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Theoretically Automated Conversations: Collaborative Artistic Creativity for Autonomous Machines

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Abstract

The race is afoot to build fully autonomous systems that equal human performance capacities, particularly for autonomous driving and navigation situations. If we are to create fully autonomous intelligent systems made to successfully interact with humans, fundamental questions pertaining to complex human cognition such as improvisatory and collaborative real-time adaptive problem-solving, decision-making, and action must be seriously addressed, solidly understood, and adequately integrated. To address such high-order human cognition, experiments can no longer be singular and reductive; instead, they must implement relevant observations from spontaneous human behavior within real-world dynamic contexts and innovate sensory-rich experimental paradigms to reliably elicit and record behavioral, physiological, and neural output. With these goals in mind, this paper's contribution is three-fold: (1) I lay out the motivating and increasingly specific theoretical factors behind original multidisciplinary cognitive behavioral research in the domain of spontaneous human-human communication dynamics within an artistic multisensory context; (2) I break down improvisatory problem-solving and decision-making processes within the performing arts (i.e. drama and music); and (3) I discuss analogous collaborative human-machine interaction situations for autonomous vehicle research and development.

Introduction

The discussion and amount of research dedicated to the effective, efficient, and safe development of autonomous intelligent machines, particularly driverless cars, has been steadily increasing. As this paper will present, the research and development sector is poised to gain from a multidisciplinary perspective that fully recognizes the value of and integrates the cognitive and behavioral sciences and the arts. I introduce the motivating scenario behind the issues addressed in this paper with the following fictitious dialogue between an imaginary interviewer and their interviewee:

> **Interviewer**: *All of this talk of human-like intelligent machines reminds me of a 1949 Ray Bradbury short story–* [1]
> **Interviewee**: *Of course,* Marionettes, Inc.*! I stumbled upon it during college. I confess I didn't think much of it until I had read it a second and third time during graduate school while studying cognitive science. It's only a handful of pages but it's deep, actually filled with implicit computational assumptions, ethical dilemmas, and societal consequences*.
> **Interviewer**: *Oh yes, it's quite mighty for its length! Let me remember the story: a husband has been seduced into secretly buying an exact robotic replica of himself from the company, Marionettes, Inc., in order to eschew his hateful wife and domestic responsibilities in favor of freedom. At the same time, his friend, whom he informs about the availability of robotic replicas, learns that he has already been duped by his own wife with her own secretly ordered and functioning robotic replica.*
> **Interviewee**: *Right! And just as the other husband is about to happily jet off to Rio on his own, his robotic replica confronts him about the unfairness of his actions! Here's the rub. If you think about these replicas, it's a wonderful feat of engineering and computation: they not only look and smell exactly like their human doubles, but they move exactly like them, reason like them, react like them, have feelings and intentions and, wait, the big one… are aware of those feelings and intentions!*
> **Interviewer**: *And, a buyer with dominance over his specialized purchase has every reason to believe he can order his purchase around. Talk about this robot's ability to reason about abstract concepts like ownership and retaliation.*
> **Interviewee**: *Exactly! And this robot is most humanlike because it can learn; it perceives and analyzes its situation, confronts itself, knows its owner has subjective experiences too, and can behave to change the course of events. Now imagine walking into a lab to purchase your very own conscious, intelligent, and sentient double for better or for worse…*
> **Interviewer***: Looks like we'll have robot rights' issues to start contemplating now...*
> **Interviewee**: *Indeed. But we have quite a long ways to go before robotic versions of ourselves!*

I begin with a nod to Bradbury's short story because it highlights a key point in our (fantastical) expectations regarding future successful human-machine interaction: machines may be equal to us at the physical, behavioral, and cognitive levels. Restated, not only will they look like us, but *be* like us in all our imperfect, variable, sentient, intelligent, and conscious ways. Not an easy feat but neither an entirely impossible one. *Marionettes, Inc.*, however, is about robotic humanoids. How does this relate to autonomous machines, particularly in the domain of driverless cars? The answer is: in many ways. The point I endeavor to argue for more aggressive and nuanced attention is the following: the recognition of a multifaceted situation and its real-time relationships and their consequences, whether spontaneous immediate and/or long-term, is a high-level intelligence phenomenon. This phenomenon not only will underlie the successful accomplishment of an intelligent marionette double, but the effective, efficient, and safe interaction between humans in their conventional cars and automated driverless cars as we transition into an eventual era of only fully autonomous vehicles. This human-level perception and cognition means at least considering these three issues more significantly:

(A) The space in which navigation occurs is multisensory and continually changing – much more than a single driver is on the road at any given moment and no two drivers, pedestrians, animals, and/or objects are the same in terms of trajectory, goals, and/or size/density, not to mention changing weather situations. There is acceptance and a recent surge in the need to integrate the dynamism and uncertainty of a particular space within the machine's decision-making algorithms as in, for example, [2], [3].

(B) Human emotions are live and continually changing – whether caused by the driver or pedestrian's prior mood or due to the current environmental situation, emotions are variable and affect behavior in both positive and negative ways. There has been incipient interest in identifying and integrating very simple human internal states and resulting behavioral changes into the machine's decision-making algorithms [4].

(C) The symbiotic relationship between the environment, individuals, and their separate internal states (e.g. emotions, goals, risk levels), and the collaborative communication between individuals is an essential part of human life – the back and forth give and/or take interactivity and negotiation that occurs between two or more parties is paramount for agreement and a mutually successful outcome. While somewhat mentioned in passing in [5], this phenomenon has not been fully addressed and/or mastered computationally. In spite of this, sales of fully autonomous driverless cars are predicted to enter the market by 2020 [6].

Figure 1 illustrates a real-life urban traffic situation common in one of the most dense cities of the U.S. and visually underscores the imperative need to integrate the above, particularly the cumulative implications of (C) to maximize the likelihood of effective, efficient, and safe human-machine interaction on all types of possible roadways and conditions.

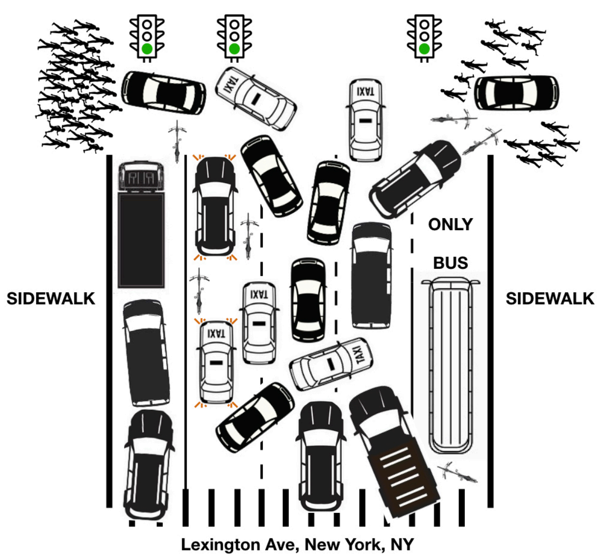

Figure 1. A representative diagram of daily traffic on a block along Lexington Avenue in New York City, NY. Diagram was created based on multiple observations of impromptu traffic situations as a frequent driver on this street. From farthest left and in the first lane there are parked service vans and trucks and a pedestrian crowd crossing the street. In the second lane there are two cars randomly parked with flashers and cyclists maneuvering around them as well as other cars. In the third and fourth lanes, cars, SUVs, vans, and service trucks drive bumper-to-bumper creating improvised lanes to pass the parked cars and each other. In the fifth lane, the bus lane, cyclists and a SUV intercept the bus as pedestrians cross the street. The diagram illustrates the reality of bumper-to-bumper improvised and chaotic movement of traffic, not to mention the often seen intervention of horse-drawn carriages and construction crews and/or police enforcement (not pictured), in a constricted urban space.

I present Figure 1 to make explicit that key questions research and development in this area must focus on are those relevant to understanding the nuances of creative thinking and execution processes within open-ended environments. Crucially, how do we humans integrate relevant bottom-up information with relevant top-down information at just the right moment to combine, recombine, predict, signal, and transform information to result in a new action and/or object? Moreover, and of particular interest in this situation, how does spontaneous improvisatory ideation and goal-making arise as a human adapts online to her changing multisensory world? Moving this question from singular to plural, how do two or more humans coordinate spontaneous improvised ideas as they adapt to their changing multisensory world?

Insights from the Arts

These questions ironically come at a time when brain scientists seem to have forgotten that our brain has a mind, belongs to a body [7], and does not exist alone in a sterile laboratory environment. I return to a key point George Lakoff made in the eighties in his book on categorization and the mind titled *Women, Fire, and Dangerous Things* [8]: "Human reason…grows out of the nature of the organism and all that contributes to its individual and collective experience: its genetic inheritance, the nature of the environment it lives in, the way it functions in that environment, the nature of its social functions, and the like. …it is not incidental to the mind that we have bodies, and that the capacity for understanding and meaningful thought goes beyond what any machine can do." (p. xv-xvii)

This section lays out the motivating and increasingly specific theoretical factors behind original cognitive behavioral research in the domain of human-human communication dynamics that leads to the breakdown of various principal elements involved during the spontaneous generation of creative behavior within a multisensory artistic platform.

1.0. Human interaction with the world is multisensory/multimodal.

2.0. Efficient and successful interaction with the world necessitates human behavior to adapt to continuously changing environments.

3.0. Adaptive behavior is a result of integrated top-down and bottom-up information processing.

3.1. Adaptive behavior recruits such higher-order cognitive functioning like knowledge retrieval from long-term memory and integration, planning, imagination, creative thinking, and problem-solving with incoming information retained in short-term memory.

3.2. Adaptive behavior is assumed to have a positive outcome both in the moment and in the immediate future.

4.0. Understanding how adaptive behavior operates in multisensory environments has direct consequences for building sensitive human-computer interfaces that require human interaction, interference, supervision, and/or indirect engagement.

4.1. Any computer system considering real-time human intervention in order to successfully operate must articulate a system capable of integrating spontaneous human problem identification, solution finding, and decision-making choices.

4.2. Any computer system considering real-time full autonomous maneuvering to successfully operate among humans must articulate a system capable of integrating the online decision-making choices made by nearby humans.

4.3. Empirical work on spontaneous adaptive behavior must focus on the integrative aspect of top-down and bottom-up information processing in order to be useful.

5.0. A complex, observable behavior that serves as an excellent empirical model for studying real-time adaptive thinking and maneuvering is spontaneous, in-the-moment creative ideation and production as performed by a single individual.

5.1. Moving beyond a single individual engaged in spontaneous creative ideation and production and investigating a group of individuals engaged in such behavior underscores the information necessarily shared for successful and efficient collaborative communication. This type of setup is known as "group creativity" and promotes interactional synchrony [9] and, crucially, integrates mutual prediction and signaling.

5.2. Any computer system considering real-time full autonomous maneuvering to successfully operate among humans must articulate a system capable of integrating itself within the situational group creativity nearby.

6.0. Under the cybernetic viewpoint, humans are complex goal-directed systems who interpret, intend, and anticipate/expect in an effort to solve problems presented by the environment [10].

6.1. Human-to-human interaction is a dynamic, communicative, and complex process that involves many interdependent linguistic, physical/gestural, and emotional cues, among others, defined by nature and nurture.

6.2. Cues exchanged undergo interpretation and transformation as defined by nature and nurture.

6.3. As humans interact with their environment, anecdotally, any number of cues are given greater weight of importance depending on the context and navigating space in question as problems are identified and attended to.

6.4. Identification of precise cues in various contexts can offer precise data sets towards building more efficient hypotheses about human decision-making within yet-to-occur online problem-solving situations.

7.0. Understanding the type and amount of shared information during spontaneous creative ideation and production in a collaborative setting can reveal key characteristics of human attention and focus, as well as the influencing elements (both bottom-up and top-down) leading to the spontaneous generation of new ideas and the consequential productive output.

7.1. Making sense of how this dynamic behavior arises, formulates into action, transforms across time, and harmonizes into a final product with a positive (adaptive) outcome has direct implications for human-computer integrative systems that depend on human real-time intervention and/or no internal human intervention but outside human interaction to function completely, correctly, and reliably over a period of time.

8.0. A unique platform to empirically study collaborative creative ideation and production are the Arts.

8.1. The Arts are multisensory/multimodal human-created environments.

8.2. Given the similar, if not identical, cognitive processes engaged during the active perception and creation of the arts as in other highly complex problem-solving, decision-making, and adaptive situations, the Arts offer unique environments from which to learn, mimic, and understand for consequent application.

8.3. La Petite Noiseuse Productions has pioneered a merged artistic –theatre and film– and scientific –cognition– platform to empirically address the points above within the visual, literary, and performing arts [see [11], [12], and [13] for details].

8.4. This platform is supported on stage during live public performances and includes the creation of novel scripted actors' dialogues specifically written to incorporate one or more musicians improvising music in reaction to both (i) the actors' dialogues and body language and (ii) the overall storyline. Figure 2 shows three theatre sets created for three different theatrical productions.

8.5. The multidisciplinary nature (science-art integration) of this innovative platform offers a wealth of novel musical output improvised in real time and exemplifies real-life interactive communication and negotiation that brings together two symbolic languages (i.e. natural and musical).

8.6. The merging of scripted natural language and improvised musical language provides rich behavioral data from which to infer what humans interpret, intend, relate, and anticipate/expect –either individually or within a group– as they spontaneously and creatively maneuver within an artistic environment in pursuit of the production of a coherent artistic object (i.e. overall goal).

8.7. Music does not convey meaning in the way linguistic expressions do in natural language. Simply stated, language conveys propositional thought, music enhances affect [14]. Adding improvised musical language to scripted natural language provides an empirical setup for what music will express and how it will do so during a live, public artistic performance.

Figure 2. Snapshots from three theatre sets of three different theatrical productions created to mimic possible real-world multisensory environments.

Results from Center Stage, Under the Spotlight

Tables 1 and 2 summarize the primary cognitive behavioral processes identified from the analysis of musical-linguistic results obtained from ecologically valid and multisensory artistic experiments [see [11], [12], and [13] for setup, procedure, data].

Table 1: Breakdown of the spontaneous creative process of one musician improvising musical output as part of the real-time goal to produce an optimal coherent artistic experience.

Agent	Solo Musician (M_1)	
Task at Hand (overall goal)	Generate novel musical outputs (MOs) that fit/match the changing audiovisual space in real time	
Ideation (defined by)	Bottom-up Information (Incoming sensory stimuli)	Top-down Information (Knowledge and experience)
	• Actors' scripted dialogue • Actors' body language • Set design (e.g. lighting, furniture) • In-the-moment executed musical outputs	• Instrument's characteristics • Established rules & norms in music • Individual style
	Narrative built from emotions and non-emotion concepts	Translation of emotions and non-emotion concepts
Decision Triggers (determined via Agent's judgment) ❖ Bottom-up stimuli filtered through top-down knowledge schemas	• *Narrative saliency*: what is most salient (S) in the audiovisual space? ❖ Least salient, least significant → more risk against expectation • *Cognitive consonance*: how close can the musical output (MO) be to S item identified? ❖ Greater distance, greater dissonance → more risk against expectation • *Novelty*: how far away is the MO from expected representation? ❖ Greater distance, greater novelty → more risk against expectation	
Executed Behavior most probable action (narratively more general) least probable action (narratively more nuanced)	1. Scene representation = interpretation of overall narrative mood 2. Character representation = interpretation of individual actors' emotion(s) and/or body language 3. Character signature/leitmotif = interpretation of individual actors' repeated mental/physical state(s) with repeated MOs 4. New scene representation = interpretation of new overall mood 5. Random non-salient narrative items = interpretation of individual words, phrases, and/or on set objects (choice dependent on time (t) perceived available for execution) to buttress any of 1., 2., 3., or 4. 6. Random non-instrumental use = interpretation of nearest available object as tool to execute any of 1., 2., 3., 4., or 5. to buttress any of 1., 2., 3., 4., or 5. 7. Random narrative synthesis outside specific scene narrative items 1., 2., 3., 4., 5., or 6. executed for musical flow = interpretation of overall created melodic, harmonic, and rhythmic stimuli (choice dependent on: (i) t perceived available for execution, (ii) loss of musical idea(s) and path taken to search for new idea(s), and/or (iii) personal emotional state)	
Ideation Continues (piggybacking on already executed behavior)	Agent checks 1., 2., 3., 4., 5., 6., and 7. in real time with her/himself for: - *Narrative saliency* levels - *Cognitive consonance* attributes - *Novelty* characteristics	
	Risk assessment: Level of risk taken on each behavior dependent on Agent's personal style (i.e. willingness to hedge uncertainty) as filtered through Agent's threshold of allowable novelty.	

Table 2: Breakdown of the spontaneous creative process of more than one musician collaborating to improvise musical output as part of the real-time goal to produce an optimal coherent artistic experience.

Agents	Group of Musicians (M_N)	
Task at Hand (overall goal)	Negotiate the generation of novel musical outputs (MOs) with others that fit/match the changing audiovisual space in real time	
Ideation (defined by)	Bottom-up Information (Incoming sensory stimuli)	Top-down Information (Knowledge and experience)
	• Actors' scripted dialogue • Actors' body language • Set design (e.g. lighting, furniture) • In-the-moment executed musical outputs	• Instruments' characteristics • Established rules & norms in music • Individual styles • Negotiation styles & strategies
	Narrative built from emotions and non-emotion concepts	Translation of emotions and non-emotion concepts

Decision Triggers (determined via summation of each Agent's individual judgment) ❖ Bottom-up stimuli filtered through shared top-down knowledge schemas and those unique to each Agent	• *Call or response*: does Agent want to call or reply to a musical output (MO)? ❖ Less cooperation, less continuity → greater risk against expectation ❖ Negotiate to lead or follow action • *Narrative saliency*: what is most salient (S) in the audiovisual space? ❖ Least salient, least significant → more risk against expectation • *Cognitive consonance*: how close can the MO be to S item identified? ❖ Greater distance, greater dissonance → more risk against expectation ❖ Negotiate allowable amount of cognitive dissonance • *Novelty*: how far away is the MO from expected representation? ❖ Greater distance, greater novelty → more risk against expectation ❖ Negotiate allowable amount of novelty
Executed Behavior (traded and buttressed between Agents) most probable action (narratively more general) ^ ⋮ least probable action (narratively more nuanced)	1. Scene representation = interpretation of overall narrative mood 2. Character representation = interpretation of individual actors' emotion(s) and/or body language 3. Character signature/leitmotif = interpretation of individual actors' repeated mental/physical state(s) with repeated MOs 4. New scene representation = interpretation of new overall mood 5. Random non-salient narrative items = interpretation of individual words, phrases, and/or on set objects (choice dependent on time (t) perceived available for execution) to buttress any of 1., 2., 3., or 4. 6. Random non-instrumental use = interpretation of nearest available object as tool to execute any of 1., 2., 3., 4., or 5. to buttress any of 1., 2., 3., 4., or 5. 7. Random narrative synthesis outside specific scene narrative items 1., 2., 3., 4., 5., or 6. executed for musical flow = interpretation of overall created melodic, harmonic, and rhythmic stimuli (choice dependent on: (i) t perceived available for execution, (ii) loss of musical idea(s) and dependency on others to initiate new idea(s) introduced via cues and/or (iii) personal emotional state and receptivity from others via specific cues that encourage or discourage)

Ideation Continues (piggybacking on already executed behavior)	Agents check 1., 2., 3., 4., 5., 6. and 7. in real time with her/himself and against others for: - *Narrative saliency* levels - *Cognitive consonance* attributes - *Novelty* characteristics - *Call and response* choices
	Collaborative risk assessment: Level of risk taken on each behavior dependent on equilibrium between each Agent's personal style (i.e. willingness to hedge uncertainty) as it compares to that of the others. Agents characterize risk levels of others against their own to predict what best to musically trade and buttress (i.e. compromise). ❖ Greater perceived risk in the others' behavior, greater or lesser likeliness to coax for more risk (feedback response) in search of novelty (as filtered through the negotiated allowed cognitive dissonance as determined by the overall goal to create a positive experiential outcome).

As Tables 1 and 2 illustrate, there are several crucial differences between a single agent and several agents who have the same task of producing an optimal coherent artistic experience (i.e. positive outcome):

A. Different personalities are present vs. one type.
   a. Various musical styles available.
   b. Various negotiation styles available.

B. Different knowledge of and experience with established rules and norms in music and performance vs. one kind.
   a. Various instrumental characteristics available.
   b. Various negotiation strategies available.

C. Different internal emotional states are present vs. one set.
   a. Various personal emotions available.
   b. Various expression strategies available.

D. Collaboration and therefore negotiation of actions are necessary through real-time self vs. group feedback.
   a. Behavioral risk assessed (i.e. how much to break away from expectation) in comparison to others. Others may increase or decrease risk-taking with specific cues.
   b. Personal styles kept in check or not. Others may constrain or encourage personal style with specific cues.
   c. Personal emotional states tested in comparison to others. Others may agree with or contradict emotional state(s) with specific cues.
   d. Behavioral predictions defined by the call and response actions of others (i.e. cues of leading or following).
   e. Creative ability revealed as compared to others. Others may be faster or slower and encouraging or discouraging to ideate novel sequences.

These cognitive behavioral observations of musicians positively adapting to their environment by improvising (and gauging others' behaviors/actions) to changing multisensory stimuli are quite similar to the open-ended situations human drivers encounter on a roadway and, more broadly, what fully autonomous machines being built to interact with humans will encounter. Revisiting Figure 1 above under this perspective essentially illustrates a group of human drivers all with the same goal of moving forward to arrive at some destination x with their own individual personalities, emotional states, driving experiences, and car types and the improvisatory moves resulting from varying degrees of spontaneous risk-taking actions (defined by individual personality and others' real-time feedback) made to keep traffic flowing. Figure 3 illustrates Figure 1 with aerial photographs during rush hour.

Figure 3. Screenshots from a recent article in The New York Times discussing the increasing rise of traffic congestion in midtown Manhattan, New York City, NY with the rise of App-hailed vehicles from Uber and others [15]. The photographs underscore the density of traffic and the improvised adaptive behavior implemented in the moment to keep traffic flow moving forward with the least amount of negative outcomes (e.g. traffic stagnancy, crashes, injury).

Directions for Autonomous Driverless Cars

What I have presented in this paper is a cognitive behavioral characterization of in-the-moment adaptive problem-solving and decision-making. Moreover, I have examined this higher-order human intelligence situation as it develops throughout a live artistic performance context with the goal of opening the door to a multidisciplinary perspective disciplines ignore or simply do not consider. The result is a nuanced understanding between internal and external elements as they integrate to monitor behavioral strategies and engender action with positive outcomes. While the elements and behaviors presented are specific to a multisensory human-human collaborative artistic environment, they are ultimately translatable to other multisensory and human-machine environments. Fully autonomous machines and driverless cars are specifically targeted here because they are bound to introduce a hybrid human-machine interaction space in the very near future and will require computational algorithms that master the seamless negotiable qualities and risk-taking responses evident in successful human-human collaborative interactions.

I will now highlight and analyze key crash data and road safety and road sharing issues brought up by two recent reports from the Transportation Research Institute at the University of Michigan, along with other consequent matters, for the purpose of connecting the cognitive behavioral processes in the arts discussed above with the immediate future of machine intelligence R&D:

I. All crashes (11 between 2012 and 2015) involving self-driving vehicles have been 100% the result of conventional cars crashing into self-driving cars, with rear-end crashes the most common type at 73% (while the self-driving vehicle was stopped or moving at ≤5mph) followed by sideswipes at 18% and angle collisions at 9% [16]. Although the exact reasons for why the crashes occurred are not mentioned or unknown, the authors make a simple yet key far-reaching statement in regards to the issue: "This fact [of at-fault parties being conventional vehicles] is consistent with the anticipated uncertainty about what to expect from self-driving vehicles on the part of the drivers of conventional vehicles." (p. 17) Expectations are knowledge-driven and therefore learned. Human drivers have expectations about other human drivers and pedestrians and their behavior –negotiations and responses to risk-taking actions– is dependent on such. This is grounded in the concept of 'theory of mind' whereby we all have thoughts and beliefs about our own and others' mental states [17]. As mentioned above, human-human interaction is collaborative and that collaboration is assessed in the moment with continuous feedback (positive and/or negative). Although not yet dealing with such complex push-pull collaborative situations as discussed here, research has shown that the more anthropomorphic features an autonomous vehicle has (i.e. name, gender, voice), the greater the human's trust on that vehicle's performance [18]. Therefore, until all vehicles are fully autonomous and driverless, and conventional cars are obsolete, humans will expect a machine capable of handling their own human adaptive capacities.

II. As implied in Figures 1 and 3 and asserted in [5], feedback is paramount in an unstructured environment. "…interacting drivers of conventional vehicles make eye contact and proceed according to the feedback received from other drivers. Such feedback would be absent in interactions with self-driving vehicles. The degree of the importance of both driver expectations and feedback from other drivers, and the consequent effects on the safety of a traffic system containing both conventional and self-driving vehicles, remain to be ascertained." (p. 5) Whether making eye contact, flickering one's headlights, softly honking one's horn, edging forward cautiously, or giving particular musical cues to suggest a 'go,' 'stop,' or 'edge on' response in whatever relevant context, computationally integrating nuanced (and creative) feedback options within decision-making algorithms is essential.

III. Risk-taking and the pros and cons of hedging uncertainty. Although the situations are different and outcomes vastly more consequential –artistic contexts and possible aesthetic experiences vs. machines and possible deaths–, when and when not to take risks must be characterized. Risk can be generally defined as the distance away from expectation. In the artistic context, as much as risk is perceived to be the bread and butter leading to success, risk assessment becomes a balanced computation between self interests (e.g. how far away from expectation do I want to go), societal norms (e.g. how far away from expectation is acceptable before rejection), and current audience anticipation (e.g. how far away from expectation to play around with now before rejection). This is done by a solo musician/artist or in conjunction with others. While not necessarily at the level of death, artistic risk is punishable in many more ways than one (e.g. emotional, intellectual, economic) and artistic production is constantly being evaluated against such. In the driverless car situation, risk appears more tangible because of the possible results of injury and/or death and hedging any uncertainty is maximized. In a recent autonomous driverless golf cart experiment in a crowd of people [2], the reasoning is expressed as such: "…the consequence of choosing a wrong action is severe. The vehicle must hedge against this uncertainty." (p. 459) And during a four-way intersection roadway experiment with a fully autonomous vehicle prototype [3], penalties are rewarded for "…selecting policy-violating high-risk actions." (p. 4771) In the simulation experiment in [19], "cases considered too risky (collisions included) and situations with a high score on the driver's subjective risk (> 8 on a scale from 1 to 10) are discarded" (p. 4) all together as if the variety of human risk assessments were useless pieces of data. In all these situations, high-risk actions (e.g. accelerating to pass a pedestrian) are assumed to lead to 100% negative outcomes (e.g. collisions, property damage, pedestrian injury). What about the situation when human high-risk actions lead to positive outcomes? Returning to Figures 1 and 3, we have an interesting human-human interaction situation whereby traffic flows –let's define for sake of example as equivalent to a positive outcome– because drivers more likely (a) do not follow sign directions regarding no parking, bus lane specifics, etc. (b) do not stay in their lanes and either create an undefined new one or persistently maneuver between them, (c) do not wait for pedestrians to cross the street, (d) inch along in tight proximity, (e) do not use their signaling lights, and (f) do not obey red lights, etc. Granted, each of these behaviors separately and combined do not always lead to positive outcomes (i.e. continuous traffic flow) and accidents happen. However, I bring up these issues for experimental purposes and as a call for not underestimating but rather understanding and learning from the nuances of human-human collaborative risk assessment in highly unpredictable, dense and irregular speed and maneuvering situations so that the knowledge gained can be coupled with current machine risk assessment and decision-making algorithms.

IV. Renewing the old and developing new strategies in real time to adapt to open-ended situations. Strategies can be defined as "flexible mappings associating stimuli, actions, and expected outcomes" [20]. Merging the repeated and over-learned from long-term memory with incoming information and spontaneously arising responses (e.g. emotions) held in short-term memory to move forward with a goal, otherwise known as 'flexible cognitive control,' may well be the hallmark of creative adaptability [21]. That is, a balanced amount of control as much as a lack of control is the requisite ingredient for fruitful creative production. In the artistic examples discussed above, whether a solo musician or a group of musicians, that flexibility and balance of information are essential. In fact, collaborative work relies on the negotiation of a variety of flexible abilities that are assessed in the moment from the various resulting musical outputs (MOs). As such, MOs are all dependent on each other as musicians respond to each other. In Figure 4, for example, musician M_1 produces never-before-heard MO_1 and musician M_2 is either surprised ($_{SU}$) or indifferent ($_{IN}$) to MO_1 and thus replies accordingly with, for example, the never-before-heard $MO_{2(SU)}$ which is subsequently interpreted by M_1 with the following never-before-heard $MO_{1'}$ to avoid conflict and continue the novel musical idea going since it minimally fulfills the current goal irrespective of emotional reaction. A particular aspect of musical improvisation ripe for analogous interpretation is the observation that no matter how experienced a musician is entering the improvisatory situation, the end result of that situation is completely unknown. Success of a fruitful and aesthetic outcome depends on the balancing of old and new strategies.

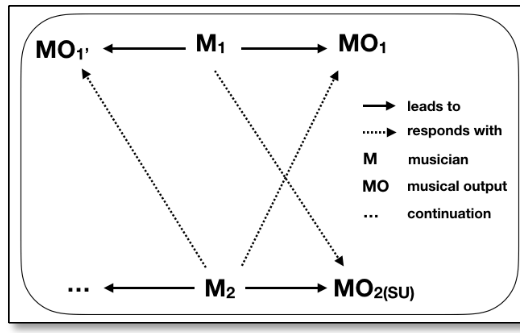

Figure 4. Illustration of dependent responses between collaborating musicians to create musical outputs.

In the case of fully autonomous driverless cars, there are so many *a priori* pre-solved behavioral strategies to predict and program before the tunnel of possible new strategies is entered. Therefore, computational algorithms must consider that if-then strategies are only as good as their environments and since many unknown environments exist, real-time learning of and adaptive negotiation with human responses is pivotal. As such, penalties cannot be, for example, singular and dependent on the large distancing of the autonomous vehicle from others, as in [2], for it would remain unmovable in a novel situation of the kind in Figures 1 and 3 where distance between conventional vehicles, humans walking or biking, and/or objects is not only minimal but irregular.

V. Emotion and associated external behavior. Affective and social cues are essential in human-human communication. Music is a particularly interesting symbolic system to study because of its capacity to communicate emotion and its universality in emotion expression and elicitation [22]. In musical improvisation, the success of novel musical sequences depends on calculated judgments by the musician regarding what to focus on (recognition), when to do so (interpretation), and how to musically translate the scene (response). The data from which the cognitive behavioral processes identified in Tables 1 and 2 are derived reveal that musicians choose and elaborate on specific musical features and instrument attributes to mimic the physical characteristics of emotional and physical elements identified within the scene's narrative [11], [12], [13]. Musical communication is an exchange of ideas through the (re)combination of available features. In the case of human-machine interaction, affect detection is paramount for user-friendliness. For the kind found in iCat, Nao, B21r, and Sony AIBO robots, for example, facial expressions, body language, voice, and/or physiological signals are computed and interpreted in order to collaborate, assist, or mimic the human user accordingly [23]. For smooth human-driverless vehicle interaction, detecting emotional intent will depend on the vehicle's nuanced perception and cognition of human behavioral changes in distance, light signaling, movement, and/or speed.

In sum, I have presented a set of theoretical human cognitive-behavioral parameters designed for direct computational translation for practical use in online decision-making for autonomous systems. These are the foundations of our future work towards successful human-like machine intelligence. My hope is that machine intelligence R&D will more actively and vigorously bring together research focusing on bottom-up sensory processes with unique research focusing on top-down processes, like the original and multidisciplinary kind presented, so innovation may ultimately be more efficient, effective, and safe.

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