HOW VAST IS MUSIC?

CREATING "THE FIBONACCI VARIATIONS" WITH COLORS AND SCALES

JACQUELINE CORDES AND JAY CORDES

ABSTRACT. Music has incredible power to create different moods and environments and composers can use a variety of musical elements to evoke emotional responses from listeners. This article highlights two underused approaches: uncommon musical scales and synesthetic colors. Jacqueline Cordes is a composer who experiences musical chromesthesia, a form of synesthesia, and describes what colors she "sees" when listening to music, including the particularly vivid pieces from the band Radiohead. Restricting herself to melodies determined by the Fibonacci sequence, she also composed pieces in a variety of colors to highlight the intersection between colors and emotional environments. This article also introduces the Jacqueline Scale ID (JSID) for identifying and communicating all possible musical scales. By encouraging composers to explore the "scale space", this paper aims to influence music towards new levels of creativity and variety.

INTRODUCTION

It has been said that music is infinite. While probably not literally true, it is more true than people may realize. The amount of freedom a composer has in regards to melody, tempo, rhythm, chord progression, instrumentation, harmony, dynamics, and form (the overall layout of the piece) allows for a vast number of variations that would each be considered distinct pieces. This discussion will focus on two sources of musical variation: color and scales.

This article will describe how different musical elements evoke colors in music. Color is to be taken literally here – composer Jacqueline Cordes has musical chromesthesia (a type of synesthesia that causes a perception of color when listening to music) and has demonstrated how it can be put to use by creating musical samples of each basic color for the July 2024 Fibonacci conference at Harvey Mudd College. She minimized variables by creating all of the color samples for solo piano and with the same sequence of melodic notes derived from the Fibonacci sequence.

The variety of musical scales used in musical compositions can, in theory, include any combination of the 12 chromatic tones in an octave. We introduce a new way to identify and enumerate all possible scales, called the Jacqueline Scale ID (JSID), which provides a systematic approach to cataloging and communicating scales without writing out the notes. We also demonstrate how the use of different scales can dramatically alter the feel of a musical piece.

BACKGROUND: WHAT IS MUSICAL CHROMESTHESIA?

Synesthesia is a hereditary perceptual phenomenon that causes the mixing of senses, and among the synesthetes with musical chromesthesia, a perception of color automatically and consistently comes to mind when they listen to music. This subset of synesthesia is rare, experienced by only about 1 in 3,000 people according to one estimate [1]. Some perceive colors for each individual pitch they hear, some, like French composer and organist Olivier Messiaen, see colors for various scales or chords [2], while others may have color responses to the specific instruments being played. In Jacqueline Cordes's synesthesia, however, the color is affected by the mood or feel of a musical piece, which makes it particularly interesting to study as it provides a useful way to categorize music and can be mostly understood in a metaphorical way by non-synesthetes.

Not all music has color for Jacqueline, in fact, most music doesn't. However, music with a melodic line, a chord progression, and a particular "feel" can subconsciously be associated with a specific shade of color in her mind: red, orange, yellow, green, blue, purple, brown, grey, or pink. Red music includes most sea shanties, Irish jig music, heroic themes such as *Game of Thrones* or *Pirates of the Caribbean*, and other energetic or triumphant pieces. Orange music is rare – some examples are Johann Sebastian Bach's "Jesu Joy of Man's Desiring" and extravagant piano pieces such as Łukasz Michalski's "The Autumn." Yellow is very common (especially for folk songs) and is typically a piece in a major key, such as "Better Place" by Rachel Platten, "Fast Car" by Tracy Chapman, and "Hey There Delilah" by Plain White T's. Green music includes dramatic movie themes with a strong repeating chord progression, such as the main theme of *Black Beauty*, *Night at the Museum,* or *The Power of the Heart*. Blue is another very common color, and includes most music with a slow tempo, such as the song "I Will" by Radiohead (the color of some music changes to blue if the tempo is reduced). Purple music has a strong melody and interesting chord progressions that follow it, and sometimes sounds French. Examples include "Little 15" by Depeche Mode, Felix Mendelssohn's Violin Concerto in E minor, and Franz Schubert's "Gretchen at the Spinning Wheel." Brown music is extremely rare and has a comical feel as it's fast, fun, and spooky, such as Danny Elfman's *Beetlejuice* theme or the Haunted Mansion theme at Disneyland. Grey songs are currently a mystery to us, in the sense that we don't yet know what musical elements they have in common. Some examples are "Exit Music (For a Film)" and "Lucky" both by Radiohead, and Gustav Mahler's "Funeral March." Pink songs are so rare, that Jacqueline has only ever "seen" them in Radiohead's song "Nude," Thom Yorke's song "The Conjuring of Anke," and Portishead's "The Rip" (which, coincidentally or not, was one of the few songs covered by Radiohead).

RADIOHEAD: ONE OF A KIND

It's notable that several of the color examples above are from Radiohead. Radiohead's music has the widest variety of colors; in fact, they are the only band/composer Jacqueline is aware of with compositions in all of the main colors (although she gives Danny Elfman an "honorable mention" for producing the second most distinct colors). This doesn't seem to be by chance, as Thom Yorke, the head of Radiohead, experiences a type of musical chromesthesia [3]. Figure 1 shows precisely what synesthetic color Jacqueline experiences for the most vivid Radiohead/Thom Yorke songs.

Radiohead - More Colors Than Any Other Band

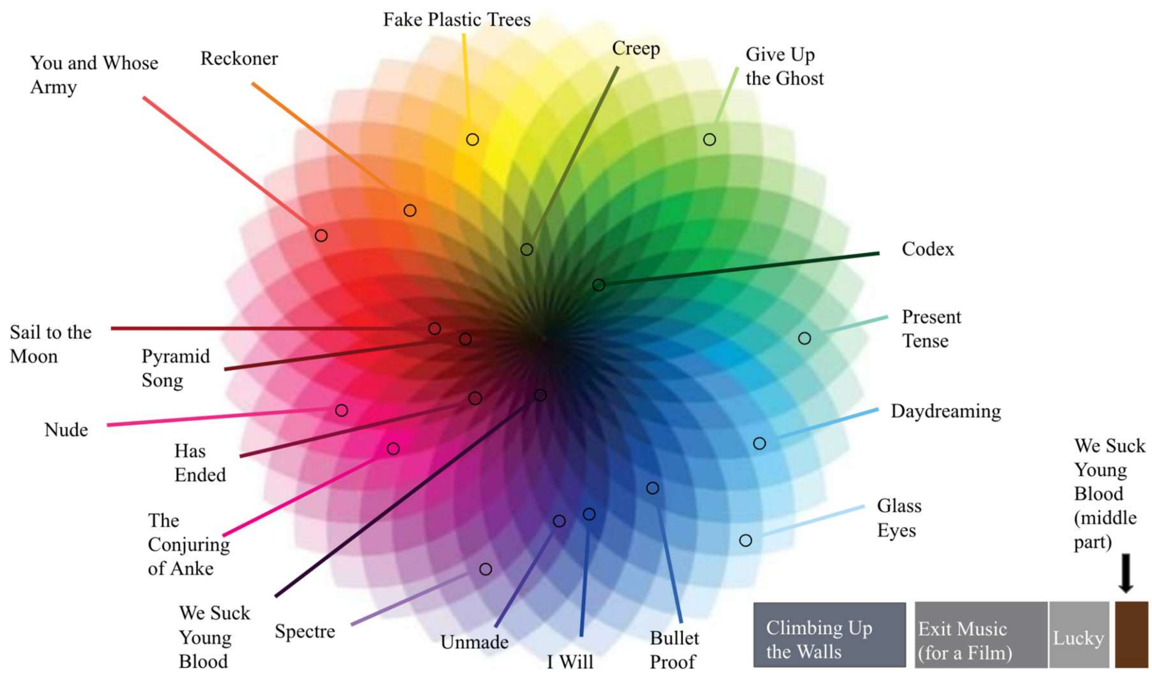

Figure 1. The precise colors of selected Radiohead/Thom Yorke tracks according to Jacqueline [4]

Anecdotally, Jacqueline has noticed that there is a large overlap between musical chromesthetes and Radiohead fans.[1] When Jacqueline first heard "I Will," it stopped her in her tracks with its vivid dark blue color. She later marveled at how striking and consistent the colors of many songs in Radiohead's discography turned out to be, relative to other artists. When preparing the slide in Figure 1 for her talk, Jacqueline noticed something she had never noticed before: Radiohead's songs above rarely fall into the most common shade of colors. It's almost as if they have "the sight" and strategically avoid the more conventional colors.

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[1] Jacqueline's father Jay noticed while watching the HBO show Westworld that Radiohead songs often found their way into the episodes. He alerted Jacqueline, who wanted to know which tracks. Jay listed the half-dozen or so tracks that had appeared in the show and Jacqueline responded "it's interesting, those aren't the most popular Radiohead songs, but they ARE the most vivid. I wonder if the composer is a synesthete!" Given the rarity of musical chromesthesia, it sounded far-fetched. However, when we found out that the composer was Ramin Djawadi, who also did the soundtrack for Game of Thrones. Jacqueline said "the Game of Thrones theme is red; he has to be a synesthete!" Sure enough, we went to his Wikipedia page and his synesthesia was confirmed [6].

For example, consider the specific colors for the musical pieces below…

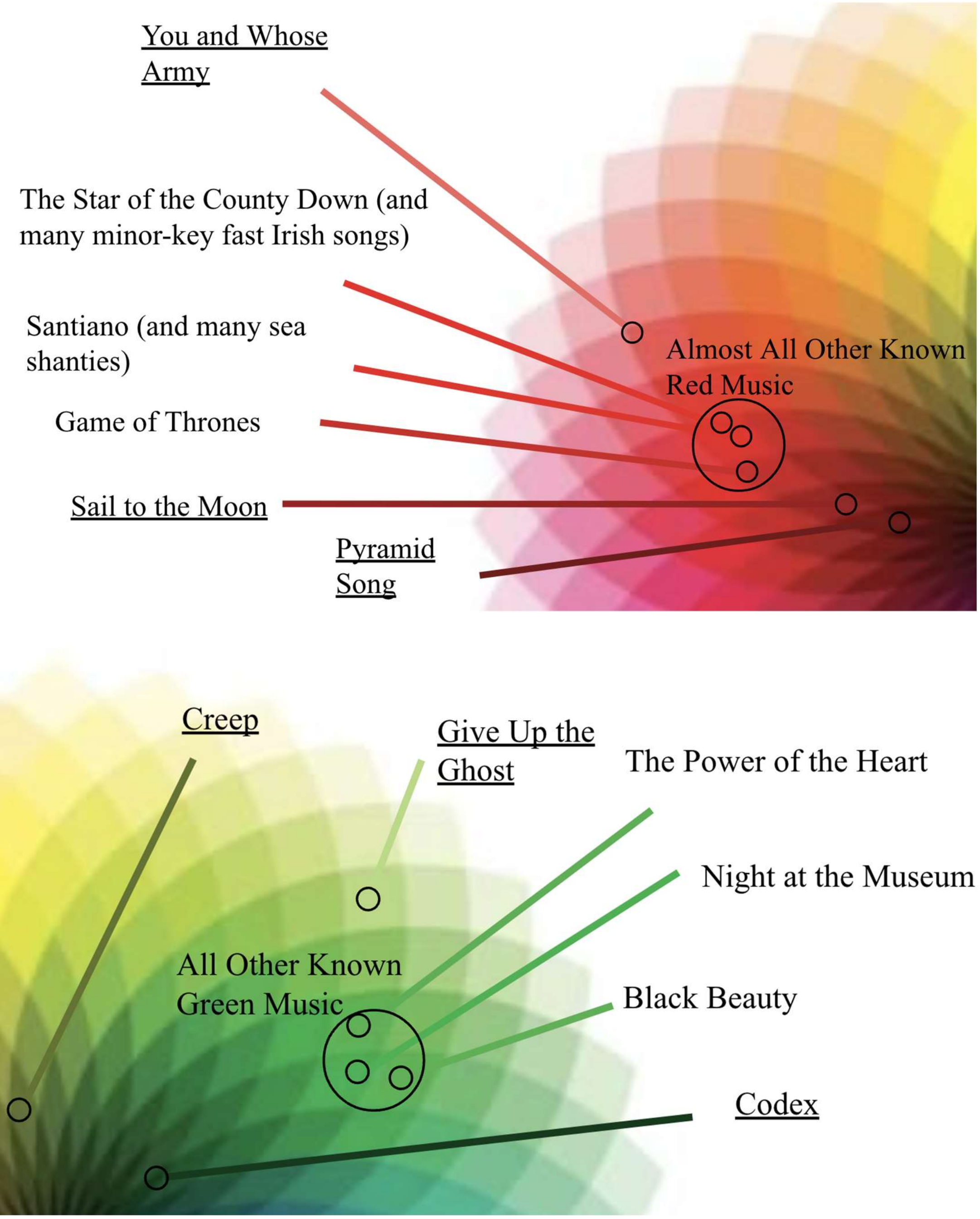

Figure 2. Radiohead colors are separate from other composers/artists

In each of these cases, Radiohead's colorful tracks (underlined) are significantly separated from the colors created by almost all of the other songs or compositions that Jacqueline has heard. Even to a non-synesthete, the similarity of the non-Radiohead tracks with the same color can be appreciated, while it's difficult to hear any similarity between the Radiohead tracks to the other songs of the same basic color. One of two things must be true, either of which would be very interesting: (1) each basic color may represent some combination of musical elements or environment, and the subconscious mind of a synesthete is somehow able to automatically and consistently categorize music into a handful of basic types, or (2) there are no meaningful elements in common between the Radiohead tracks and the more conventionally-colored pieces of music. This would mean that the Radiohead shades of colors are essentially new colors altogether, and implies that there are many more colors of music yet to be discovered.[2]

Something else interesting: Jacqueline experimented with different tempos and found that practically all of Radiohead's pieces lose color at precisely 1/2 speed or double speed. Only one piece seemed to be "too fast" in the sense that its range of colors was 50-100% speed. This could suggest that the tempos of the pieces were fine-tuned by a synesthete with color, literally, in mind (Jacqueline does that). It could also simply be that music for a given emotional feel generally just feels right at a particular tempo and that composers and listeners subconsciously agree about it.

By the way, if you're interested in knowing what color Thom Yorke thinks Radiohead songs are, evidently you can just pay attention to the lighting at their concerts. In the foreword to a book by his lighting and stage designer Andi Watson, Thom Yorke wrote:

> *I watch a video sometimes, and I just say to him how did you know this tune was that colour?? I guess we are firm believers in synaesthesia…we won't have even discussed it, but he just seems to know the right colour.* [5]

WHAT CAUSES A COLOR RESPONSE?

There are still many unanswered questions regarding why particular pieces of music are associated with particular colors in Jacqueline's mind's eye, but the most basic one is "what causes music to have any color at all?" Similar to how visible light only makes up a small slice of the electromagnetic spectrum, she can only perceive color for a small subset of music.

Let's use the frequency of light as a metaphor to describe the level of tonal predictability in music, with a simple repeated rhythm as the lowest "frequency" and seemingly random microtonal music as the highest frequency. Most jazz, medieval, and baroque music would be located just above the visible spectrum. Specifically, while Johann Sebastian Bach has a few pieces that have color ("Jesu Joy of Man's Desiring" is orange, "Sheep May Safely Graze" is yellow, and "Air" and "Chaconne" from Partita No. 2 in D minor are blue), it is possible that the majority of his music, while beautiful, is too complex and unpredictable to be associated with color, with multiple independent melodies

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[2] While Radiohead's song "Creep" has been noted for its similarity to the song "The Air That I Breathe" by the Hollies, Jacqueline sees the two songs as completely different colors. The song by the Hollies is mostly colorless, with yellow sections in the middle. However, the more recent song "Get Free" by Lana Del Rey does have a similar color to "Creep" (it starts as blue when it's slower and then turns into a similar shade to Radiohead's olive green and then becomes colorless in parts). So at least in one sense, Lana Del Rey's song is more similar to "Creep" than the Hollies's.

intertwining in contrapuntal patterns[3]. It may also simply be that color requires clear chord progressions along with the melody, and most of Bach's music consists of layered melodic lines. Our current hypothesis is that the visible spectrum is the subset of music with strong melodies and chord progressions, in a sweet spot between predictable and unpredictable, unobscured by strong rhythm tracks.

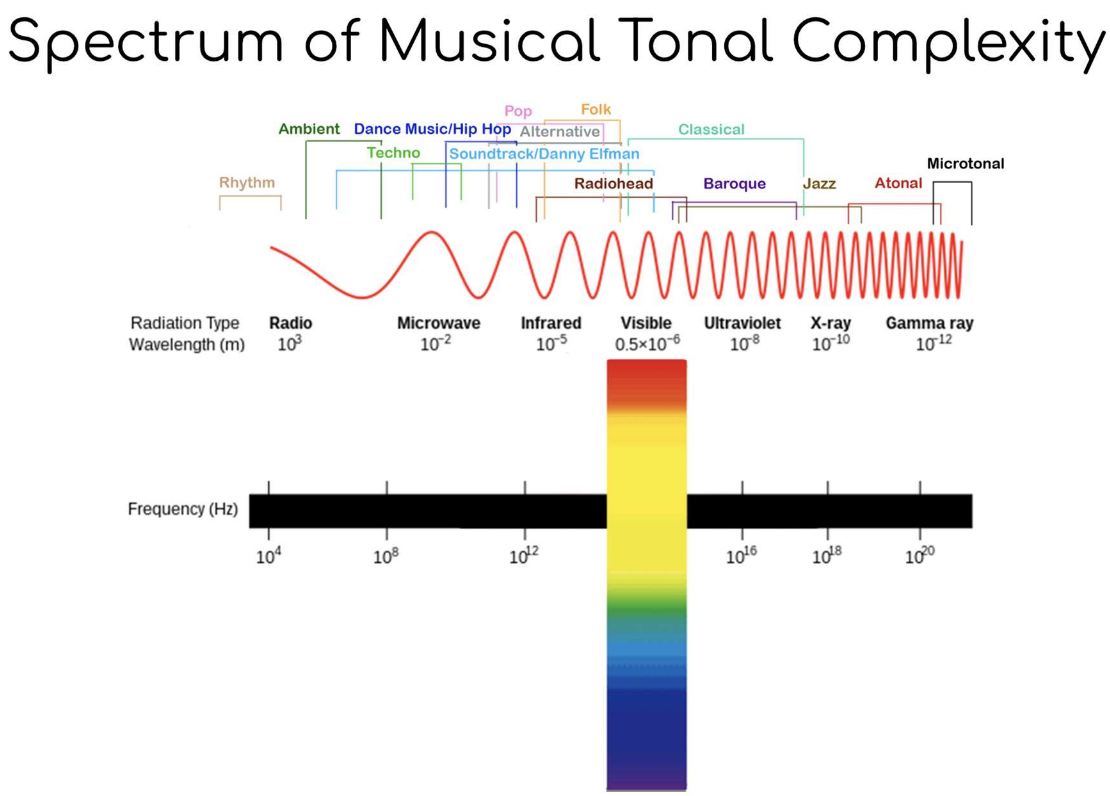

Figure 3. Colorful music is rare, similar to visible light in the electromagnetic spectrum

As mentioned earlier, Radiohead's and Danny Elfman's music spans many colors. However, most popular music is limited to yellow, blue, or colorless (the proportions of the colors in the gradient in Figure 3 approximate the likelihood of finding the various colors).

In the area of the spectrum just below the visible range is dance music / techno, which can be infectious and hypnotic, but is never colorful. Possibly, the repetitive and elemental nature of dance music and the heavy rhythmic elements puts the entire genre out of the visible range. It's not clear

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[3] Contrapuntal means following the rules of counterpoint, which are built around creating pleasing interactions between simultaneous melodies.

why rhythmic elements are destructive to color, but dance remixes of even the most vivid tracks will be colorless.

THE SCALE SPACE (INTRODUCING THE JSID)

Those creating music without the aid of synesthesia tend to use various musical scales to communicate emotions; major keys typically convey a happy or upbeat feel, while minor keys can provide a melancholy mood.

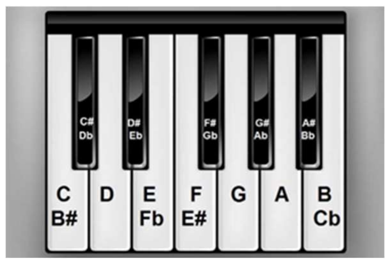

Figure 4. An octave on a piano

Consider the octave in Figure 4. If you were to play an ascending scale on the white keys starting with C, it would be a major scale. However, playing the same keys, but starting with A as your lowest note, you would hear a minor scale, which has a very different feel. Most modern popular songs reside in one of these two scales, which tends to make them sound somewhat similar. However, there are many other options to explore that can bring variety and uniqueness to musical pieces.

It turns out that there's no reason the white-key scales need to start on C or A. For example, starting the scale on D gives a distinctive medieval-sounding scale called Dorian mode. The scales starting with each of the seven tones of the major scale are called modes. Below are the seven modes, depending on the bottom note of each scale, and if you play each of them, you will notice their distinct sounds. These modes sound different because the starting note, or tonic, changes the perceived intervals and emotional character of the scale, even though they use the same set of notes.

1. C Ionian (C major)
2. D Dorian
3. E Phrygian
4. F Lydian
5. G Mixolydian
6. A Aeolian (A natural minor)
7. B Locrian

Let’s define a musical scale as a one-octave collection of notes (on an equally tempered instrument such as a piano). Each scale includes an initial lowest note, followed by 11 potential notes a half-step apart, which are either played or skipped. This means that, mathematically, there can be 2^11 = 2,048 possible scales (the first note plus all possible combinations of notes #2-12). Each scale can be identified by a distinct 12-character string of 1s and 0s where 1 means “play” and 0 means “skip” (for example, a major scale can be described as the sequence “101011010101”). The benefit of writing the sequence this way is that the scale description can be interpreted as a binary number and therefore be assigned an identifying decimal (one can use an online binary-to-decimal converter), which is its JSID. The range of JSIDs would be 2048 (a one-note scale would be one played note followed by 11 “skips”: 100000000000 in binary = 2048 in decimal) through 4095 (the chromatic scale includes all 12 tones: 111111111111 = 4095 in decimal).[4]

So, for example, a distinctive and recognizable scale is the “Lydian flat 7 scale” or “acoustic scale.” The JSID identifying (and much more clarifying) string for the scale would be “101010110110” (“play-skip-play-skip…”), which when interpreted as a binary number is equivalent to the decimal number 2742. So if someone says “Trent Reznor used scale JSID 2742…” anyone can convert the number 2742 into its 12-digit binary code and immediately be able to play the scale on a musical instrument.

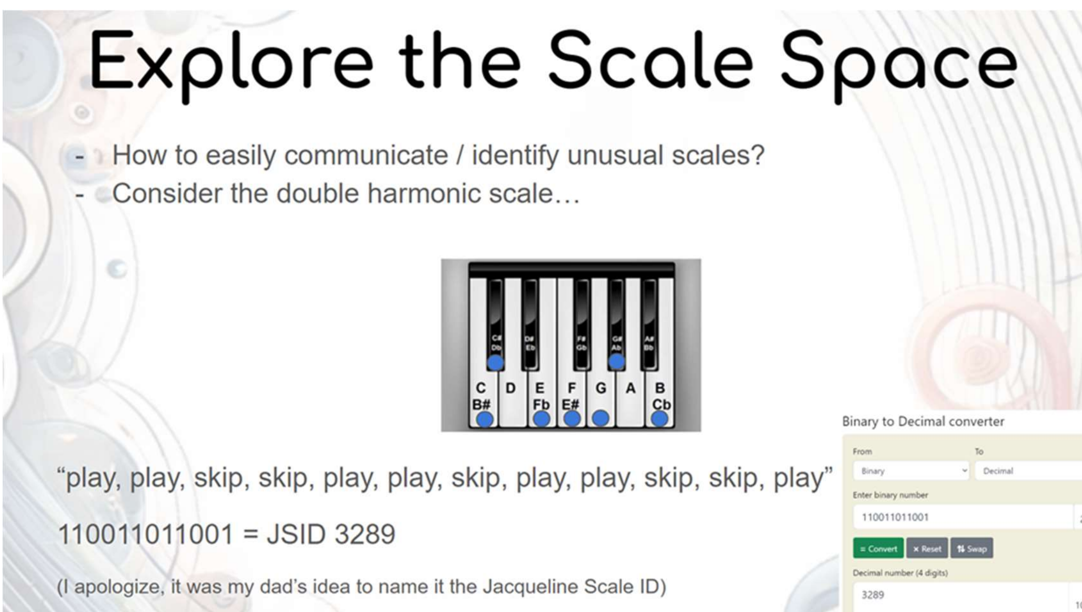

Figure 5. Slide from presentation demonstrating representation of a scale as a JSID

[4] Similar binary encoding of musical scales was introduced by Andrew Duncan in 1991 in his work on combinatorial music theory [10]. While we developed the JSID format independently, it can be considered an extension of this idea which includes notation for directionally distinct (like the melodic minor scale) and multi-octave scales.”

For clarification, every scale with the same JSID can be played with any starting note. Even the seven modes mentioned earlier (all modes are scales but not all scales are modes) can be transposed to any other key and still sound much the same. So that means that while we may refer to "Dorian" as a single scale with one JSID, there are technically 12 similar-sounding Dorian scales starting with each of the 12 distinct keys. We do not specify where the scales start, only the relation of the notes to the initial pitch.

Below are some familiar scales and modes from the "scale space," encoded with their JSID. Note: multi-octave scales can be multiple JSIDs separated by a "/" to denote that the scale is still ascending, while scales that differ on the descent (like melodic minor below) can be represented with a "\" indicator. The first binary number would be played left to right for the ascending part of the scale followed by the second binary number played from right to left for the descending part of the scale).

Melodic Minor	JSID 2901\2906 = 101101010101 and 101101011010
Harmonic Minor	JSID 2905 = 101101011001
Major Pentatonic	JSID 2644 = 101001010100

The Modes

1. Ionian (Major)	JSID 2773 = 101011010101
2. Dorian	JSID 2902 = 101101010110
3. Phrygian	JSID 3418 = 110101011010
4. Lydian	JSID 2741 = 101010110101
5. Mixolydian	JSID 2774 = 101011010110
6. Aeolian (Natural Minor)	JSID 2906 = 101101011010
7. Locrian	JSID 3434 = 110101101010

Other Miscellaneous Scales

Lydian flat-7 or Lydian / Mixolydian	JSID 2742 = 101010110110
"A Scale Has No Name" (Faceless Man from GoT) [5]	JSID 2778 = 101011011010

[5] Jacqueline was watching Game of Thrones when she noticed that when a character known as "the Faceless Man" appeared on screen, he was accompanied by an interesting and mysterious musical scale (created by composer Ramin Djawadi). The Faceless Man had an unusual way of speaking, avoiding pronouns and using "a man" when referring to himself and "a girl" when referring to Arya Stark, whom he trained to inhabit any persona. Eventually, Arya reached a stage of her training where it could be said "a girl has no name." After hearing the music, Jacqueline thought it was a great example of using a musical scale to set a mood and went to the piano to find out what it was. Using her JSID method in reverse ("play-skip-play-skip…" → 1010…) she determined that the JSID was 2778 and opened up her spreadsheet of named scales she had collected and couldn't find it. Of course, she exclaimed, to her father's amusement, "a scale has no name!"

Double-Harmonic Major	JSID 3289 = 110011011001
Phrygian Dominant	JSID 3290 = 110011011010
Chromatic Scale (all 12 tones)	JSID 4095 = 111111111111
Whole Tone Scale	JSID 2730 = 101010101010
Octatonic Scale (Whole-Half)	JSID 2925 = 101101101101
Octatonic Scale (Half-Whole)	JSID 3510 = 110110110110

So why are so few of the possible scales actually found in popular music? Almost all of the commonly used scales contain seven tones (such as major, minor, or other modes), but even most of those are very rarely, if ever, used. Is there some minimum requirement that causes musicians to avoid particular types of scales? Consider the Locrian mode, which may have never been consistently used throughout a popular song (although Björk gets an honorable mention for her song Army of Me, which heavily uses Locrian but slips out of it when she includes the perfect 5th in the chorus) [7]. We believe the avoidance of Locrian along with a large chunk of these scales is precisely due to the lack of that perfect 5th (the 8th half-step). Without a perfect 5th, the home chord (typically consisting of the 1st, 3rd, and 5th notes of the scale) is a dissonant-sounding diminished chord rather than a major or minor chord like the more popular scales.

Notice a few interesting patterns in the binary representations above: (1) there are never more than two consecutive half-steps skipped (two 0s in a row), (2) other than the chromatic scale, there are never more than three consecutive half-steps included (three 1s in a row)[6], and (3) other than Locrian, the 8th digit (the perfect 5th) is always a 1. Even if we only consider scales that share these features, we are still left with a list of hundreds of scales which appear to be usable scales, and only a small minority of them are common enough to have been identified and named.

Each of these scales can provide a piece with a distinctly different feel or sound. For example, Jacqueline created short musical pieces in which the Fibonacci numbers were mapped to the double-harmonic scale, Lydian mode, and Mixolydian mode [8]. The sound and feel of the musical samples are vastly different, despite using the same sequence of scale degrees (the enumerations for the seven pitches), so the scale space represents a fruitful place for composers to explore for inspiration.

Since scales and modes can provide a distinct feel to a musical piece and Jacqueline's colors are associated with the feel of a composition, are scales and modes associated with her synesthetic

[6] A careful reader may ask why we say more than "three 1s in a row" when there are no more than two consecutive 1s in the list above. The reason is that the double-harmonic scale (JSID 3289 = 110011011001) starts with two half-steps in a row and ends with one, which means that if multiple octaves are played, those three half-steps are actually consecutive, even though it's not initially apparent.

colors? The short answer is yes. In fact, when discussing the correlations between modes and colors with her advisor at Pomona College recently, he asked if any pieces using Phrygian were red. She didn't know of any, but within a week she had composed one! This is a topic she will be exploring further.

HOW CAN THE FIBONACCI SEQUENCE BE USED TO CREATE A MELODY?

Given the challenge of composing music based on the Fibonacci sequence for the July 2024 Fibonacci conference, Jacqueline had to first find a way to connect the sequence to musical notes. The Fibonacci Sequence is a series of numbers starting with 1,1 in which each number is the sum of the two preceding numbers. Starting with F_{1}, the sequence would be…

Fibonacci numbers

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987, 1597, 2584, 4181, 6765…

Since most popular scales have seven distinct notes, modular arithmetic can be used to reset the numbers back to 1 when they reach 8 (mod 7). In this way, no matter how large the numbers get, they can be mapped to scale degrees.

Fibonacci numbers mod 7

1, 1, 2, 3, 5, 1, 6, 0, 6, 6, 5, 4, 2, 6, 1, 0, 1, 1, 2, 3, 5…

Notice that as soon as the digits "1, 1" are repeated, we have started the sequence again.[7] That means that, for the purpose of providing a sequence of pitches to use in compositions, we have gone far enough. For example, in the keys of C major and D major, the seven distinct numbers can be mapped as follows:

[7] Fans of number theory will note that the length of this repeating cycle of numbers is 16 and is referred to as the 7th Pisano period or $\pi(7)$.

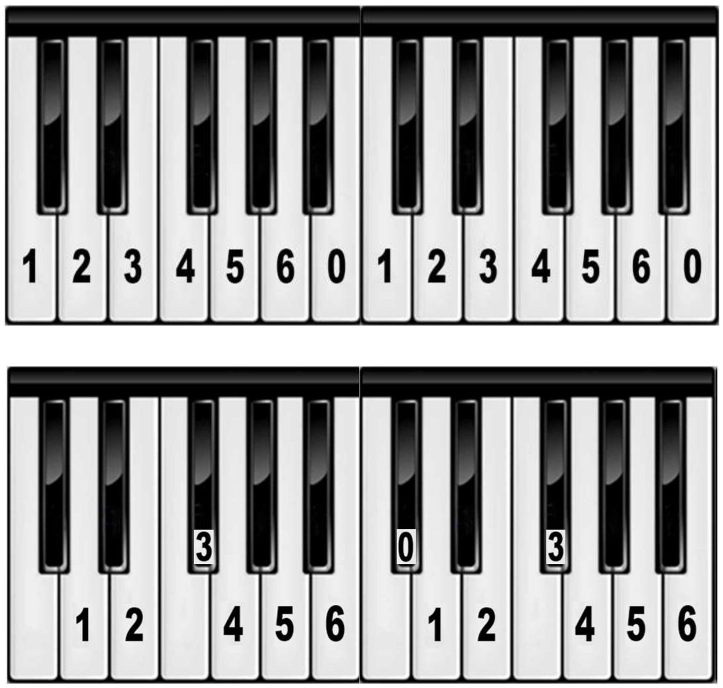

Figure 5. Mapping Fibonacci mod 7 to the C major scale (top) and D major scale (bottom)

A more intuitive way to understand how the Fibonacci numbers become scale degrees may be to "subtract sevens" until you get a number between 1 and 7. It's easier to think of the 7th scale degree as "7" instead of "0".

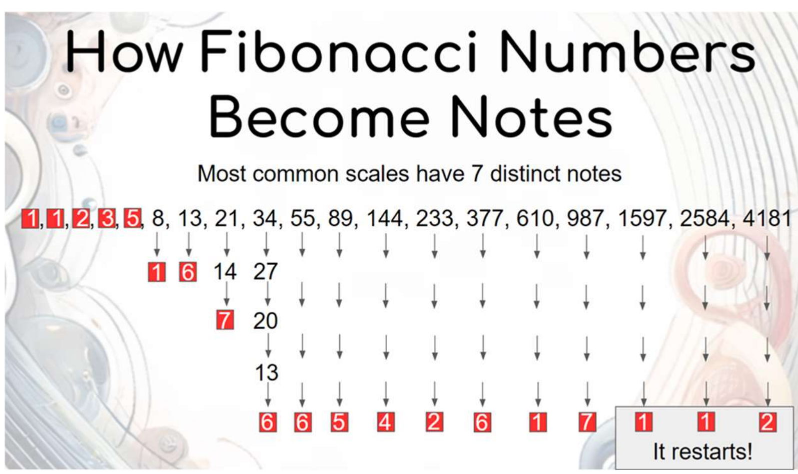

Figure 6. Presentation slide showing the mapping of Fibonacci numbers to pitches 1 through 7

This gives us a structured yet creative way to generate melodies for our experimentation in musical variations. Figure 7 illustrates the sequence of notes in the major scale that (along with accompanying chords) created a synesthetically orange piece for Jacqueline. The width of the bars corresponds to the length of time each note is held. Also note that Jacqueline chose to play notes 1, 6, and 7 in two different octaves.

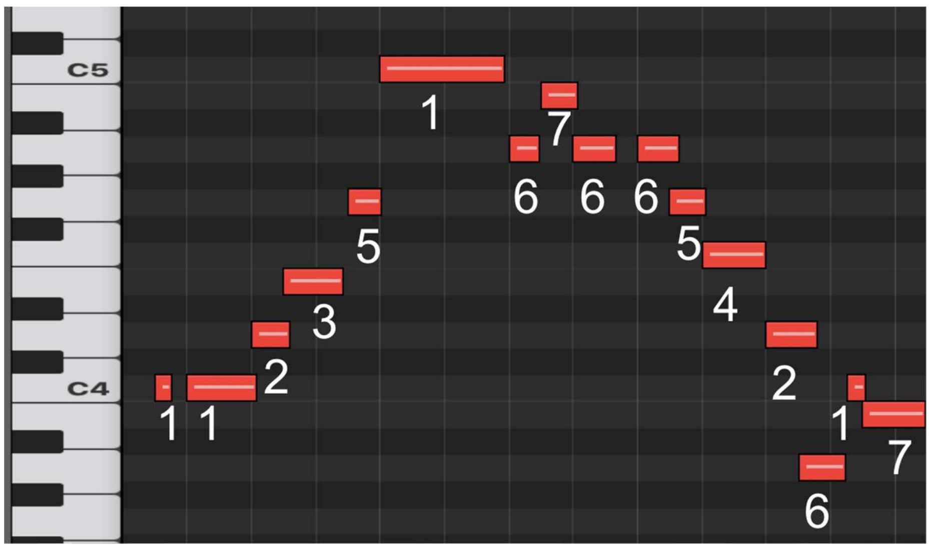

Figure 7. Fibonacci sequence mapped to the major scale

Note that mapping these numbers to the pitches of different scales would create a quite different feel, demonstrating the importance of the selection of scales or modes in composition. In contrast, if these numbers were mapped to a different *key*, such as C major vs. D major, the piece would sound practically identical, just a step higher in pitch.

THE FIBONACCI SEQUENCE IN A VARIETY OF COLORS AND SCALES

For the Fibonacci conference, Jacqueline composed samples of piano music, all including the Fibonacci sequence mapped to seven tones as described above as the melody, for each of her synesthetic colors (see SoundCloud [8]). Because her musical chromesthesia maps colors to musical moods or environments, it is quite easy for anyone to hear the difference between each of her colors and to appreciate the variety of emotional language that the selection of scale, rhythms, tempo, and chord progressions can provide. These color mappings could actually be learned by non-synesthetes. For example, Jacqueline's father, who doesn't have synesthesia, alerted her to a red composition ("The Pilot's Theme" from the movie Stealth) by the composer BT [9].

In addition to the "colorful" examples, Jacqueline composed colorless musical examples of the Fibonacci sequence in a few different scales to demonstrate the incredible variety that scales can provide. Given that there are hundreds of interesting scales to choose from, we believe that many more potential pieces could be created, all of which contain the Fibonacci sequence in their melody but would sound like distinct pieces.

There are a vast number of soundscapes and emotional environments yet to be discovered, and composers should embrace the challenge of finding them, "explore the scale space," and expand their toolboxes to include more modes and scales outside of major and minor. Also, making the effort to recognize and identify the musical elements that can cause a variety of synesthetic colors can expand a composer's palette and open up possibilities for new moods they may not have considered. Music is more than just a way to "decorate time[8]," it can be a language for expressing a specific environment. We hope that this discussion of the vastness of music will inspire composers to expand their musical vocabulary to enable them to express themselves when words fail.

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[8] Jean-Michel Basquiat famously wrote "Art is how we decorate space, music is how we decorate time."

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