

A Per Grain Simulation of Film

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Film captures the world in a unique and distinct way which can form an important part of a final image. However digitally captured, or synthesised images lack the characteristics of film, which must be explicitly added if it is to match traditionally captured material, or simply meet aesthetic requirements.

Grain is perhaps the most obvious artifact introduced by film, but most existing treatments of film grain in both photography and computer graphics consider grain as a layer of noise added onto a perfect image, amplitude of the noise being modulated by the image density. However real grain *forms* the visible image, with individual grains either being developable or not. Density is formed by the presence or absence of developed grains, rather than being continuously variable.

Here we present a simulation of film based upon individual silver halide grains. Photon's are simulated striking these grains to form the latent image. Using this simple model the film response curve, reciprocity failure and Selwyn's law of granularity are all present as emergent properties.

1 Film Grain

Traditional film consists of silver halide grains which are sensitive to photons. When a photon strikes a grain it liberates an electron. This electron can combine with another free electron to create a stable centre. It may also join an existing centre, increasing the its size. When the film is developed centres which contain 4 or more electrons are likely to initiate a chain reaction, so that the entire grain is reduced to pure silver creating a stable negative image.

We note that grains are either developable or not, depending on the presence of sufficiently large centres. There are no partially opaque grains, and the grain pattern produced is dependant upon the exposure in a complex and non-linear fashion.

2 Simulation

Rather than attempt to statistically model film grain as a form of noise, we choose to simulate the processes which lead to its creation. We consider grains as disks of varying size with a typical average diameter of $6\mu m$, storing $10^5/mm^2$ in a $2d$ kd-tree. Photon's are then fired at the kd-tree with a density of around $10^7/mm^2$ to create an appropriate exposure.

Each grain within the kd-tree records its geometric details, the number of free electrons, and the number of stable centres of 2,3 and 4 or more electrons on its surface. The time of the previous photon impact is recorded, so that when a subsequent impact occurs the simulation of that grain can be updated to the current time, before the free electron count is incremented. Free electron behavior is modeled as a multiple exponential decay processes, where an electron can join with another electron, join a stable center, or be removed from the simulation due to other absorption events.

Once all the photons from the scene have been fired at the negative, the grains are updated to a time substantially after then end of the exposure to allow any final recombination to occur. The grains



Figure 1: Processed Images

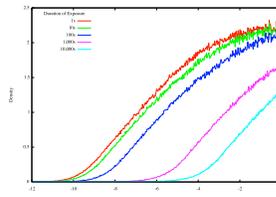


Figure 2: The Characteristic Curve

are then developed with a probability of $1 - (1 - d)^{n_4}$ where d is a function of development time, and n_4 is the number of centers containing 4 or more electrons. Developed grains are then drawn in a pixmap which can then be measured and displayed.

Implementation of the simulation requires some care as the huge numbers of photons, and grains can exceed the resolution of int and float data types, and for large negatives the grain structure will not fit within a 32bit address space.

3 Results

Figure 1a shows an exposed step wedge. Grains are present even in the least exposed area, and while a grey scale image is visually apparent, closer examination demonstrates that this is formed by varying the number of developed grains, rather than the opacity of individual grains, producing a realistic "grainy" image.

Measuring the image density reveals the characteristic curves shown in figure 2. These match the response of real film, including reciprocity failure. The sensitivity of the film is also dependent on the grain size, as per real film. Development times can be adjusted to control image contrast. Measurements of the Granularity reveals it to be approximately proportional to the square root of density, and inversely proportional to the square root of the measurement area, in accordance with Selwyn's Law.

Though simple, the simulation reproduces many of the characteristics of real film, both in terms of sensitometric properties, and visual appearance. Because it is physically based, each part of the simulation can be adjusted, and improved based on known properties of existing materials and processes, potentially allowing specific film stocks to be recreated virtually.

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