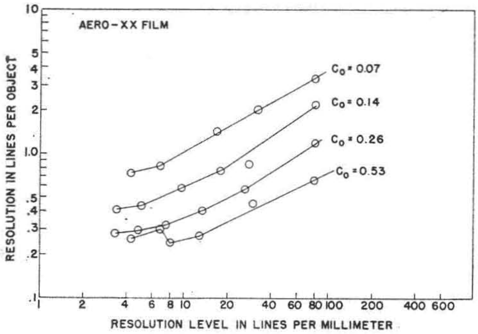


FIG. 1. Comparison of two objects, each recorded at one line per millimeter.





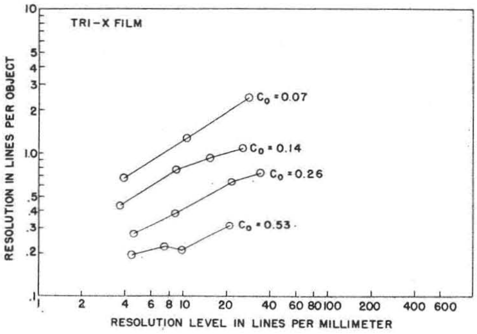


FIG. 2. At the limit of detection, the number of resolution lines per object required as a function of the resolution of the system. Object contrast ($C_0 = \log B_0/B_b$) is parameter.

compact objects as a function of resolution scale and contrast can be interpreted to verify this conclusion. This is shown by Figure 2, where the number of resolution lines per object, required to detect its image at the limiting performance of the system, is plotted as a function of resolution of the system. These data are shown for Aero Super-XX, Micro-file and Tri-X emulsions, each at several object contrasts.

Calculating from the data of Figure 2, or taking directly from the original experimental data, it is possible to tabulate or plot the limiting detectable image dimension at each level of resolution for each contrast. This is tabulated in Table II.

This tabulation points out clearly that the basic criterion for equality of interpretability, i.e., the rendering of the same types and sizes of details detectable, involves more than a resolution measure. Clearly Micro-file, at 20 lines per millimeter, enables the detection of smaller images throughout the range of contrasts studied than does Super-XX at 40 lines per millimeter. Thus, the interpretability of the 20 line per millimeter picture is better than the 40 line per millimeter photograph. It is obvious from this that other factors play a most significant role and that resolution by itself can be a misleading criterion.

A grainless receptor with no contrast degradation in the fine detail would allow a doubling of scale factor for each doubling of resolution. In practice graininess and the transfer function work against this ideal as has been shown in Figure 2. From the Table II data, it is possible to determine the actual ratio of increase in scale factor that holds the same size and contrast objects to the same detection threshold each time the resolution is doubled. This is shown in Table III. The gain factor is from 15–40% less than that available to the perfect receptor. Interpretability improves as resolution improves, but the gain in interpretability is always a lesser factor than the gain in resolution. It is neither the purpose or function here to enter into a discussion of some of the apparent trends that are indicated by the

TABLE II

DIAMETER OF SMALLEST DETECTABLE IMAGE AS A FUNCTION OF RESOLUTION

Emulsion	Resolution	Object Contrast			
		0.53	0.26	0.14	0.07
Super XX	10 1/mm.	0.025 mm.	0.036 mm.	0.059 mm.	0.105 mm.
Super XX	20 1/mm.	.017	.025	.043	.077
Super XX	40 1/mm.	.012	.019	.032	.057
Super XX	80 1/mm.	.008	.015	.026	.042
Micro-file	10 1/mm.		.021	.026	.039
Micro-file	20 1/mm.		.012	.016	.026
Micro-file	40 1/mm.		.008	.012	.020
Micro-file	80 1/mm.		.006	.009	.015
Micro-file	160 1/mm.		.004	.006	.011
Tri-X	10 1/mm.	.021	.041	.080	.125
Tri-X	20 1/mm.	.016	.030	.050	.100

TABLE III

INCREASE IN SCALE FACTOR THAT ACHIEVES SAME LEVEL OF INTERPRETABILITY AS RESOLUTION IS DOUBLED

	Object Contrast			
	1.53	0.26	0.14	0.07
Super-XX				
from: 10–20 lines/mm.	1.47	1.44	1.37	1.36
20–40 lines/mm.	1.42	1.29	1.45	1.35
40–80 lines/mm.	1.41	1.29	1.24	1.34
Micro-file				
from: 10– 20 lines/mm.	—	1.70	1.62	1.50
20– 40 lines/mm.	—	1.50	1.39	1.33
40– 80 lines/mm.	—	1.39	1.32	1.34
80–160 lines/mm.	—	1.44	1.35	1.38

table. There is an obviously fruitful area for analysis and treatment of factors that bear upon the result. By the same token, there are obvious minor departures from consistency which can only be attributed to experimental errors.

Suffice it to say here that the mean value of the entire table is sufficiently close to the square root of two to suggest a general conclusion. Such a conclusion would state, as a working rule of thumb in the prediction of performance, that the *AREA* (not a linear dimension) of just detectable objects on the negative is inversely proportional to the resolution. Such a relationship would appear to hold reasonably well over the working range of the emulsions tested.

Finally, as has been mentioned before, a gain factor greater than 2 is available by transferring from an Aero-XX type of receptor at 20 lines per millimeter to a Micro-file type of receptor at the same level of resolution. This would appear to clearly indicate the direction for research emphasis if we are to make significant strides toward obtaining photographs that contain the elements for marked improvement of levels of interpretability.