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Creating Music and Texts with Flow Machines

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Abstract

This chapter introduces the vision and the technical challenges of the Flow Machines project. Flow Machines aim at fostering creativity in artistic domains such as music and literature. We first observe that typically, great artists do not output just single artefacts but develop novel, individual *styles*. Style mirrors an individual's uniqueness; style makes an artist's work recognised and recognisable. Artists develop their own style after prolonged periods of imitation and exploration of the style of others. We envision style exploration as the *application* of existing styles, considered as *texture,* to arbitrary constraints, considered as *structure*. The goal of Flow Machines is to assist this process by allowing users to explicitly manipulate styles as computational objects. During interactions with Flow Machines, the user can create artefacts (melodies, texts, orchestrations) by combining styles with arbitrary constraints. Style exploration under user-defined constraints raises complex sequence generation issues that were addressed and solved for the most part during the first half of the project. We illustrate the potential of these techniques for style exploration with three examples.

Introduction

The word "creativity" has become so popular that virtually every noun, when coupled with the adjective "creative", becomes hype: creative writing, creative thinking, creative problem-solving, creative accounting, creative finance. Creativity has become a modern myth [Bartezzaghi 2013] and the nucleus of Western working life [Florida, 2002]. Accordingly, research on creativity is developing rapidly. The "science of creativity" focuses on topics such as creative behaviour, motivation, evaluation, correlations with other aspects of personality, social influences and other themes that we briefly review here.

Concepts and definitions of creativity

Creativity is a relatively recent target of scientific attention and social praise. In Ancient Greek, the ability to create was often related to divine inspiration [Albert & Runco 1999]; for instance, in the dialogue that Plato devotes to the sources of

artistic creation, the Ion, Socrates argues that art cannot be defined as a set of skills but as the outcome of the *enthousiasmos*, a sacred inspiration whom the poet has to obey. In the 20th century debate this mystic notion has disappeared from the Western concept of creativity, passing through a phase of transition: the study of "Genius", conceived as an exceptional and superhuman quality, during Romanticism [Duff 1767]. In the course of time, focus shifted from external, imponderable forces to the active processes taking place inside the creator's mind. Examples of this perspective shift are given by [James 1880], who describes for the first time a process that today we would label as divergent thinking[1], or Francis Galton, who, observing his own chain of thoughts during a whole day, tried to understand which mental associations lead to new ideas. Nevertheless, creation is sometimes described as a supernatural activity by artists accounting for their experience: "This is the doom of the Makers — their Daemon lives in their pen […]. When your Daemon is in charge, do not try to think consciously. Drift, wait, and obey." (Richard Kipling, from *Something of Myself for My Friends Known and Unknown*, 8 (1937), quoted in [Lubart 2013].

This appropriation process led to a democratisation of the subject itself: today, creativity is considered a resource that everybody can apply to every context, and not a prerogative of a few exceptional individuals. While, during the early days, famous artists and inventors were the main focus of creativity research (see [Rossman 1931] and [Cox 1926]), later on the discrimination between "eminent creators" and laymen has been substituted by the one between "Historical" and "Psychological" creativity [Boden 1990]. Psychological creativity generates P-novelty (a novelty "with respect to the individual mind which had the idea") and Historical Creativity generates H-novelty (a novelty "with respect to the whole of human history").

Today, most researchers agree to define creativity as the production of an *original* result *fitting* in a specific context. This is the consensual definition of creativity proposed by [Lubart 2003]: "creativity is the ability to realise a production at the same time new and adapted to the context to which it is applied."

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1 "Instead of thoughts of concrete things patiently following one another in a beaten track of habitual suggestion, we have the most abrupt cross-cuts and transitions from one idea to another, the most rarefied abstractions and discriminations, the most unheard-of combinations of elements, the subtlest associations of analogy; in a word, we seem suddenly introduced into a seething caudron of ideas, where everything is fizzling and bobbing about in a state of bewildering activity, where partnerships can be joined or loosened in an instant, treadmill routine is unknown, and the unexpected seems the only law". [In Horn, J.F., (2014) Creative Confluence, Linguistic Approaches to Literature, John Benjamins and Becker, M., (1995), Nineteenth-Century Foundations of Creativity Research, Creativity Research Journal, Vol.8, Issue 3].

Creativity research and the individual

Although accounts and considerations about creative minds were published before the 1950s [Runco 1999], it is J. P. Guilford, founder of the first Conference on Creativity and advocate of creativity among the American Psychological Association, who can be considered the "father of creativity" [Sternberg 2001]. Thanks to Guilford's research, creativity has begun to be considered as a trait of individual difference. Since then, creativity research has taken the route of the so-called 4P's model: "person" (the characteristics of the creative individuals), "processes" of the creative behaviour, "press" (influence of the environment and evaluation) and creativity's outputs, or "products".

Person: psychological traits and emotions

Studies on creative individuals have identified many psychological traits, behavioural characteristics, social and historical features correlating with creative behaviour.

These studies show that creative individuals follow intrinsic motivations [Conti 1999] [Stohs 1992] (an internal need or desire), rather than external motivations (for example: pleasing a professor, receiving a reward, winning a competition). Following [Maslow 1943], the intrinsic need to create is so powerful that, if fulfilled, leads to the maximum degree of self-actualisation. Nevertheless, for [Eisenberg 2002], receiving a reward is directly proportional to success, and for [Gralewski 2013] intrinsic and extrinsic motivations work as a synergy.

Scholars have also extensively investigated the connection between psychological traits and creativity. One of the characteristics correlating with creativity is flexibility: the ability of being ready to change one's point of view, imagining different developments, and not being "fixed" on a solution. [Carlier 1973] gave a first definitions of flexibility and [Lubart & Georgsdottir 2004] confirmed the correlation. Other traits correlating with creativity are perseverance [Rossman 1931], tolerance to ambiguity (the willingness to accept alternate interpretations, alternate outcomes) (see [Tegano 1990] for a first definition, and [Cravens 2014] for an application to scientific creativity), openness to new situations [Zenasni 2008], independency of judgement [Barron 1981], and risk taking [Lubart & Sternberg 1995].

The correlation of intelligence (measured with IQ tests) and creativity is not unquestionably assessed. This uncertainty produced different models and theories: for an extensive review, see [Lubart 2013].

A great amount of research is also devoted to correlations between mental diseases and creativity (see the popular [Ludwig 1995], the reframing by [Glazer 2009] and a cautionary warning by [Schlesinger 2014]). Studies investigating the link between schizophrenia and creativity [Schuldberg 2001] underline a similarity of "thinking styles", since divergent thinking can have outcomes similar to schizophrenic processes [Rubinstein 2008]. The literature on psychological traits also includes insight [Sternberg & Davidson 1995], reviewed from a neuroimaging

perspective by [Dietrich 2010], intuition [Raidl 2001], Janusian processes (i.e., the ability to consider two very different perspectives simultaneously, which was examined for scientific creativity by [Rothenberg 1996]), and synaesthesia [Dailey 1997].

Regarding the influence of emotions, there is no consensus among scholars. While for [Isen 1987], recently supported by [Zenasni 2011], positive emotions foster creative behaviour, [Kauffman & Vosburg 2002] posit that negative emotions stimulate problem resolution whereas positive emotions inhibit cognitive effort. See [Baas 2008] for a meta-analysis of 25 years of mood-creativity research. [Martin 1993] introduced the "mood as input" theory, stating that opposite emotions have different influences depending on drive. In any case, arousal (versus emotional stability) seems definitively favourable for creativity [Adaman & Blaney 1995]. These results have led to the hypothesis, tested by [Kohanyi 2009], that creativity is a long-term "mood controller", protecting the individual from emotional excess and mood variability. This thesis resonates with the flow theory by [Csikszentmihalyi 1975], stating that creative activities lead to an optimal state of fulfilment (flow) where all external influences are ignored.

Press: environment and influences

Murray calls research on "press" [Murray, 1938] the study of the environment's influence on the individual. Scholars investigate how "press" inhibits or stimulates creativity, and especially the role of age, society, family, and education.

Developmental research evaluates which periods of life are more favourable to the emergence of creativity [Simonton 1988] [Jones 2011]. Without reaching a consensus, they agree on the typical shape of the age curve, which varies more over time than across fields of achievement. Early investigations have also identified "slumps" in creative abilities at certain ages [Torrance 1968].

Stemming from the observation that these "slumps" correlate with changes in the educational system, a considerable amount of research investigates the relation between school and creativity. Slumps have been ascribed to the need to conform to conventions, e.g. normative or typical behaviour, peer and teachers' pressure, the value of traditional skills over creative ones in education - but also to an increased capacity of logical thinking, or, lately, brain development [Runco 2007].

Scholars have extended their focus to cultural taboos that, within a culture, can inhibit creative behaviour. For example [Adams 1986] identified specific cultural, perceptual and emotional barriers to creativity. Family is another central node for press research; typical objects of study are family internal rules and organisation, number and age of siblings [Sulloway 1996], level of stress [Runco 2004], possible genetic inheritance of creative skills, and parental creativity [Runco & Albert 1986].

The correlation between socioeconomic status (SES) and creativity has been studied too, with the general result that a higher socioeconomic status appears directly proportional to creative thinking [Bruininks 1970], [Dudek 1994), probably because SES determines the range of available cultural experiences.

Among other topics, we find differences of creativity levels and models across cultures, conceptualized in terms of individualism versus collectivism [Triandis, 1995]. Empirical studies in this domain usually compare creativity test from individuals from different cultures, (see [Niu & Sternberg 2002] for a review on literature and results' analysis).

Finally, authors such as [Boring 1971], [Feldman 1994], [Burke 1995], and [Simonton 1984] singled out the impact of role models, war, religion and *zeitgeist* in analysing data concerning historical creative individuals.

Product: Evaluating creativity

Evaluation is an important part of research on creativity, but also an elusive topic: how is it possible to evaluate how creative a person is, or how creative are the ideas or works s/he produces? One of the first tests proposed to evaluate creativity was the Guilford test [Guilford 1967] which was intended to measure divergent thinking (DT). In the course of time the test has been modified and expanded, for instance by the famous Torrence test [Torrence 1974] which evaluates the number of generated ideas, the number of solutions proposed to a problem and the originality of subjects' answers (the frequency on a sample). DT tests are still widely used today [Furnham, & Bachtiar, 2008].

DT tests, however, were designed within the educational system, in order to identify gifted children and steer their career. Other tests are based on subjective parameters, such as self-evaluation, evaluation from experts and psychological profiling. A more recent trend displaces the focus of attention from the subject to the product of the creative process: in this method, designed and used for the first time by [Amabile 1982], the evaluation of creative objects is carried out by peers and/or experts in the field.

The creative processes

A certain number of mental skills, thinking habits and psychological skills have been identified as favourable for creativity. Notable among these, is the ability to identify and redefine problems [Csikszentmihalyi 1965], to develop analogies and metaphors supporting the thinking process (especially in scientific creativity, following the several examples given by [Holyoak & Thagard, 1995] and [Hofstadter 1985]), and divergent thinking [Guilford 1950].

Scholars investigated how these mental procedures are organized, trying to model the process of creative production. The first description of the creative process is probably [Wallas 1926], who suggested a four-stage model: preparation, incubation, illumination, and verification. The preparation phase involves problem identification, and the incubation phase is defined as unconscious, or "inactive" processing of information [Guilford 1979]. The four steps have been widely questioned and challenged, and today the model seems too simplistic to suffice (for a general discussion, see [Lubart 2013]).

Computational creativity

Creative processes play a central role in the recent debate on computational creativity, i.e. "the study and support of behaviour exhibited by artificial systems which would be deemed creative if exhibited by humans" [Wiggins 2006]. It is precisely the lack of these processes that was used as counter-argument against artificial creativity: it cannot be denied that machines can create something new and adapted to a context, but the undergoing process of "arriving there" is lacking [Boden 1999]. Nevertheless, most recent efforts in computational creativity are headed towards the modelling of such processes [Colton & Wiggins 2012].

Style development: a diachronic model for creativity

Although most creators are known for singular works, we argue that creative behaviour is primarily a style production process, rather than an artefact production process.

The traditional four-stage model (preparation-incubation-illumination-verification) and its derivatives still lack a diachronic dimension, which could account for the connection between personality, creative outputs, and external influences: style development.

In creative productions, style is so pervasive that it is difficult to circumscribe and transform in an object of observation. The term "style" is used in two different contexts and with slightly different meanings. First, style is an individual trait referring to a personal approach used by each individual to, e.g., carry out a task, learn, solve a problem, or lead a group. For instance, in this stream of research, [Runco & Basadur 1993] identified individuals with distinctive problem-solving styles, such as "generator", "conceptualizer", and "optimizer".

Second, "style" refers to "the extent to which an individual's creative output exhibits an identifiable character" [Gabora 2012], independently from the domain in which it is expressed. In this definition, style is an elusive subject and a feature largely neglected by academic literature. To our knowledge, no current theory of creativity accounts for the phenomenon of style development.

Style development in the context of creativity

Style is a feature that emerges clearly after a period of training and in relation with the *zeitgeist,* and thus it is hardly identifiable with classical creativity evaluation methods which, when applied to "P-creativity", investigate exclusively one-time creative outputs. Actually, creative outputs are related to one another and potentially pave the way for one another: style is a quality that makes sense only if applied to quantity.

To include style development in a diachronic model for creativity, we have modified Csikszentmihalyi's Flow diagram and defined style development as an extension of skills acquisition (Figure 1). When creators have acquired all the needed skills, the next natural step is to create their own, unique style. This is true

also for scientific creativity, which can be applied to different domains only starting from the required level of knowledge.

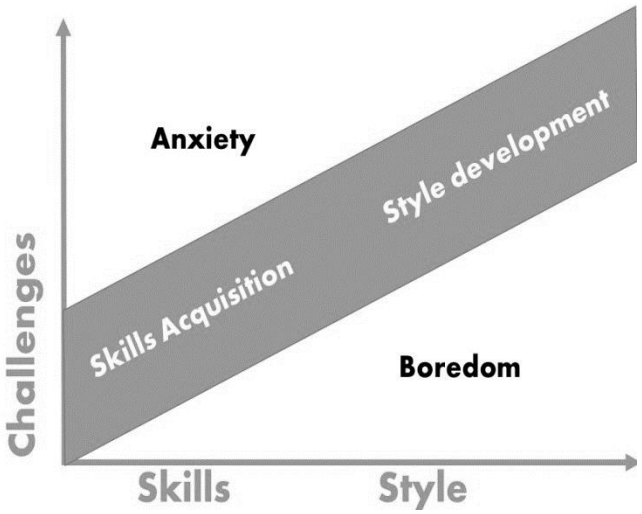

Figure 1. The diachronic Flow diagram: skills lead to style

The lithographic series of Picasso's bull (Figure 2) is a perfect illustration of the process of style development. Picasso created the bull series at the end of 1945: it is a series of eleven lithographs that develops from an academic, realist representation of a bull to a final form purged from any realism and stylised. During this process[2], Picasso erases one by one all the non-relevant information in different stages, recreating the same image while recombining and rebalancing the elements that compose it. The final abstraction is a concise image consisting in a pure one-line drawing. At the end of this process, we are left not only with the stylised image of a bull, but more importantly with a *style* that can be applied to other objects: the line drawing style of Picasso, which he applied to many productions (see Figure 3).

2 "One day...he started work on the famous bull. It was a superb, well-rounded bull. I thought myself that that was that. But not at all. A second state and a third, still well-rounded, followed. And so it went on. But the bull was no longer the same. It began to diminish, to lose weight... Picasso was taking away rather than adding to his composition... He was carving away slices of his bull at the same time. And after each change we pulled a proof. He could see that we were puzzled. He made a joke, he went on working, and then he produced another bull. And each time less and less of the bull remained. He used to look at me and laugh. 'Look,' he would say, 'we ought to give this bit to the butcher. The housewife could say: I want that piece or this one...' In the end, the bull's head was like that of an ant. At the last proof there remained only a few lines. I had watched him at work, reducing, always reducing. I still remembered the first bull and I said to myself: What I don't understand is that he has ended up where really he should have started! But he, Picasso, was seeking his own bull. And to achieve his one line bull he had gone in successive stages through all the other bulls." (An account of Picasso's assistant quoted in "Picasso's Lithograph(s) 'The Bull (s)' and the History of Art in Reverse", Irving Lavin, Art without History, 75th Annual Meeting, College Art Association of America, February 12-14, 1987)

The same process of style development is illustrated in *Abstraction of a Cow*, by Theo van Doesburg (see Figure 4), a Dutch painter belonging to the Dutch artistic courant De Stijl (the Style), whose series probably inspired Picasso's bull. The difference is that whereas Picasso's bull is a planned series, Doesburg's work is a sequence of sketches meant to support the design of the final abstract painting.

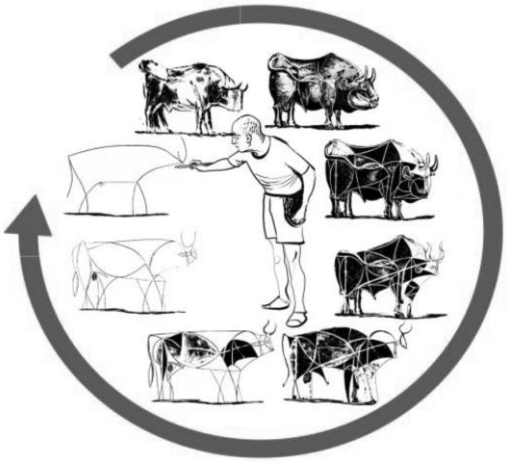

Figure 2. Illustration of Picasso's lithographic series: from realism to line-drawing style

If we had only the last images from the two series, the process of style development necessary to "get there" would go unnoticed, as well as the needed skills.

Figure 3. Illustration of Picasso's line-drawing style applied to other objects

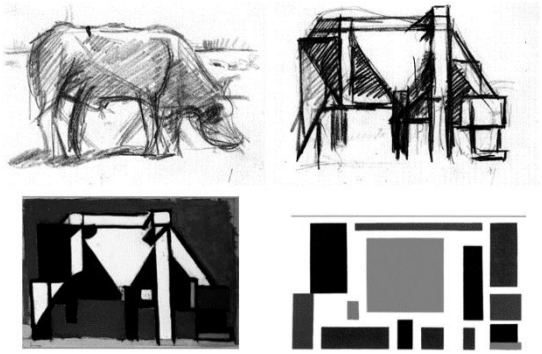

Figure 4. Theo van Doesburg, "Abstraction of a Cow, Four Stages" (1917)

Style: uniqueness and novelty

Style development, as part of the creative process, involves extensive interpretation and transformation of creative material by oneself and by others.

For example, visual artists often find a style that feels as 'theirs' only after prolonged periods of exploration with different media and established styles and art forms [Ericsson 1996]. Similarly, writers and musicians speak of the transition from a stage in which they were merely imitating the styles of creators they admired to a stage in which they felt they had discovered their own authentic 'voice' [Feinstein 2006]. Indeed, when artists have found their own voice, their creative outputs are characterized by originality and uniqueness, while expertise and experience in non-creative domains are more likely to lead to standardized performances [Ackerman 2007].

Actualising one's uniqueness could be a motivation for style development, since a sense of self-discovery due to creative activities has been observed by [Singer 2010] and is mirrored by the tendency for artists to have a more developed sense of who they are than less creative persons. Moreover, both laypeople and eminent creators assert attaining a stronger sense of themselves as unique individuals from carrying out creative activities [Gabora 2012].

Another drive of style development is the need for novelty, which for instance [Martindale 1990] explains from a historiometric point of view. Martindale posits that, when a new artistic style is developed, the works in that style are relatively simple because the style itself is so novel that they do not induce habituation (in psychology, the gradual loss of interest in repeated stimuli). Yet the longer the style is exploited, the more the society and the public will habituate to works in that style. Eventually, the potential for that style to incorporate novelty has run out, and the only way to keep avoiding habituation is to develop a new style.

Style: perception

[Gombrich 1960] considered that compiling a list of stylistic properties precisely defining artistic style was impossible. However, recent research in computer science

showed successful attempts at detecting styles in the visual domain [Castro 2014] as well as in music [Hedges 2014].

Empirical studies demonstrate the role of colour and texture in style recognition for the visual arts [Gardner 1970] and many other features, such as complexity, order, balance, and arousal potential [Berlyne & Ogilvie 1974]. These studies show that, in absence of training, style recognition is a property which is acquired after fourteen years of age [Gardner 1970]. Nevertheless, young children can potentially discern stylist features if they know how to "look" for them after a period of training [Gardner 1970]. On the other hand, musical style appears to be more discernable even among children from first through sixth grade [Campbell 1991]; even three year old children are able to make accurate discrimination between musical styles [Marshall & Shibazaki 2011].

Flow Machines: tools for style development

The above quoted study by [Gardner 1970] on style recognition demonstrated that training children in recognising styles has an effect on children's' own drawing. With Flow Machines, we exploit and expand this concept.

Flow Machines are a new generation of authoring tools aiming to foster users' creativity. Flow Machines are not creative systems *per se*: they are interactive computer programs that let users literally *play* with styles.

We focus here on sequential content, i.e. content that can be faithfully represented as sequences of items, such as text or music. In this context, we equate styles with corpora [Pachet 2013]: the style of a composer, for instance, is defined by the corpus of sequences he/she has composed, or a subset deemed representative. Of course, there is more to style than corpora, but we consider that the core problem lies not in the definition of style, but in the way styles can be playfully manipulated and tweaked to explore new ideas. How is this possible?

We consider style as malleable texture that can be applied to a structure, defined by arbitrary constraints. Applying style to well-chosen structure may lead to creative objects. Figure 5 illustrates this idea in the graphical domain: the texture of a leopard skin (the style) is applied to the structure consisting in the body shape of a rhinoceros (the constraint), resulting in the new creature on the right. The goal of Flow Machines is precisely to implement such a sum operation. Of course, no guarantee is given regarding the intrinsic quality of the produced artefact. Users play until they produce an object that they find interesting.

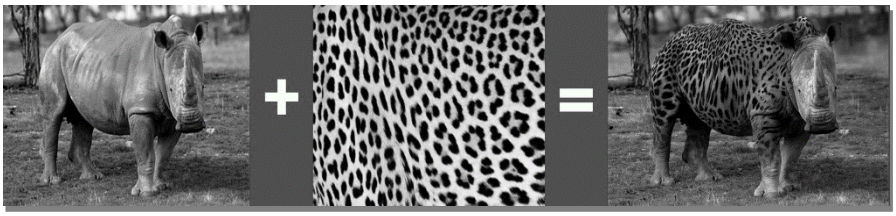

Figure 5: Constraint (structure) + Style (texture) = New object

The core technical problem

The core technical issue we are faced with is the representation of style as a computational object, amenable to such application of user-defined constraints. The project has produced novel techniques to solve this problem in the sequential domain. Style is represented by so-called Markov models, and constraints by arbitrary relationships between items of a sequence, representing situations that the user wants to explore. The description of these techniques is outside the scope of this paper and the interested reader is referred to [Pachet & Roy 2011] and [Roy & Pachet 2013][3].We illustrate here how these techniques may be used in three domains: music composition, music harmonization, and text writing, under this "style + constraint" scheme.

Music Composition

The so-called "Boulez Blues" is the result of applying the style of Charlie Parker Blues compositions (we consider here only harmony, i.e. sequences of chords) to a "Boulez" constraint that all chords be different)[4]. We exhibited the most probable of them, i.e. a chord sequence that sounds optimally like Charlie Parker (which has the highest probability in the model of Charlie Parker), while satisfying the *all different* constraint: a strange object that lies on the fringe of bebop harmony (see Figure 6).

C7 (.03)	***Fm (.06)***	***Bb7 (.57)***	***Ebm (.06)***	***Ab7 (.57)***	***Db7 (.13)***	***Dbm (.01)***	***Cm (.08)***
F7 (.57)	***Bbm (.06)***	***Eb7 (.57)***	***Abm (.06)***	***Gm (.08)***	***Gbm (.08)***	***B7 (.57)***	***Gb7 (.07)***
Bm (.06)	***E7 (.57)***	***Am (.06)***	***D7 (.57)***	***Em (.04)***	***A7 (.57)***	***Dm (.06)***	***G7 (.57)***

Figure 6. The Boulez Blues is a unique sequence of chords that is the most probable sequence in the style of Charlie Parker Blues compositions that satisfies an allDifferent constraint.

The Flow Composer system pushes this idea further [Pachet & Roy 2014a]. Flow Composer lets users generate leadsheets, i.e. monophonic melodies with an underlying chord sequence, in the style of arbitrary composers (e.g. Coltrane, Miles Davis, Wayne Shorter, Michel Legrand, etc.), or corpora (e.g. the Real Book). Users

[3] See http://francoispachet.fr/markovconstraints/markov_ct.html

[4] This constraint actually originates from the second Viennese School (Schoenberg, Berg, Webern), and the invention of the serial, dodecaphonic music principle, which states that all 12 pitch classes should appear the same number of times in a musical piece. Boulez was a major proponent of this school in France.

can generate melodies and harmonies in the style of a composer, and set arbitrary melodic and harmonic constraints [Pachet & Roy 2014b]. For example, it is possible to apply the style to specific segments of a targeted sequence (e.g. a beginning in Miles Davis' style, a segment in Wayne Shorter's style) and adding specific properties, such as "have one occurrence of a F#7 in this sequence", etc. Figure 7 is an example of a leadsheet generated in the style of George Gershwin[5] with such user constraints.

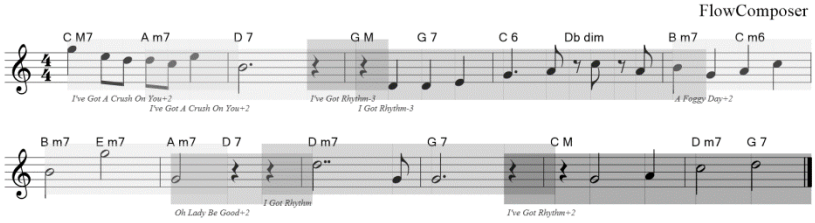

Figure 7 - An example of leadsheet generated by the Flow Composer, in George Gershwin's style with user constraints. Colors indicate the origins of the various chunks making up the leadsheet in the leadsheet database.

We have also shown that virtuosity in solo improvisation can also be modelled as a constrained Markov sequence generation problem with unary constraints holding on specific notes of the melody [Pachet 2012].

Text writing

Flow Machines can be applied to text in the same spirit. We have shown that Markov Constraints can be used to generate text sequences that were hitherto unreachable with conventional techniques. In [Barbieri et al 2012] we rewrite the lyrics of songs such as Yesterday by the Beatles in the style of any author for which we have a sufficiently large corpus. We consider properties of the original song, such as its prosody, rhymes and syntax as constraints. We then apply the style of Bob Dylan (see Figure 7), the Beach Boys or ACDC to these constraints. The resulting texts[6] satisfy the constraints, while being "in the style of" the selected author. More complex constraints can be specified on the text such as meter [Roy & Pachet, 2013]. This enables users to generate, for instance, alexandrines (verses with 12 syllables) in the style of Marcel Proust or Churchill. More prosaically, we envision email assistants able to generate phrases or paragraphs in the style of the user, while being controlled by high-level targets such as structural properties or

[5] Generated leadsheets can be found at www.flow-machines.com/leadsheetGeneration

[6] See www.francoispachet.fr/markovconstraints/markov_applet_style/lyricsgenerator.html to explore all the generated lyrics.

semantics (a phrase that talks about a particular subject).

Yesterday	Rhythmic templates	Rhyme structure
Yesterday all my troubles seemed so far away	101, 1, 1, 10, 1, 1, 1, 01	A
Now it looks as though they are to stay	1, 1, 1, 1, 1, 1, 1, 1	A
Oh I believe in yesterday	1, 1, 01, 1, 101	A
Suddenly I'm not half to man I used to be	100, 1, 1, 1, 1, 1, 1, 1, 1, 1	B
There's a shadow hanging over me	1, 1, 1, 10, 10, 10, 1	B
Oh yesterday came suddenly	1, 101, 1, 100	C
Why she had to go I don't know she wouldn't say	1, 1, 1, 1, 1, 1, 1, 1, 1, 1	A
I said something wrong now I long for yesterday	1, 1, 10, 1, 1, 1, 1, 1, 101	A
Yesterday love was such an easy game to play	101, 1, 1, 1, 1, 10, 1, 1, 1	A
Now I need a place to hide away	1, 1, 1, 1, 1, 1, 1, 01	A
Oh I believe in yesterday	1, 1, 01, 1, 101	A

Figure 8: "Yesterday" by the Beatles yields a set of constraints, taken as a structure.

Innocence of a story I could leave today
When I go down in my hands and pray
She knocked upon it anyway
Paradise in the dark side of love it is a sin
And I am getting weary looking in
Their promises of paradise
Now I want to know you would be spared this day
Wind is blowing in the light in your alleyway
Innocence in the wind it whispers to the day
Out the door but I could leave today
She knocked upon it anyway

Figure 9. The style of Bob Dylan is applied to constraints, to yield new lyrics.

Harmonisation

In the same vein, Flow Harmoniser lets users harmonise leadsheets in the style of any arranger [Pachet & Roy 2014b]. With this system, styles of arrangers can be applied to melodies (considered as constraints) which are outside of their original context. With Flow Harmoniser, users can generate harmonisations[7] in the style of award-winning vocal group Take 6, as well as in the style of classical composers such as Wagner. Figure 10 shows the jazz tune "Giant Steps", composed by John Coltrane, harmonised in the style of Wagner. The musical output definitely sounds Wagnerian yet follows strictly the Giant Steps melodic line.

[7] See www.flow-machines.com/harmonization for more examples of harmonisations

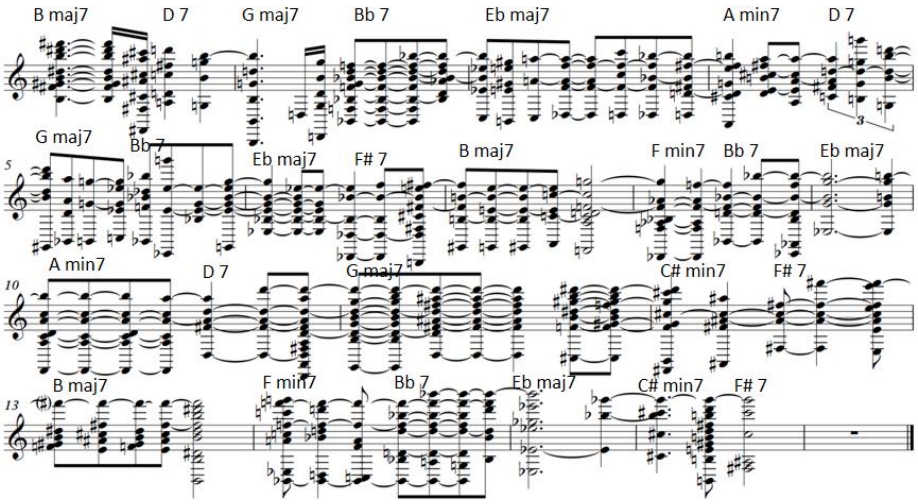

Figure 10: Giant Steps harmonised by Wagner: yet another novel object created by applying a style (Wagner) to a new constraint (a leadsheet).

The big questions

The Flow Machines project raises many conceptual and technical issues concerning the reification of style, i.e. its representation as a computational object. A key question concerns the relation between style and probabilities. A sequence that has a high probability in a given statistical model is not necessarily stylistically recognizable for humans, because it may use many commonly used words: notions of typicality should ideally be incorporated to control generation more intuitively. Other questions concern the mathematics of style exploration. Generating sequences from a statistical model that satisfy arbitrary constraints raise, in general, complex combinatorial problems. Some of them have been solved in the course of the project: unary constraints, cardinality and meter, as well as max order [Papadopoulos et al., 2014]. Others are still subjects of research. For instance, "nice melody" generation should involve not only Markovian properties but also specific *distributions*, such as 1/f [Voss & Clarke, 1975].

Beyond these technical issues, we believe that explicit style manipulation is a key mechanism in style creation, and therefore in creativity development. Preliminary results show that this vision can be turned into practical applications, and related experiments will allow us to generate novel data. In particular, it will be possible 1) to track the evolution of one's style in correlation with creativity assessments, and 2) to evaluate the impact of a computational "creative assistant" such as a Flow Machine on style development. Preliminary results have been

obtained in the domain of musical creativity, where the positive effects of a computational system conceived by our team (MIROR IMPRO) on untrained children and young pianists have been measured [Alexakis 2013].

We therefore envision that a computational study of style could improve and expand not only individual artistic productions but also our general understanding of the creative process.

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