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Music and Color: Relations in the Psychophysical Perspective

Relations between music and color have long been debated, it seems inconclusively. I describe the theory behind three electronic sound-to-light transducers built to give a visual impression of music to students and deaf people. In psychophysical theory, any psychological correlation between music and color must derive primarily from the physical stimuli, which, as sonic or radiant energy, have only two variables: (a) amplitude, causing loudness or brightness/lightness: and (b) wavelength, causing musical tone or hue. Correlation of tone and hue is also indicated by their cyclic nature, as octave cycle and hue cycle. Accordingly, only the latter cycle can represent the former.

INTRODUCTION

Sebba's recent article[1] gave an interesting review of her and others' attempts to relate music to color. The nature of this relationship has fascinated many minds, including the composers Beethoven, Rimsky–Korsakof, and Scriabin,[2] and is a good exercise in cross-disciplinary analysis. Perhaps the best known modern attempt at correlation is Walt Disney's[3] relating music to color patterns in his classic film *Fantasia* (1940).

This article describes my own attempts, which fall into Sebba's category of "the technical approach" which, as she notes, "coordinated colors with tones on the basis of . . . wavelength . . . by . . . color organs. These experiments . . . based upon oversimplified interpretation of Newton's ideas . . . took place between the end of the 17th century and the beginning of the 20th century . . . [and] were rejected."

The Oxford Companion to Music[2] similarly denigrates the technical approach (though "technical" is hardly the word for obscure interpretations of Newton's hue circle, as recently discussed in this journal[4]). Nevertheless, I intend here to support the technical or scientific approach as the only possible way of finding a constant and objective correlation (rather than arbitrary and subjective). My research and development of *sound-to-light transducers* (1977–1984) represents technical and theoretical advances over previous and ancient *color organs*[2] or *ocular harpsichords*[5] so a short description may be of interest or future use. This is a first report, other than local newspapers of that time.

Sebba concludes that a joint code exists for expression of tone and hue, from her experiment in which architecture students rendered short pieces of music (four bars, within a very limited range of 10–13 semitones) as painted colors. In these renditions, the highest tones (frequencies) corresponded generally to brighter/lighter colors such as yellow, pale magenta, and white. But in the round, music consists of over a hundred semitone intervals (1.06, or $2^{1/12}$, ratio between each semitone frequency, e.g., C of 262 Hz and C^b of 247 Hz), from about 30 to 15,000 Hz (the minimum range for high-fidelity music reproduction). Tone comprises some nine cycles (octaves), each repeating the same 12 semitones, whereas hue is limited to only one cycle of hues.

Sebba's examples demonstrate that music–color correlation does exist, if only in short musical pieces to which are matched carefully selected short ranges of hues. However, this is rather like my claiming a correlation with Einstein because we have some resemblances, such as grey hair or thin legs. To demonstrate a correlation between two wholes requires a whole (rather than piecemeal) relationship. Sebba's correlation examples of 10–13 semitones do not stand expansion to the gamut of semitones (say, 100), *unless* the white or yellow representing the highest tone were made another 90 steps lighter (impracticable), or *unless* the hue cycle progresses from red through yellow to 90 even lighter hues: it does not, as yellow is one of three brightness/lightness maxima, together with cyan and magenta.[4] To progress from Sebba's work with very short musical pieces to the bigger picture, we must find a color system to comprehensively represent all of a symphony, or indeed all music; even if it does so less perfectly than Sebba's selected examples.

THEORETICAL CONSIDERATIONS

In the psychophysical perspective, psychological similarities between music and color, if such exist, must derive primarily (but not only) from the physical stimuli. These, as sonic or radiant energy, have only two variables: (a) amplitude, causing loudness or brightness/lightness: and (b) wavelength, causing musical tone (*note* in British parlance) or hue. Correlation of tone and hue is also indicated by the cyclic nature of each, as octave cycle and hue cycle (or color wheel). No other psychological dimension of sound or color is cyclic, so no other correlation than tone and hue is possible, at least technically.

The octave cycle is physically defined as the range of frequencies from x to $2x$, say, middle C of 262 Hz to C of 524 Hz; and psychologically defined as the range of tones from a given tone to the same tone repeated, e.g., *do-ray-me-fah-soh-lah-te-do* (in the verbal notation of octave). The hue cycle is similarly defined psychologically but not physically, because it does not comprise a physical octave. It consists of the spectrum (physical wavelengths, about 400–

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700 nm) and the *nonspectral purples* or compound colors of no single wavelength. Further, not all the spectrum is efficient, since its ends (red and violet) fade below our sensitivity, as do the ends of our audio range at about 20 and 20,000 Hz. Omitting these inefficient ends reduces the audio range to about 30–15,000 Hz and the spectrum to 442–613 nm, spectrum limits to *optimum color stimuli*.[6]

Principal differences between light and sound are (a) one hue cycle in contrast to nine or ten octave cycles; (b) hues mix completely (to form new hues) whilst tones do not (they remain semidiscrete as chords); and (c) the hue cycle varies in amplitude (brightness/lightness maxima at yellow, cyan, and magenta)[4] whilst the octave cycle is uniform in amplitude (loudness), per unit of radiant or sonic flux.

DESCRIPTION

Applications

In my initial research (1976), the following applications were indicated for a sound-to-light transducer:

(a) Education of primary school students, in accord with current methods of teaching music by colors (e.g. those of Dr. Senator of London University U.K., Pat Beaton of Canberra, and Dorothy Mewes of Sydney).

(b) Analysis of music, speech, automotive engine noises, etc., by playback (in slow time or stills) of a film of the transducer's visual representation.

(c) Teaching deaf persons to speak by seeing visual representations of speech and its elements, e.g., fricatives and tone-variation.

(d) Conveying an impression of music and its elements to deaf persons for intellectual (if not intuitive) understanding.

(e) Music and color therapies, presently administered to convalescents and mental patients, may be combined for a greater effect.

(f) Entertainment, in domestic or public situations, by a *son et lumiere* show which correlates, rather than conflicts, with the harmony and cyclic structure of music.

Required Capabilities of a Sound-to-Light Transducer

Initially, the required capabilities were hazy. But after trialing the first two transducers (1977), they were defined as:

1. *Intensity*. Represent loudness by brightness.
2. *Tone*. Represent a semitone (in any octave) by a constant hue.
3. *Cycles*. Correlate each octave cycle with the hue cycle.
4. *Chords*. Represent the aural character of a given chord (two or more tones) by a constant visual character.
5. *Pitch*. Discriminate visually between the many audio octaves.
6. *Harmonics*. Discriminate visually between the several harmonic frequencies of a sound, as in hearing.
7. *Discrete sounds*. Discriminate visually between a number of simultaneous sounds, as in hearing an orchestra.

TABLE I. Correlation between hue and tone in the equal-temper scale. Hue correlate is found as $\lambda = C/f$ (see text); where C is light speed (2.997×10^8 m/s), f is frequency in Hz; and wavelength λ is limited to *optimum color stimuli*[4] (approx. range 440–620 nm). Compound colors (no single wavelength) are interpolated as equally discriminable hues over the remaining hue cycle. *Alternative System* (as yet untried) distributes the unique hues (r, b, g, y) uniformly, at every third semitone.

Equal-temper Scale		Hue Correlate, 1984		Alternative System, 1991
Tone	f (Hz)	λ (nm)	Hue	Hue
G	392		Crimson	Orange-red
G♭ F♯	370		Magenta	Red
F	349.2		Purple	Magenta
E	329.2		Violet	Purple
D♯ E♭	311	438	Indigo-blue	Blue
D	293.7	464	Blue	Aqua
C♯ D♭	277	491	Cyan (aqua)	Bluish-green
C	261.6	521	Green	Green
B	247	552	Yellow-green	Yellowish-green
A♯ B♭	233	585	Yellow	Greenish-yellow
A	220	619	Orange	Yellow
G♯ A♭	207.5		Red	Orange
G	196		Crimson	Orange-red

8. *Tone/Hue*. Retain the ratios between tones in the ratios between hue correlates. (Note. In hindsight, a psychologically more uniform scale would be a unique hue to every third semitone. Table I shows both scales.)
9. *Real Time*. Visually represent the rhythm, amplitude and frequency of sounds in real time, if possible.

Requirements 2 and 3 overcome the failing of "color organs" or "musicolor" devices which represent the same tone in different octaves by quite different hues, despite the tone (*not* the pitch) remaining exactly the same to human hearing. Requirements 2, 3, and 8 are met systematically by converting a tone's equal-temper or piano frequency (e.g., C, 261.6 Hz) to wavelength (1,145,642 m) and dividing it by multiples of two (i.e., octave intervals) until within the visible range (e.g., 5.21×10^{-7} m, or 521 nm); restricting wavelengths to those of monochromatic *optimum color stimuli* 442–613 nm, or, say, 435–620 nm. See Table I. (Note the arbitrary choice of light speed rather than sound for this "conversion" of tone to hue.) Thus middle C, a tone which is median to the high and low tones of the piano and of the voice range, is represented by 521 nm green, a hue aptly in mid-spectrum. (Incidentally, previous technical correlations from the late 1700s to recent times[7,8] usually tied middle C to red, at the spectrum extreme.) Compound colors (red through purple to violet, outside the range 435–620 nm) were interpolated. See Table I.

Requirements 2, 3, and 5 may be met by displaying separate octaves as rows (see Fig. 1), one above the other as in pitch; or as concentric circles; or ideally, as most continuous, as a spiral; whilst sectors would each represent one semitone (by a constant hue) in all octaves. See Fig. 2. Lower tones were given a larger display area because they are psychologically larger sounds, shaking the stomach (as deaf people "hear" low tones); whilst higher tones (thin and squeaky) were given smaller areas.

Requirements 4 and 7 may be met by visual representation of discrete tones as discrete areas of color. Requirement 6 is met automatically by Requirement 1's higher levels of sonic energy displaying higher brightness, in respective (usually first) harmonics. Requirement 9 is within the capabilities of electronics.

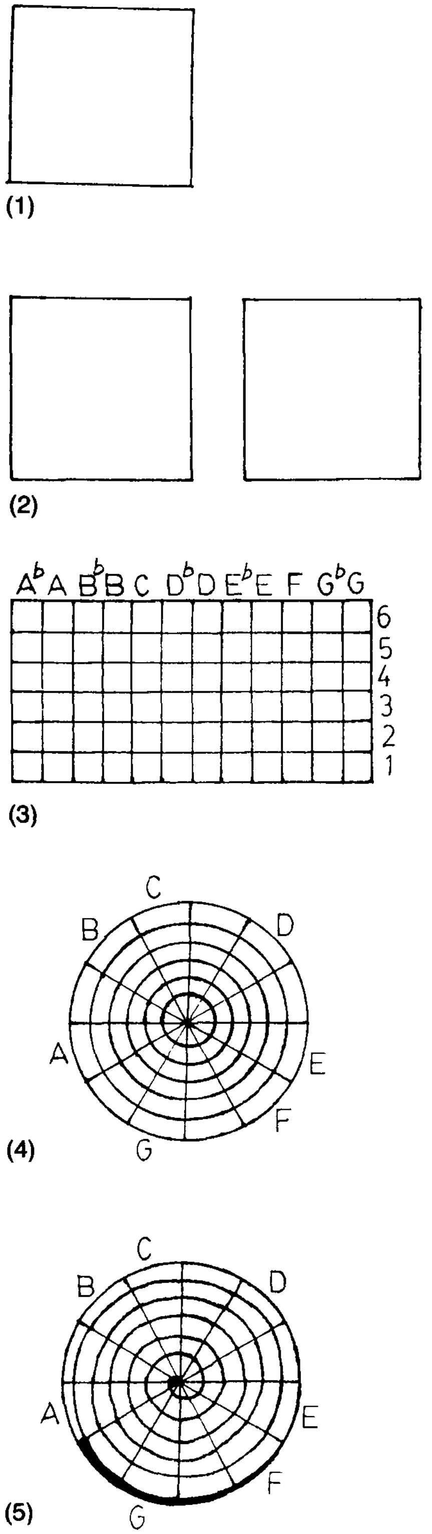


FIG. 1. Evolution of visual display layouts, in imagination and fact (Nos. 1, 2, 5). (1) Single display (tristimulus lamps **RGB** for all sounds); (2) Twin display (as for 1, either stereo or lower and higher octaves); (3) Matrix display (6 octaves each of 12 semitones, about 100–6300 Hz); (4) Concentric circles display (octave per circle, semitone per sector); (5) Spiral display (octave per cycle, semitone per sector).

Execution

Model 1. Ian Knotts, a young electrical engineer with Mount Stromlo Observatory, built our first transducer to my design in 1977. Having gained support for my ideas from Don Banks,[3] (a world leader in electronic music composition, then head of Composition at the Canberra School of Music), we demonstrated the transducer (and a reverse process, light-to-sound transducer to give color information to blind folk)* to 50 scientists and representatives of disabled persons' organizations in Canberra School of Music on 14 June 1977. That model was relatively primitive, designed only for one sound at a time, i.e., it had only one visual display area. Basically, the display panel was a translucent white square, behind which were three lamps (red, green, blue) driven by electronic filters simulating **RGB** tristimulus curves, driven in turn by a microphone or the speaker wires of a gramophone. But even with one sound or tone at a time, the tone's third harmonic (which, unlike the second harmonic) commonly contained sufficient energy to desaturate (by its near-complementary hue) the hue representing first and second harmonics. This model could, of course, visually display the sounds of a full orchestra, with beautiful color effects, often desaturated but delicately so, as in tinted skies at sunset. But because it pooled and mixed all the sounds of any one time, the display did not correlate recognizably with the music other than with its rhythm and overall volume (by brightness).

Model 2. This temporary arrangement had two visual displays, one each for higher and lower octaves. One used dichroic halide lamps; the other used cheap incandescents, which seemed as good.

Model 3. In sketching an evolution of display layouts (see Fig. 1) which might overcome my problems, I realized the final set of required capabilities, above, and the spiral display as its ideal embodiment. Mick Eaton and Bill Storms, Army electrical engineers in Sydney, supervised the construction of our third transducer in 1982–1983, which I finished with the aid of Ian McWhirter (manufacturer and inventor, of Berowra) in early 1984. It was demonstrated in my Sydney home to several representatives including two from Sydney University's Conservatorium of Music. Reactions were mixed, from enthusiasm to polite interest, and a request to use the transducer as visual accompaniment to electronic music performances at the Conservatorium. Further development was curbed by the idea's technological complexity and costs.

*Now a commercial product, to which I am not connected.

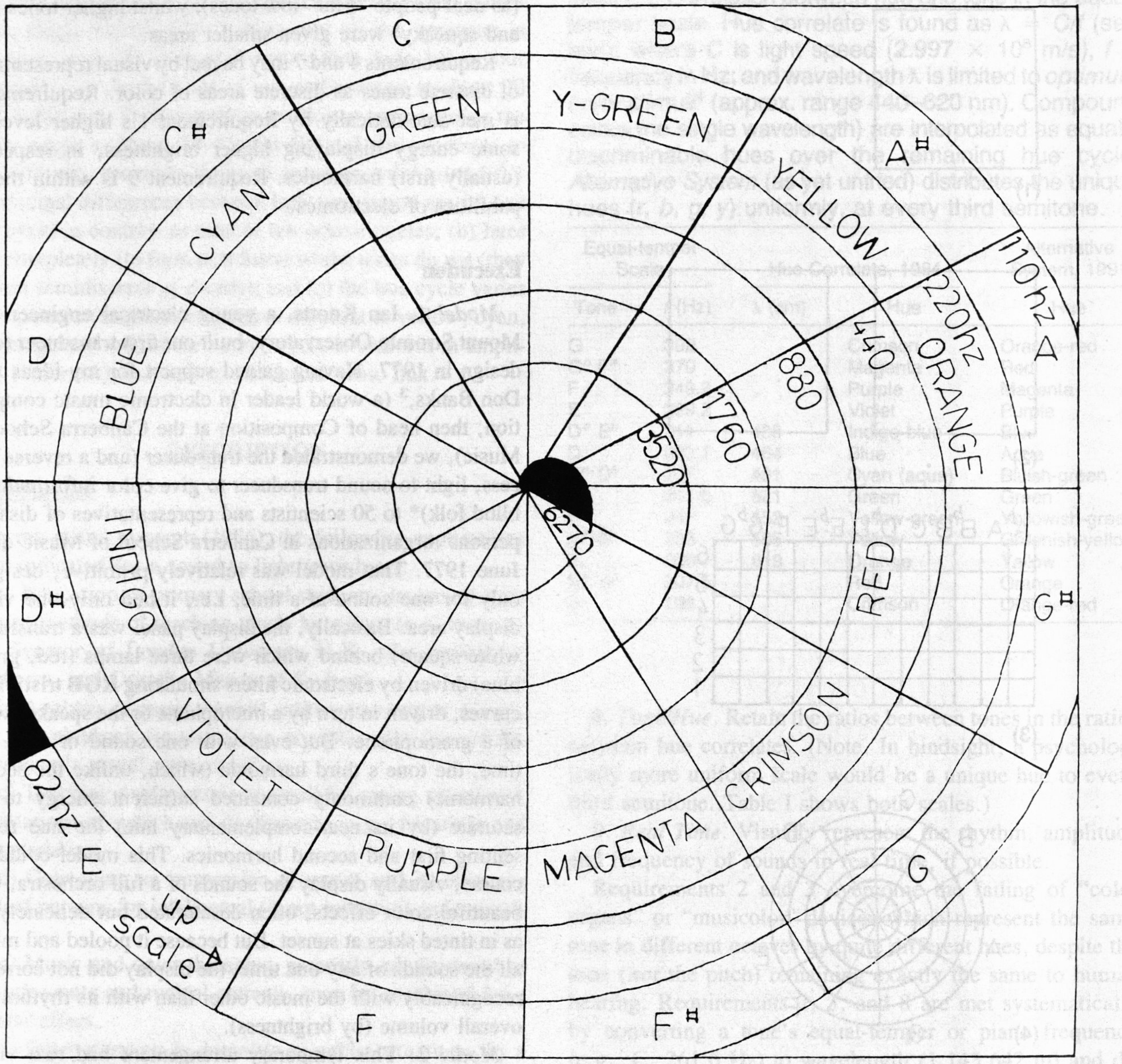
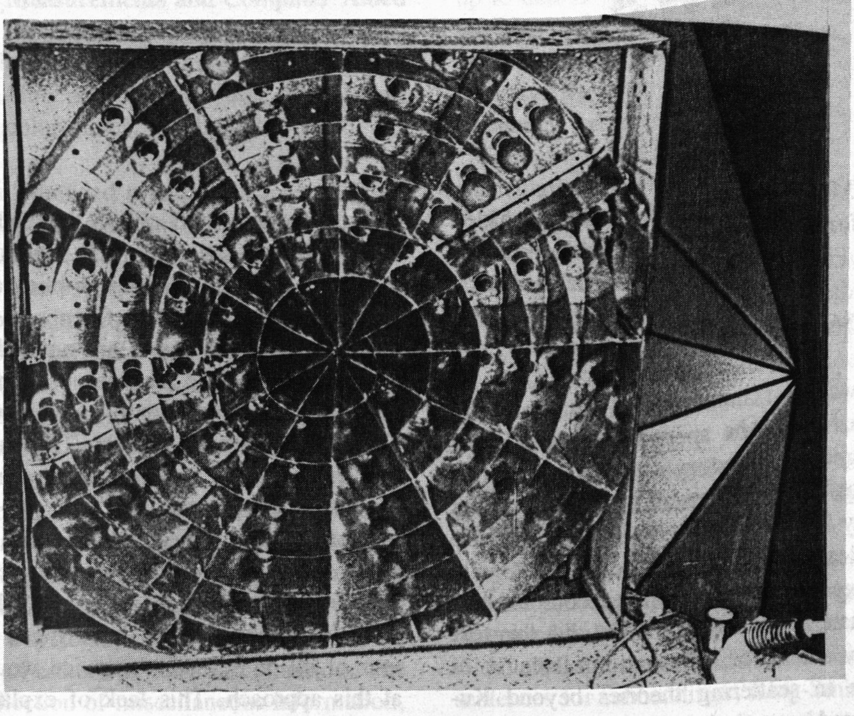


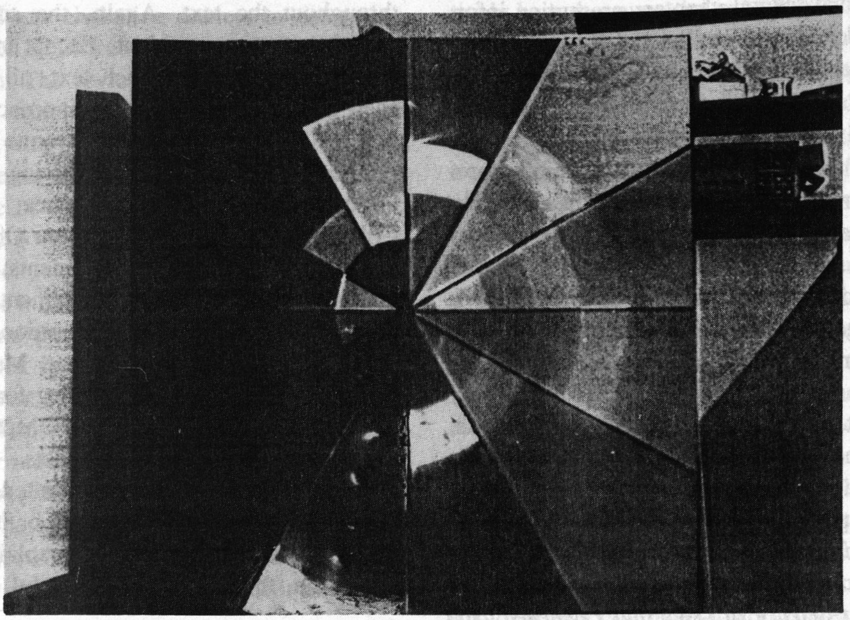
FIG. 2. Layout of final (1984) display panel. A given tone (e.g., C#) in all octaves is represented by a constant hue (e.g., cyan). Each octave is represented by a cycle, and each semitone (and its hue) by a sector.

This was a sophisticated device which realized (to some degree at least) all the required capabilities, above. The display area was one meter square (Fig. 3). It displayed over six octaves, from 80 to 6300 Hz. More octaves reduce the ratio of one sound's area to total display area, and thus visual impact. The brighter colors, e.g., yellow, were compensated by lower wattage lamps. It was a great pleasure to watch "visual music," whether classical or pop. (Interestingly, all-time famous pop bands, e.g., The Beatles, play very "colorful" music.) Volume, tones, harmonics, chords and rhythm were fairly well represented. Even single-instrument music was colorful due to harmonics (other than second, fourth, etc) having different hues from the first harmonic. With the sound turned down, the visual display alone could not convey the emotional impact of music; though one could follow the visual music intellectually.

The transducer's main weaknesses were (a) cost, then some $4,000 (US) in labour and material, particularly 76 electronic filters driving 76 lamps; and (b) inability to display sharp sounds like drum beats, from an insufficiently sensitive brightness response to audio signal. A minor weakness was the predominance of reddish and bluish hues (see Table I) over yellows and greens. I see now that a better solution to Requirement 8 would be equal intervals between *hue sensations* rather than *physical wavelengths*, by evenly distributing the unique hues (red, blue, green, yellow) over the octave (Table I, "Alternative System"). In summary, the display layout seemed almost ideal but, as in most pilot



(a)



(b)

FIG. 3 Photos of 1984 transducer: (a) Cellular structure for lamps (20–100 W). (b) Translucent 12-hued display panel in operation. (Better seen in the dark to hide the panel's bright surface colors.)

projects, the execution was imperfect. Hopefully, our efforts will help others.

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