Cognition as a Part of Computational Creativity

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***Abstract*—Computational creativity and cognitive computing are distinct fields that have developed in a parallel fashion. In this paper, we examine the relationship between the two, concluding that the two fields overlap in one precise way: the evaluation or assessment of artifacts with respect to creativity. Furthermore, we discuss a particular instance of computational creativity, culinary recipe design, and how cognitive informatics and cognitive computation enter into the domain.**

I. Introduction

The two paradigms *computational creativity*, and *cognitive informatics and computing* have had parallel research progress in the last decade [1]–[3]. The question we pose in this paper is: to what extent are these parallelly-developed paradigms related to one another? Is one a proper subset of the other? Is there a non-empty intersection between the two? If so, what is in the intersection and what is outside of it?

Computational creativity is the field of study and design concerned with machine systems that produce novel, useful, and quality artifacts or products (broadly construed) for the pleasure and consumption of people. Such systems could produce jokes, poems, visual art, architectural blueprints, music, or any other such artifact that is popularly viewed by people as creative output. In this paper, we focus primarily on culinary recipes, which include both the set and quantities of ingredients to be used as well as the methods and procedures of preparation.

On the other hand, the focus in cognitive informatics and computing, while also considering humans and machines, is not creating something new; the focus is typically in sensing, calculation, inference, understanding, and solving a given problem. The idea is to take inspiration from human information processing in the design and architecture of a sense-making machine, or to even simulate the processes of human cognition within it.

One aspect of cognition is understanding where on a wall a painting hangs, but another aspect is understanding whether that painting exhibits creativity. There are certainly connections between computational cognition and creativity, which we attempt to understand in this paper. We argue the intersection between the two fields is in the recognition or assessment of creativity, i.e. assessment of novelty, usefulness, and quality of work products. This is so because creativity is only in the eye of the (human) beholder and only makes sense or nonsense as part of the human condition.

In the episode "Poetic Justice" of the television series *Clarissa Explains It All*, a strange sequence of words produced by a standard programmable computer, but presented as if written by the main character Clarissa, is lauded by a committee of humans as excellent poetry. In this story, the sequence of words cannot be described as creative until and unless judged so by people—humans are the only arbiters of creativity. A computational creativity system has no meaning in a closed universe devoid of people unless the system contains a cognitive component. Even then, it is up for philosophical debate whether or not a cognitive computer can declare an artifact creative.

Regardless of philosophical considerations, a computational creativity machine without a cognitive piece to evaluate its potential outputs is not really a computational creativity machine because generation and assessment are duals that must coexist for proper functioning. In the same way that information cannot be encoded without a model of the receiver that will decode that information [4], artifacts cannot be created without a (necessarily cognitive) model of human evaluators.

However, this duality does not preclude the system from generating artifacts that could not be imagined by humans. In fact, a generation or design procedure wholly different from the human approach is valuable precisely because it would create things different from what a human would. It may have different kinds of 'illusions' or 'blindspots' than a human, and thus would be a great supplement or support to human creativity.

Thus overall, we view computational creativity's design component as being informed by cognition, but probably not being cognitive, whereas the assessment piece of computational creativity must have elements of cognition. Also, there are many aspects of cognitive informatics and computing, such as asynchronous logic and problem solving, that are not required in the assessment component of a computational creativity machine. In this work we do not consider the computer architecture of a creativity system; we are only concerned with the computational and algorithmic levels in Marr's hierarchy, not the physical level [5]. Our view of the relationship between computational cognition and creativity is summarized in Fig. 1 via a Venn diagram.

The remainder of the paper discusses these ideas in more detail and is organized as follows. First, in Section II, we provide an overview of computational creativity. Then in Section III, we describe a current understanding of how food is perceived by humans. In Section IV, we discuss the general problem of recipe design. The data model that we propose to enable computational recipe design is described in Section V. The cognitive component of computational creativity, assessment,

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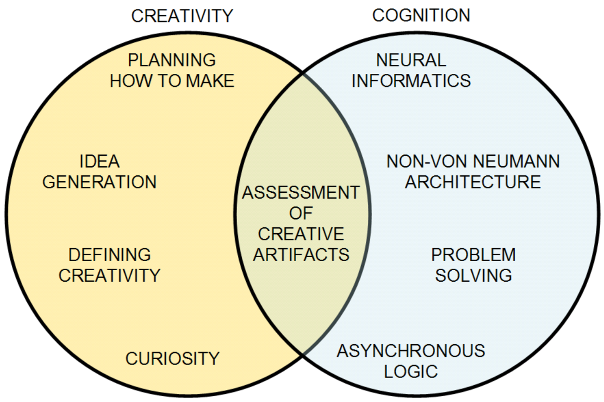

Fig. 1. Relationship between computational creativity, and cognitive informatics and computing.

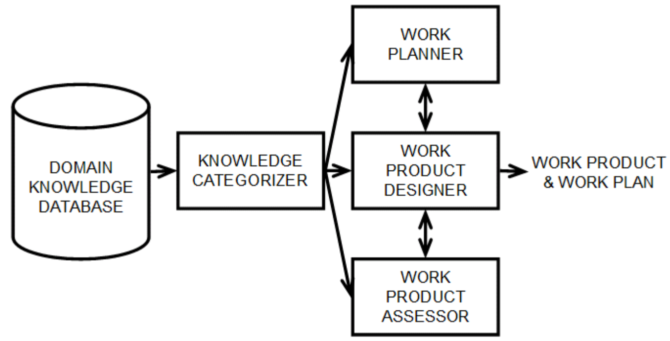

Fig. 2. Block diagram of computational creativity system that produces a work product and a work plan.

specifically for food, is discussed in Section VI. Finally, Section VII provides further discussion and concludes.

II. Overview of Computational Creativity

In this section, we provide a discussion of computational creativity in two parts. We first present several definitions of creativity including the definition we use. Second, we propose a system architecture for computational creativity that includes a cognitive assessment component.

A. Definition of Creativity

It is difficult to pin down a precise definition of creativity in the human context and even more so in the computational context. One approach is to list several properties of a creative output, such as being novel, being useful, rejecting previously held ideas, and providing clarity [6]. Another approach for computational creativity is by analogy to the Turing test—a system is creative if it produces artifacts indistinguishable from those produced by humans or having as much aesthetic value as those produced by humans [7].

A third approach, and the one we adhere to herein, is to view creativity as a relationship between the creator/creation and a (human) observer or evaluator [8]. If a human evaluator deems something creative, it is creative. If something provokes and disgusts an audience (or delights), it is creative [9]. Therefore, by definition, creativity is only meaningful in the presence of an audience or evaluator perceiving the creation.

As creativity is only meaningful when human perception is present (under the third definition), a creative system without a human cognitive component for the purpose of evaluation is severely handicapped because it cannot know itself whether its output is creative or not. Furthermore, since a *computational* creativity system is purely machine-based and does not have a human component, it can be considered more impaired than a deaf music composer or a blind painter. (Lacking the sense of creativity is more restrictive than lacking a physical sense because the various physical senses are commensurate [10]; the act of perceiving without the missing sense, nevertheless informs a person of what perception with the missing sense could be. There is no replacement for the sense of creativity.)

However, a computational creativity system can contain a cognitive assessment piece to lessen its handicap with respect to knowing whether or not it is producing creative artifacts and guiding its design process. Such a component cannot be the final arbiter of creativity as that is a purely human determination, but it can be a very useful aid. A cognitive assessment component fits with the first definition of creativity.

One final note in this section is that a creative computer can be operated in support of human creators, not only in a self-operation mode. When the computer is in this support role, a human creator can extrapolate from computer-created artifacts, meld them with his or her own creativity, and so on. In this setting, the definition of creativity may be of a different kind than considered in the literature.

B. Computational Creativity System Architecture

Having discussed the definition of creativity and broached the idea of a cognitive component as part of a computational creativity system in Section II-A, we propose an architecture for such a system in this section. A block diagram is presented in Fig. 2, with three main components, a work planner, a work product designer, and a work product assessor, being fed by a domain knowledge database and knowledge categorizer, interacting, and outputting a work product and work plan. It is important to note that in our proposed system, the work planner and the work product assessor do not directly interact, but only do so through the work product designer.

The domain knowledge database represents information collected on the creative field of interest, including information on styles, tastes, constituents, combinations, permutations, evolution, regionality, culture, and methods of preparation. It also includes a repository of existing artifacts that have been deemed creative by human audiences. This knowledge is resolved and organized by the knowledge categorizer. It is the source of data that the designer, planner, and assessor components draw from.

The designer generates new ideas for artifacts. The assessor evaluates those potential design ideas for creativity and the planner determines the methods by which the ideas could be manifested. All three components take input from the categorized database: the designer to draw inspiration for new ideas, the planner to learn from extant methods of preparation, and the assessor to evaluate a design idea against the repository of existing artifacts as well as against properties of constituents and combinations for creativity.

The designer is the lead component of the system. Based on our discussion of the definition of creativity, the designer need not have nor emulate human cognition. In fact, behavior in the designer component that is different from human cognition may be better for computational creativity, precisely because it will generate ideas different from what people would. These differences enlarge the hypothesis space and allow the machine to break new creative ground.

A creative computer does not require humanness for its idea generation and design, but is limited if it does not have elements of human cognition for its evaluation of proposed artifacts for creativity. The work product assessor component is the only necessarily cognitive element of the computational creativity system. This piece models human perception, taste, and culture. It examines creative ideas produced by the designer along two main dimensions: novelty and quality [11].

Novelty can be assessed via information-theoretic or other similar quantifications of innovation within the context of all other existing artifacts in the domain of interest. Quantifying quality (or other goodness measure) requires a strong cognitive model because the quality of a creation truly is in the eye (or nose or tongue) of the human beholder. Such a model involves psychological as well as physical and chemical considerations of perception. The novelty dimension is less specific to the particular creative domain of interest, whereas the quality dimension is intimately tied to it. We provide details for a specific domain, the flavor of food, in Section III.

The final component, the work planner, determines the steps needed to take concept to realization. Again here there is no requirement of human cognition. The work plan provides constraints on what designs are possible and can be optimized for efficient production, but can be purely machine-oriented. The plan itself may be judged to be creative if the audience can observe the method of production. However, an artifact can be deemed creative whether the work plan is creative or not, and whether the method or algorithm used to produce the artifact is observed or not.

One point we have not described is input to the creator (either human or machine). Often, a creator is given general instructions as input, e.g. "paint a landscape that includes the Hudson River." Such input seeds the creator's idea generation in a particular direction. Input is not necessary however; many creators allow ideas to flow without direction. Also, in a support role, a creative computer may need to take direction from a person, e.g. "the artifact should be more cheerful," in which case a cognitive interpretation component for the direction is required.

III. Human Flavor Perception

In Section II-B, we discussed the idea of the work product assessor evaluating creativity, and that this component requires a cognitive aspect modeled on human perception. In the remainder of the paper, we focus on one specific area: the culinary domain. Before discussing a computational creativity system for food, we first describe current understanding of human flavor perception, primarily following [12].

Human flavor perception is very complicated, involving a variety of external sensory stimuli and internal states [12]. Not only does it involve the five classical senses, but also sensing through the gut, and the emotional, memory-related, motivational, and linguistic aspects of food. First of all there are the basic tastes: sweet, sour, salty, bitter, and umami. The smell (including retro-olfaction) of foods is the key contributor to flavor perception, which is in turn a property of the chemical compounds contained in the ingredients [13]. There are typically tens to hundreds of different flavor compounds per food ingredient [14].

Other contributors to flavor perception among the classical senses are the temperature, texture, astringency, and creaminess of the food; the color and shape of food; and the sound that the food makes. The digestive system detects the autonomic and metabolic properties of the food. Moreover, there are emotion, motivation, and craving circuits in the brain that influence flavor perception, which are in turn related to language, feeding, conscious flavor perception, and memory circuits. Furthermore, stimuli beyond the food itself, such as the ambience of the room, influence flavor perception.

The complication in flavor perception is due to the interconnection and interplay between a multitude of neural systems, many of them not memoryless. Recreating such a flavor perception system in a computer is an ambitious goal for cognitive computing and informatics. However, any progress towards such an end is progress towards a viable computational creativity system for food. Also, we should note that simply describing the factors and pathways of flavor perception fails to consider the settings of those factors that make food flavorful. We return to this point in Section VI, where we describe a tractable proposal for the work product assessor of a computational culinary creator motivated by human flavor perception.

IV. Culinary Recipe Design

In the food domain, a dish is the basic unit of creation. A cooked and plated dish is presented to a diner who perceives it and determines whether it is creative. This presented dish can be the output work product of a culinary computational creativity machine, as described generally in Fig. 2. The other output in Fig. 2, the work plan, is a description of how to cook and how to plate the dish. A recipe is a work plan for how to cook a dish, but it is also a description of the work product, as it describes the ingredients to be used, their quantities, and their transformations and combinations.

Innovative, cutting-edge chefs must have impeccable culinary technique, but become renowned for their creative recipe designs. Cooking at the highest levels is very much regarded as a creative art, especially concocting new dishes. A computer system that could create novel and flavorful recipes as judged by people, would certainly be deemed creative.

The computer-generated culinary recipe design problem is not just one of locating existing recipes and recommending them [15], but of creating new ones. It is different from web search and product recommendation, and is truly part of a computing paradigm that is distinct from fields such as information retrieval and statistical learning.

Culinary computational creativity has recently been discussed in [16], where the authors focus only on soups rather than general recipes, and do not consider the cognitive aspects of recipe assessment; in particular, they do not consider any of the neural, sensory, or psychological aspects of flavor perception. In our recent previous work [11], we discuss the general conceptions of novelty and flavor of dishes, but neither contextualize them with respect to cognitive informatics and computing nor present an overall system.

The overall culinary recipe design problem has many facets. Through the lens of Fig. 2, the first is to design and construct a suitable domain knowledge database. This requires a data model enabling the system to reason about food and support algorithms for design, assessment, and planning. In particular, it should be a repository of food ingredients and existing recipes, but also include knowledge about culinary styles and techniques, regional and seasonal cuisines, flavor compounds and their combinations, etc. We propose and discuss a data model for food in Section V.

A related aspect to building a computer chef is ingesting and processing raw data to populate the knowledge database structured according to the data model. Sources include cookbooks and other repositories of recipes, culinary guides that explicate the culture of food, repositories of culinary techniques, and chemical databases of food ingredient constituents. Such conversion of raw data to usable knowledge requires semantic processing [17].

Given a designed and populated domain knowledge database, a next step is developing a way to generate recipe ideas. Since cuisine naturally has evolutionary properties [18], i.e., cooking styles, techniques, and ingredient choices evolve and even exhibit features like the founder effect, genetic algorithms are one approach to the recipe design problem [19]. Such an approach involves mutating and recombining existing recipes and can produce a myriad of potential recipes.

Besides random mutations and recombinations of recipes, there are some prominent culinary design principles that can be utilized. For example, two principles focused on the chemosenses are the flavor pairing hypothesis [14] and olfactory pleasantness maximization [20]. Additional principles center around similarity of ingredients in properties such as geographic origin and seasonal origin. A further guiding principle of food creation is maintaining balance, whether that is in terms of tastes, temperatures, or textures.

Finally, as discussed at the beginning of this section, a recipe is not only a work product but also a rudimentary work plan. Therefore, in the culinary domain, a plan to produce the artifact is a must. The plan, taking advantage of a machine system's forte, may be optimized and parallelized by formulating an operations research problem [21].

V. Data Model

In this section, we propose a data model that allows us to capture the salient pieces of domain knowledge to support all of the components of machine-generated creative recipe design. We first detail the model itself, including a schema for recipes. Then we discuss how this form of data engineering reflects cognitive principles.

As discussed in Section IV, the basic unit of cuisine is the dish, which is represented as a recipe. We propose a representational model for culinary computational creativity that too has a recipe as the basic unit. A schema—a codification of experience that includes a particular organized way of perceiving cognitively and responding to a complex situation—for cuisine that we propose is shown in Fig. 3 and Fig. 4.

Within this representation, we first capture the basic factors of the recipe, including the ingredients and their quantities, the tools required, and the sequence of cooking steps with input, output, tool and duration specified. These basic factors are enough to be able to produce the artifact, i.e. the dish. However, we need more elements in the representation to enable creative, flavorful idea generation by a computer.

We must include knowledge about cultural context, human ratings, chemical analysis of ingredients and processes, and so on, to be able to characterize and emulate flavor perception. For example, we include the name of the dish because it relates to the influence of cortical language circuits on flavor perception. We include the regional cuisine to which the dish belongs because regionality is a design principle in cooking. Similarly, we include the chemical flavor compound constituents of ingredients because flavor compound sharing is another design principle. We record the source of the recipe to better enable an understanding of the culture of cooking.

As the preceding examples of data model elements illustrate, a creative culinary system's knowledge representation needs much more than simply a recounting of the ingredient list and cooking steps because it must cognitively reason about flavor perception, which involves many diverse sensing and memory pathways. Idea generation can only take advantage of the attributes that are in the data model and nothing more. It truly is the case that how the world is internally represented impacts what can be created. Creation, in our view, is the process of decomposing artifacts into their constituents as depicted in the data model, and then recomposing and reconstituting new artifact ideas.

Philosophically speaking, schemata and diagrams define the universe within which cognition takes place [22], [23]. Without a selective, simplified universe containing blindspots, the deployment of cognitive resources becomes untenable. Diagrams, in some sense, specify the cognitive method and the way of 'doing the cognitive thing' [22]. In the computational culinary creation case, we certainly have blindspots

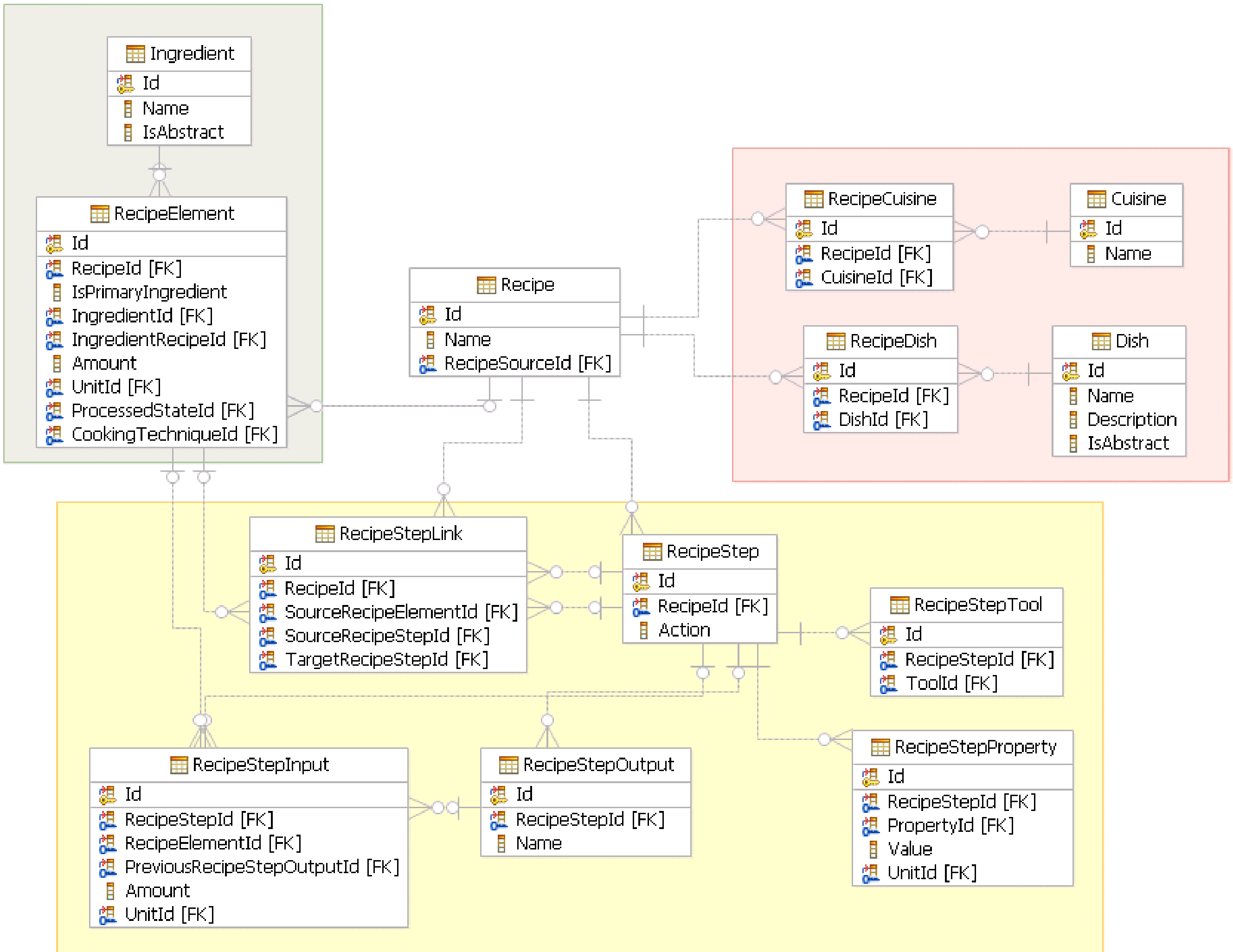

Fig. 3. Knowledge representation schema for culinary recipes. The ingredient component is expanded upon in Fig. 4.

in our proposed schema. For example, we do not include a data element about the sound of the dish even though, as discussed in Section III, it is a contributor to human flavor perception. Thus, since sound is not in the diagram it is also outside the universe of cognition for the system. Importantly, it is purposefully not in the schema because capturing every component of flavor would be unmanageable and beyond the cognitive resources of the system.

VI. Computational Assessment

Having discussed human flavor perception, a culinary recipe design machine, and a data model for such a machine, we now turn to detailing a tractable approach for assessing novelty and flavor. The approach draws from human flavor perception science and operates within the universe set forth by the data model. We begin with a computational proposal for novelty, which can be applied more generally to other creative endeavors as well. We then develop a computational quantification of pleasantness specifically for food flavor. A creative recipe should have large values for novelty and pleasantness quantifications.

A. Novelty

An artifact that is novel is unusual, surprising, has a wow factor, and changes the observer's world view. Novelty can be quantified by considering a prior probability distribution of existing artifacts and the change in that probability distribution after the new artifact is observed, i.e. the posterior probability distribution. At the level of observable representation of artifacts, the difference between these probability distributions describes exactly how much the observer's world view has changed. In recent work, such a quantitation has been given the name *Bayesian surprise* and has been shown empirically to capture human notions of novelty and saliency across different modalities and levels of abstraction [24], [25].

It is important to note that surprise and novelty depend heavily on the observer's existing world view, and thus the

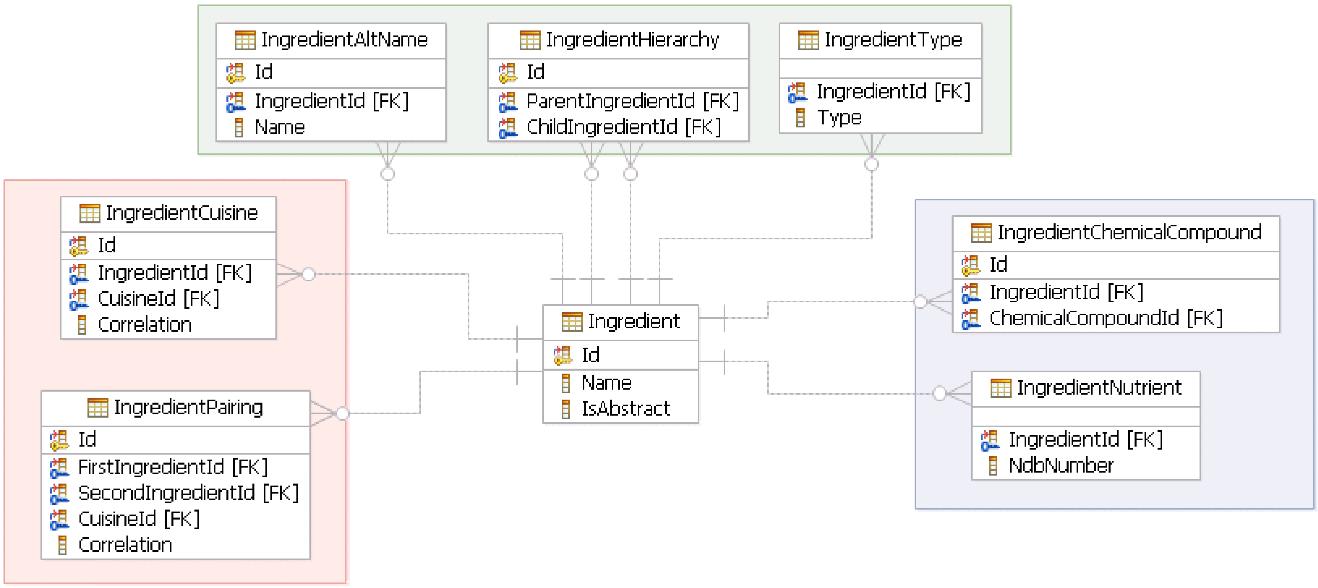

Fig. 4. Knowledge representation schema for culinary ingredients that is a part of the overall schema for recipes given in Fig. 3.

same artifact may be novel to one observer and not novel to another observer. That is why Bayesian surprise is measured as a change in the observer's specific prior probability distribution of known artifacts. The adjective Bayesian is used due to the use of this prior probability.

Mathematically, this cognitively-inspired Bayesian surprise is defined as follows. Let $\mathcal{M}$ be the set of artifacts known to the observer, with each artifact in this repository being $M \in \mathcal{M}$. Furthermore, a new artifact that is observed is denoted A. The probability of an existing artifact is denoted $p(M)$, the conditional probability of the new artifact given the existing artifacts is $p(A|M)$, and via Bayes' theorem the conditional probability of the existing artifacts given the new artifact is $p(M|A)$. The Bayesian surprise is defined as the following Kullback-Leibler divergence:

$$\begin{aligned}\text{Bayesian surprise} &= D(p(M|A) \,||\, p(M)) \qquad (1)\\ &= \int_{\mathcal{M}} p(M|A) \log \frac{p(M|A)}{p(M)} dM.\end{aligned}$$

B. Flavor Pleasantness

The other dimension of creativity is the pleasantness of the flavors. As mentioned at the end of Section III, knowledge of how flavor is perceived is not the same as quantifying which flavors are perceived as pleasant. The knowledge of the senses and perceptual pathways gives insight into the potential factors that relate to foods being flavorful. As noted in that section, the sense of smell is the key influencer of flavor perception; in particular, the constituent flavor compounds that can be sensed by the olfactory system. Thus a tractable step towards a cognitive informatics model for flavor pleasantness is a model for odor pleasantness.

Recent work has shown that there is a low-dimensional, almost scalar, hedonic quantity that describes the pleasantness of odors to humans, regardless of culture or other subjectivity [20], [26]. Moreover, this pleasantness is statistically associated with the physicochemical properties of compounds. Therefore, it is possible to develop regression models to predict human-rated odor pleasantness of chemical compounds using their properties such as topological polar surface area, heavy atom count, rotatable bond count, and hydrogen bond acceptor count. The idea is illustrated in Fig. 5, where the data points are individual chemical compounds, the vertical axis is the human-rated pleasantness, and the horizontal axis is a learned combination of chemical property features. Then given a previously unrated compound, the regression model can be used to predict its pleasantness.

There is evidence that pleasantness is an approximately linear property of compounds [27]. If two compounds are mixed together and smelled, the hypothesis is that the odor pleasantness of the mixture is approximately a linear combination of the pleasantness values of the individual compounds. With such linearity, one can predict the pleasantness of food ingredients that contain several flavor compounds and of dishes that in turn contain several ingredients. The chemical properties of flavor compounds are well-catalogued and there is a growing body of literature cataloguing the flavor compound constituents of food ingredients [14].

Thus, if the recipe assessor is given a proposed idea by the recipe designer in a computational creativity system, it can calculate its novelty using Bayesian surprise and calculate its flavorfulness using an olfactory pleasantness regression model applied to its constituent ingredients and flavor compounds in those ingredients. Such scoring represents a cognitive infor-

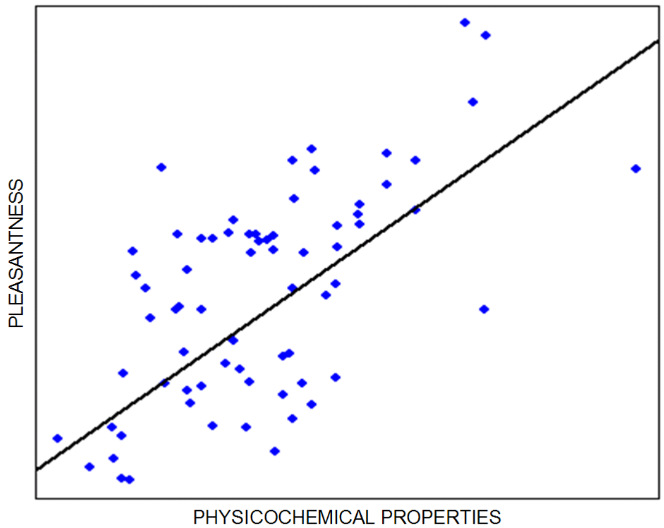

Fig. 5. Illustration of predicting pleasantness using the physicochemical properties of flavor compounds.

matics approach to assessing artifacts that have been created and have never existed before.

VII. Conclusion

In this paper, it has been our objective to study the relationship between the fields of computational creativity and of cognitive informatics and computing. In this pursuit, we proposed a structure for a computational creativity system that contains three main components: a designer, an assessor and a planner, all fed by a domain knowledge database. As we discussed, it is only the assessor that needs to be cognitive, not the other two components. Therefore it is precisely in assessment of creativity that the fields of computational creativity and cognitive computing overlap. Furthermore, we discussed the role of the domain knowledge database in structuring and setting the bounds for cognitive processing.

Taking a particular creative application domain—culinary recipe design—as an example, we discussed various aspects in further detail. Specifically, we discussed that creativity of food dishes is assessed through the dimensions of novelty and flavorfulness. We further described how people perceive flavor and novelty and proposed cognitively-inspired computational approaches for a machine to do the same, based on Bayesian probability and regression analysis. We described a knowledge representation schema for recipes that not only includes information on the basic composition and methods of preparation of dishes, but also further information needed to properly generate new recipe ideas and assess creativity, including cultural, psychological, and chemical knowledge.

Creativity is easy neither for people nor for machines, but the challenges are different. Without taking advantage of modularity, people often have trouble being creative and innovative because they are overwhelmed by the combinatorial complexity of large design spaces [28]. Since people end up thinking modularly, progression of creative thought is often evolutionary [29]. A computational creativity system can test quadrillions of ideas at once without needing to invoke modularity and may thus offer solutions that completely redefine an art. Such creations may offer advantages by being completely ‘outside the box’ through large jumps in thought rather than gradual evolutionary changes. Computers, however, have the difficulty of not being able to assess creativity by definition. A cognitive assessment component can bridge the gap, but is nevertheless limited in comparison to a real person. Progress in cognitive informatics and computing can only serve to improve computational creativity.

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