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A transformational creativity tool to support chocolate designers

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ABSTRACT

A new formulation of the central ideas of Boden's well-established theory on combinational, exploratory and transformational creativity is presented. This new formulation, based on the idea of *conceptual space*, redefines some terms and includes several types of concept properties (*appropriateness* and *relevance*), whose relationship facilitates the computational implementation of the transformational creativity mechanism. The presented formulation is applied to a real case of chocolate designing in which a novel and flavorful combination of chocolate and fruit is generated. The experimentation was conducted jointly with a Spanish chocolate chef. Experimental results prove the relationship between appropriateness and relevance in different frameworks and show that the formulation presented is not only useful for understanding how the creative mechanisms of design works but also facilitates its implementation in real cases to support creativity processes.

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1. Introduction

Computational creativity is an emerging, multidisciplinary branch of Artificial Intelligence, closely related to Cognitive Science, whose goal is to model, simulate or serve as a support tool for creative tasks. In this paper, we focus on systems for achieving the latter goal. Such systems are normally referred to as Creativity Support Tools or Creativity Support Systems (CSS). CSS can be defined as systems capable of enhancing human creativity without necessarily being creative themselves. They act as a creative collaborator with scientists, designers, artists and engineers by applying technology to help humans 'think outside the box' and expand their exploration boundaries by generating good ideas that have never been thought of before [Thornton 2007]. They can help us to look farther and avoid dwelling on the obvious concepts. The great challenge for CSS is to enable more people to be more creative more of the time [Shneiderman 2000].

Creativity can be found in painting, sculpture, music, literature, architecture but also in engineering, software development, scientific discoveries and almost all human activities. Many scientists and engineers have extended their discovery and innovation capabilities by applying computational tools able to perform fast calculations and useful simulations and visualization. For instance, genome researchers use specialized visual analysis tools to discover biological pathways, computer-aided design (CAD) is used in designing electronic, mechanical and architectural systems, and media artists are provided with powerful development environments that support animation, music and video editing tools. In fact, any tool that facilitates access to and revision of existing projects and performance, such as Web browsers, wikis and search engines, helps to enhance human creativity. However, like telescopes, microscopes and cameras, these computational applications are still only tools; the act of creation is actually carried out by the users [Shneiderman 2007].

It is assumed that creativity is closely linked to the rational decision-making process. In the literature, decision-making processes normally comprise four steps: *Framing the decision*, *generating alternatives*, *evaluating the alternatives* and *choosing and implementing the chosen alternative* [Langton 2012]. Creativity is mainly linked to the second step: generation of alternatives, but it is also associated to the third and fourth steps. Generating ideas (hypotheses for scientists, prototypes for engineers, models for architects, or sketches for artists) is often considered the key step in creativity. It is sometimes referred to as *divergent thinking*. Creating lists of questions or community brainstorming are activities which promote divergent thinking. The use of computer programs makes it easier to generate, collect, organize and present new ideas based on word combination, using hypertext databases and making different kinds of connections. However, once a new idea emerges, the creator must determine its suitability. The evaluation and selection stage is referred to as *convergent thinking*. This stage draws on large amounts of domain knowledge to assess novelty and quality.

Alternatives are normally generated by combining elements within and beyond the domain but one needs to choose potentially good alternatives if one is to avoid evaluation of a vast number of possible combinations. This is achieved by reviewing existing processes in the domain and other processes belonging to other domains with subtle common aspects. In this sense, creative people are skilled at both finding these apparently different domains with common characteristics and at pre-evaluating the alternatives, taking into account the relation between domains.

This paper presents a new formulation of the central ideas of Boden's well-established theory on creativity [Boden 1990]. This new formulation redefines some terms and also reviews the formal mechanisms of exploratory and transformational creativity. It is based on the conceptual space proposed by Boden and formalized by other authors to facilitate implementation of these mechanisms. We consider transformational creativity to be a quest for concepts that fall outside the problem framework that involves weighing up the relationship (appropriateness and relevance) between concepts in different frameworks. To illustrate this formulation, a computational system is developed and tested in the support process of a creative chocolate designer. The study was conducted jointly with the chocolate chef Oriol Balaguer and his team (*http://www.oriolbalaguer.com*). Oriol Balaguer has received a host of national and international awards. The Catalan pastry chef is actively involved in the research and development of new products.

Culinary design has long been seen as a highly creative domain within creativity research [Sawyer 2012]. Thus, CSS has a potential role in the food industry. Today, a significant portion of a food services or manufacturers' business focuses on coming up with new ingredient combinations and finding new flavors that may become a commercial success. With the availability of large-scale online recipe repositories in recent years, some recipe design principles have been formulated, inspiring creativity strategies. [Ahn 2011]. The flavor of a dish depends as much on how it is prepared as on the choice of particular ingredients. Furthermore, there are many ingredients whose main role in a recipe is not only flavoring but also to ensure mechanical stability, improve conservation or to add vivid colors a pleasing texture. However, some hypotheses ignore all these factors and focus solely on flavoring compounds in the ingredients. One of the main guiding principles in putting together two ingredients in a recipe is the so-called *food pairing hypothesis* [Ahn 2011].

Food pairing is a relatively new method for identifying which ingredients go well together. It is based on the principle that some food combines well with one another when they share key flavor components. This flavor pairing hypothesis arose when Heston Blumenthal, the famous chef from the English restaurant *The Fat Duck*[1], found caviar and white chocolate go well together. He contacted Firmenich, a Swiss perfume and flavor company, who found that both chocolate and caviar shares trimethylamine and other flavor compounds that contribute to the desirable flavors [Blumenthal 2008]. In order to apply the food pairing hypothesis, flavor and aroma compounds of an ingredient should be obtained (with the aid of gas chromatography or mass spectrometry) and compared to the compounds of other ingredients. However, this hypothesis also makes it easy to come up with unexpected combinations since food pairing suggests that the binary relation *go well together* satisfies, to a certain degree, the transitive property, (that is to say, adequacy between two ingredients depends on the adequacy between these ingredients and other ingredients). The flavor pairing hypothesis has been scientifically studied for several modern cuisines and has been found to hold strongly for Western cuisine but not for Asian cuisine [Ahn 2011].

The remainder of the paper is organized as follows: Section Two provides a review of the literature on computational creativity. Section Three covers the proposed CSS methodology. Section Four details the application of the chosen methodology.

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[1] *The Fat Duck* has been awarded three Michelin stars and was voted Best Restaurant in the world in 2005.

The fifth and last section gives conclusions and discusses future work.

2. Literature review on computational creativity

Creativity should be regarded as one of the highest-level cognitive functions of the human mind. It is a phenomenon whereby something new and valuable is produced such as an idea, a problem solution, a marketing strategy, a literary work, a painting, a musical composition or a new cookery recipe. Authors have diverged in the precise definition of creativity beyond these two features: originality (new) and appropriateness (valuable) [Mumford 2003].

One of the few attempts to address the problem of creative behavior and its relation with Artificial Intelligence was done by Margaret Boden [Boden 1990][Boden 1996]. She aimed to study creativity processes from a philosophical viewpoint focusing on understanding human creativity rather than trying to create a creative machine.

Boden distinguishes between creativity that is novel merely to the agent that produces it and creativity that is recognized as novel by the society. The first is usually known as *P-creativity* (or "psychological creativity") and the second is known as *H-creativity* (or "historical creativity"). All P-creative ideas are H-creative, but not all H-creative ideas are P-creative. What is valued by one person or social group may or may not be valued by another.

The most important contribution of Boden's study is the introduction of the idea of *conceptual space* composed of partial or complete concepts. She conceives of the process of creativity as the location and identification of a concept in this conceptual space. The creative process can be performed by combining, exploring or transforming this conceptual space. According to Boden's theory, *combinational creativity* uses familiar ideas to generate a new idea in the form of unfamiliar juxtaposition. Moreover, *exploratory creativity* explores potentiality of a conceptual space to create a new and unexpected idea. Another type of computational creativity in Boden's theory is *transformational creativity*. If the conceptual space is defined through a set of rules, when these rules change, then the process is called *transformational creativity*.

From Boden's study, it is not clear how the rules give rise to a particular conceptual space and, therefore, what is the true difference between exploring the space and transforming it. In order to clarify and to formalize the creative process, G. A. Wigging [Wigging 2006] presented several papers in which he emphasized the notion of search as the central mechanism for exploratory creativity and the notion of meta-level search related to transformational creativity. Wiggings posits a universe of possibilities $\mathcal{U}$ which is a superset of the conceptual space. The universe is a multidimensional space, whose dimensions are capable of representing all possible concepts which are relevant to the domain in which we wish to be creative. For transformational creativity to be meaningful, all conceptual spaces are required to be subsets of $\mathcal{U}$.

Wiggings conceives exploratory creativity as a search of concepts in a specific conceptual space. The process involves three sets of rules that can be denoted as *acceptability*, *appropriateness* and *strategy*. The first set of rules is linked with belonging to the conceptual space. Moreover, acceptability is related to style. On the other hand, appropriateness rules are related to the value of the concept. Valuable concepts may become successful regardless of being acceptable according to the rules associated to acceptability. This second set of rules (which defines the value of a concept) is much harder to define because it depends on cultural and aesthetic aspects, specific context, personal mood, etc. However, it is important to note that, in this context, appropriate means suitable to the task, but above all original and surprising. Finally, there exist a third set of rules linked to the search strategy. For instance, some people prefer to work "top-down", others "bottom-up", others rely on ad-hoc methodologies, using informed or uninformed heuristics and even at random. Wiggings points out that separating acceptability and strategy rules can be used to describe situations where different designers, each with a personal way of finding new ideas, are working within the same style (a shared notion of acceptability).

From Wiggins' perspective, the interaction of these three sets of rules (acceptability, appropriateness and strategy) leads to the exploratory creativity process. However, although working within three invariant sets of rules may produce interesting results, a higher form of creativity can result from making changes of these rules (transformational creativity). In other words, on the one hand, exploratory creativity consists of finding a concept in a specific conceptual space, following a specific strategy and assessing it by using a specific appropriateness set of rules. On the other hand, transformational creativity consists of the same process than exploratory creativity but changing the conceptual space, the search strategy or the appropriateness assessment.

Besides Wiggings work, there have been other formalizations of specific aspects of the computational creative process [Ritchie 2007] [Ritchie 2012] [Charnley 2012]. Although these formalizations are very helpful in clarifying the nature of creative computation and have given rise to some applications in diverse domains including graphic design, creative language, video game design and visual arts [Manurung 2012], the details of most of them are unspecified and the concepts they include are tricky to implement. The current paper starts from the central ideas of Boden and Wiggings and redefines the formal mechanisms of exploratory and transformational creativity in a way which facilitates the implementation of these mechanisms.

3. The proposed formulation

As in Wiggins theory, let us start by considering a *universal set of all concepts*, $\mathcal{U}$. The idea is that $\mathcal{U}$ is universal enough to contain concepts for every type of complete or incomplete artifacts that might ever be dreamed up. In addition, we define the following terms:

Definitions (*Framework, H-conceptual space, appropriateness and relevance*). A *framework F* is the 3-tuple (C, $a(\,)$, $r(\,)$) where $C \subset \mathcal{U}$ and $a(\,)$ and $r(\,)$ are maps from $\mathcal{U}$ to R.

- The subset C is the *H-conceptual space* (or 'historical conceptual space') formed by all concepts related to the framework F.
- $a(\,)$ is the *appropriateness* map. In our formulation it is related to the success of considering a concept in this framework.
- $r(\,)$ is the *relevance* map. It is a measure of the membership relation between the concept and the framework: $r(y)\neq 0$ if $y\in C$ and 0 otherwise.

A naïve relevance measure might be a 0/1 value (1 if $x\in C$ and 0 otherwise), but it is possible to consider more complex measures containing more information about the relation between the concept and the framework.

In the proposed formulation, we separate originality and appropriateness. This separation is not clear in Wiggins formulation where appropriate means both suitable to the task and original and surprising. We consider that any agent can act as a *spectator* and can easily obtain the relevance measure for any concept given any framework. However, only *experts* on a framework know appropriateness for some concepts in the H-conceptual space.

Definitions (*Expert and P-conceptual space*). An *expert i* on a given framework F is an agent that also knows value $a()$ for concepts from some subset C^{i} of C. Inspired by Boden's theory, we call C^{i} the *psychological* or *P-conceptual space*, that is, the concept space associated to the framework F and to the expert i.

An *expert* only knows appropriateness for concepts from his/her P-conceptual space, but the values $a(y)$ for $y \notin C^{i}$ are unknown by the expert. However, an expert can also have expertise in others frameworks. We use the notation C_{j} as the H-conceptual space associated to framework F_j and C_{j}^{i} as the P-conceptual space associated to framework F_j and expert i. It is common that different frameworks share concepts but obviously appropriateness of the same concept can differ depending on the framework. Multi-expertise can be an advantage in the creative process.

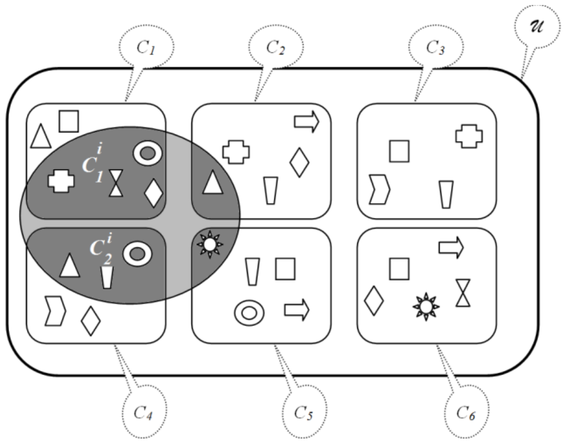


Figure 1. Universe of concepts. H-Conceptual spaces (associated to frameworks) and P-Conceptual spaces (associated to frameworks and one expert). The expert *i* is represented as a grey circle. He has knowledge on four frameworks. In the figure it can be seen that one concept can belong to different frameworks

We consider that given a framework, the appropriateness of a concept is independent of the expert. The difference between experts of the same framework is related to the different P-conceptual spaces, all them subsets of the H-conceptual space.

In addition, we consider that both a framework and an expert can evolve and both the H-conceptual space and the P-conceptual space can grow because of the creative activity.

Definition (*creative and strategy*). A *creative agent* on a given framework F, or just a *creative* (sic) (used as a noun), is an expert in this framework that has a *strategy* for obtaining concepts. A *strategy* is defined as a way to select a concept from $\mathcal{U}$ given all the knowledge that the creative has about the main framework but also about other frameworks. The strategy depends on the appropriateness and relevance values of concepts in different frameworks.

'Creatives' select concepts following their strategy. Once the concept is obtained, its relevance in the framework is modified and both the P-conceptual space and the H-conceptual space are extended to include this new concept.

The relevance is the result of creatives's activities. However, the appropriateness depends only on the concept and the framework considered. The underlying idea is that, although evaluating the appropriateness requires some kind of talent or expertise, relevance evaluation can be easily performed by any agent by means of an objective analysis of the framework. Thus a concept with high relevance in a framework is not necessarily highly appropriate. In fact, an original concept always has low relevance in the considered framework.

It is possible to simplify the model by avoiding the distinction between 'creatives' and experts but in some fields there are obviously two types of agents. For instance movie, painting or literature critics can be considered as experts who can assess concepts but they normally do not develop artistic skills.

3.1. CSS for transformational creativity

Among Boden's three kinds of creativity (combinational, exploratory and transformational), in this paper, we have focused on the third one. As combinational and exploratory creativities delimit the search in the P-conceptual space, the best strategy seems to select the concept with the best combination of appropriateness and relevance values. Although the selection of a concept from the P-conceptual space may not be trivial and can be performed using other kind of CSS, this topic will not be consider in this paper.

The main problem regarding transformational creativity is the lack of knowledge, from the expert's side, on the appropriateness values for concepts outside the P-conceptual space. The CSS cannot directly obtain this appropriateness value. However, computational intelligence can be used for obtaining relevance values for any concept with respect to any framework.

Definition (*Relevance vector*). Let us consider a set of different frameworks $F_1, F_2, \ldots, F_m$. Given a concept $x \in \mathcal{U}$, we consider the *relevance vector* of x with respect to the set of frameworks $F_1, F_2, \ldots, F_m$ as $\Phi(x)=(r_1(x), r_2(x), \ldots, r_m(x))$.

The relevance vector describes the membership relation of x to the set of frameworks $F_1, F_2, \ldots, F_m$. Given a framework F_0, the expert i and its P-conceptual space C^{i}_{0}, the utility of CSS in transformational creativity relies on proposing new concepts $y \in \mathcal{U}$, $y \notin C^{i}_{0}$ to the expert based on the relevance information of these concepts with respect to frameworks different to the one initially considered and from the relation among all these frameworks.

The system we consider is able to propose new concepts $y \in \mathcal{U}$, $y \notin C^{i}_{0}$ with likely high $a_0(y)$. In order to predict how valuable a new concept y is, i.e $a_0(y)$, our hypothesis is that no obvious relations between different frameworks exist, therefore the appropriateness $a_0(y)$ and the relevance vector $\Phi(y)$ are closely related. In this sense, it is considered that concepts with similar relevance vectors on the current framework should have similar appropriateness function. This hypothesis could not be true for a small set of frameworks but, from our preliminary experiments, seems to be true for larger ones.

Given the relation between appropriateness and relevance, our CSS will use the set C^{i}_{0}, or a subset of it, as a training set in a learning system in order to extract the relation between appropriateness in F_0 and the *relevance vector* in a set of frameworks $F_1, F_2, \ldots, F_m$. Once trained, we only have to feed the CSS with other concepts and the system will propose those concepts with expected high appropriateness.

An illustrative example is proposed in this paper to validate our formulation and hypothesis. This example highlight the relationship between the appropriateness and the relevance of a concept with respect to other apparently distinct frameworks.

4. Experimental framework: combining chocolate with fruits

To illustrate the implementation of the ideas presented in the previous section, let us consider the following creative situation: *coming up with a new chocolate cake by combining dark chocolate with a fruit* to obtain a highly accepted product. The 'creative' given the task has a lot of experience in combining chocolate with many different ingredients –cheese, liqueurs, olive oil, nuts and, of course, fruits. Due to his experience, he knows whether several combinations of specific types of chocolates and fruits are suitable or not but, obviously, he does not know how well any kind of chocolate combines with all existing fruits. Thus, a CSS is going to be developed according to the methodology presented in the previous section in order to assist the expert in creating suitable new combination.

In our case, since we constrained the problem to combine fruit and dark chocolate, the universe $\mathcal{U}$ is formed by all fruits. The H-conceptual space, $C_0 \subset \mathcal{U}$, contains all fruits that have ever been mixed with black chocolate. The P-conceptual space, C^{i}_{0}, which consists in all fruits for which the expert i knows whether they blend in well or not with dark chocolate, is just a subset of C_0. Moreover, the expert is able to assign a value $a_0(x)$ for all $x \in C^{i}_{0}$, which, in our case, is represented in our case as a qualitative ordinal value (see Table 2). The objective of our CSS consists of suggesting other fruits $y \in \mathcal{U}$, $y \notin C^{i}_{0}$, with a high predicted value function $a_0(y)$, i.e. fruits valuable to the expert for the considered problem (combining with dark chocolate).

Following the CSS methodology introduced in the previous section, we can learn the value $a_0(\ )$ of a fruit with respect to the dark chocolate (framework F_0) through the way it is related to other frameworks. In this example we are considering only frameworks related to recipes and ingredients, but other alternatives could also have been considered. To obtain the relevance value in regards to a framework, a large recipe database has been used. We counted the number of recipes containing both the fruit and each term associated to the framework.

Although the combination of fruits and dark chocolate could have nothing to do with, for instance, the combination of fruits and rice according to our assumption, given a new fruit that has a high value of a_0 and has similar relevance vector than another unknown fruit with respect to others frameworks including rice, this new fruit could be considered as a good option to extend the search.

4.1. Data collection

In order to validate our method, we used the data provided by the chocolate chef Oriol Balaguer who assessed, according to his expertise, the combinations of 28 different fruits and their suitability in combination with dark chocolate [Agell 2013]. In addition we considered 14 frameworks aside from the main framework (dark chocolate). All considered frameworks consisted in ingredients used in cooking, but not necessarily in pastry making. In this implementation of the CSS, we are not focusing on the frameworks selection problem. Instead, we think that the *ad-hoc* selection for this example is enough for illustrating how the formulation presented can be implemented and we leave framework selection as work to be undertaken in the near future.

In order to obtain the relevance vector for each fruit we used the online database of recipes www.allrecipes.com. Allrecipes.com is a food-focused social media website where millions of home and professional cooks find and share food experiences. Founded in 1997, Allrecipes.com has grown to become the world #1 food site with over 450 million visits annually. In addition to the US based site, Allrecipes has 16 international sites around the world.

Table 1 gives the list of the 23 fruits (rows) and some of the frameworks (columns). The last column of this table shows the qualitative assessment provided by the expert considering the qualitative labels detailed in Table 2. Values in Table 1 are obtained by searching both terms simultaneously (fruit and framework). This value represents the number of recipes of the database containing both terms. Table 3 gives the complete list of frameworks considered in this study.

This list of 23 fruits constitutes a subset of the P-conceptual space of the expert. This subset is employed to obtain the relation between the appropriateness value given by the expert and the relevance vector given by the website. Once this relation is captured, the CSS can be used to predict the appropriateness of new fruits whose relevance vectors were obtained from the website.

Table 1. List of the 23 fruits assessed by the expert (last column) and a list of 12 of 50 frameworks considered in this example. The last column contains expert assessment of the fruit.

	Almond	Bacon	Beef	Beans	Beer	Bread	Butter	Cabbage	Caramel	Cheese	Chicken	Chilli	…	app
Apple	188	119	155	133	23	565	1309	99	154	601	522	168	…	**1**
Pear	28	5	10	11	0	44	116	3	15	82	30	12	…	**1**
Quince	0	0	0	0	0	0	3	0	0	0	0	0	…	**2**
Apricot	63	4	13	8	2	52	156	2	5	54	73	8	…	**4**
Peach	49	6	10	18	4	57	210	7	3	64	43	13	…	**3**
Plum	16	33	48	16	5	90	114	13	2	187	118	58	…	**5**
Blackberry	6	2	2	3	2	11	89	0	5	24	6	0	…	**4**
Strawberry	89	7	6	30	3	121	323	5	9	257	40		…	**4**
Raspberry	72	3	3	14	5	54	213	2	2	127	32	4	…	**5**
Grape	44	31	20	17	2	48	61	9	6	171	115	18	…	**1**
Pineapple	66	29	57	65	5	138	321	21	12	280	215		…	**5**
Orange	201	29	78	92	24	274	684	23	16	272	342	89	…	**5**
Banana	103	13	15	44	7	361	425	4	29	125	32	23	…	**5**
Pomegranate	7	0	0	0	0	11	13	2	0	10	0	4	…	**4**
Grapefruit	3	0	2	2	0	5	7	0	0	8	7	0	…	**5**
Kiwi	5	0	4	0	0	3	18	0	0	20	9	2	…	**3**

Lime	36	27	132	51	63	110	264	63	9	289	514	322	…	**4**
Mandarine	34	6	0	9	0	7	22	8	0	36	32	2	…	**5**
Mango	21	4	7	7	0	43	66	6	0	50	119	31	…	**5**
Olive	204	386	995	202	90	1560	1321	160	112	3403	2327	1081	…	**2**
Papaya	5	0	0	0	0	3	8	0	0	7	11	2	…	**1**
Watermelon	2	3	0	0	0	3	5	0	0	25	4	5	…	**1**
Citron	15	0	0	2	0	6	24	0	0	3	0	0	…	**3**

Table 2. Labels and linguistic meaning in the fruit assessment by the expert.

Labels	Linguistic labels
1	It does not combine at all
2	It does not combine well
3	Combines well
4	Combines very well
5	It makes an excellent combination

Table 3. Complete list of frameworks considered in the study.

#	Framework	#	Framework	#	Framework	#	Framework
1	Almond	16	Fish	31	Nuts	46	Spinach
2	Bacon	17	Flour	32	Onion	47	Sugar
3	Beef	18	Garlic	33	Pasta	48	Tabasco
4	Beans	19	Honey	34	Peanut	49	Tea
5	Beer	20	Hummus	35	Pepper	50	Tofu
6	Bread	21	Jam	36	Pie	51	Tomato
7	Butter	22	Ketchup	37	Pizza	52	Tuna
8	Cabbage	23	Kidney	38	Potato	53	Turkey
9	Caramel	24	Lettuce	39	Prawn	54	Vanilla
10	Cheese	25	Liqueur	40	Rice	55	Veal
11	Chicken	26	Lobster	41	Salad	56	Vinegar
12	Chilli	27	Mayonnaise	42	Salmon	57	Wine
13	Coffee	28	Milk	43	Salt	58	yoghurt
14	Curry	29	Mint	44	Soda		
15	Eggs	30	Mustard	45	Soup		

4.2. CSS training and results

As said in Section 3, our proposal is based on the existing relation between the appropriateness of a concept with respect to a framework and the relevance vector of this concept with regard to a set of other frameworks. To validate this hypothesis, we used data from Table 1 to obtain this relation and assess its significance. This validation is performed twice by using, on the one hand, the complete range of expert's valuation shown in Table 2 and, on the other hand, using just a binary valuation (suitable or not suitable) that simplifies the expert's assessment. We used a multiclass and a two-class support vector machines (SVM) and we validated through 'leave one out' cross-validation process. If the SVM can correctly estimate the appropriateness of a fruit from the relevance vector, it can be used to propose new fruits with high predicted appropriateness.

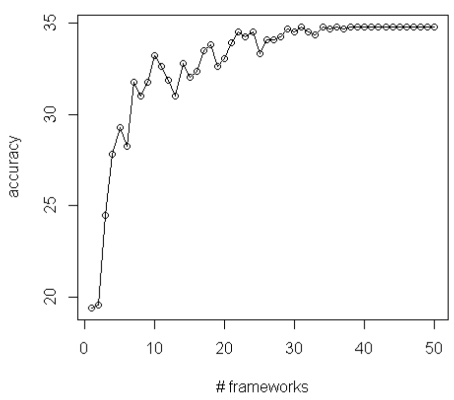
Table 4. Best parameter values and results of binary and multi-class SVM.

	5 classes	2 classes
C	10	100,000
γ	100	0.1
accuracy	34.78%	85.00%

Parameters of the SVM were tuned by optimizing the geometric mean of sensitivity and specificity because data are imbalanced [González-Abril 2014]. In the first case, we employed a multiclass SVM (5 classes) with a Gaussian kernel. The best parameters obtained were C=10 (regularization cost) and γ=100 (Gaussian kernel parameter). Software R and LibSVM library were used to train the datasets and predict accuracy of classifying [R Dev team 2008] [Chang 2013]. The total accuracy obtained was 34.78%. This value means that 34.78% of the time, the predicted value matches with the expert assessment. Taking into account that there are 5 classes and the expected accuracy in the case of random values is $\sum_{i=1}^{5} (N_i/N)^2$=24% (N_i is the number of examples of class *i* and N the total of examples), the accuracy value obtained reaffirms our hypothesis. In the second case, pattern labels are changed in order to maximize CSS utility. Instead of using the labels shown in Table 2, a binary classification when employed in which the first class contains those combinations that were suitable to the expert and the second class those were those that were not. Patterns corresponding to values 3 and less are considered to the first class and the rest of patterns are considered to belong to the second class. In this case, the best parameters obtained by the tuning process were C=100,000 and γ= 0.1. The total accuracy obtained was 85%.

In order to show that the relationship between the appropriateness and the relevance vector increases with the dimension of the relevance vector, subsets of the set of frameworks have been considered instead of the whole set. Figure 2 shows the mean accuracy according to the number of frameworks considered in each trial. For each *k* from 1 to 58, thirty different subsets of *k* elements have been considered. The mean accuracy among these thirty subsets of *k* elements is calculated when the SVM is applied considering leave one out cross validation. Figure 2 supports our hypothesis and, in addition, it can be noted that this accuracy stabilizes from the value 30.

Figure 2. **Mean accuracy of the SVM with respect to the number of frameworks considered.**



5. Conclusion and Future work

In this paper we proposed a new formalization of the mechanism of creativity based on Boden's notions of *conceptual space* and *transformational creativity* through a search beyond the boundaries of this conceptual space. This study redefines the formal mechanisms of exploratory and transformational creativity introducing the concepts of framework and relevance of a concept with respect to a framework. The formalization presented has been implemented in a real example conducted with a Spanish chocolate chef. The CSS obtained proved capable of proposing new, unknown fruits that were predicted to combine well with dark chocolate. The validation of the method was performed using both a bi-class and a multi-classs SVM. The results allowed us to conclude that the assumptions on which the method is based were satisfied in this example.

Finally, it is important to note that in this implementation, we are not aiming at the frameworks' selection problem. However, this is an important issue to be analyzed in future work. In addition, two different topics will be considered in future research. First, the inclusion of both complete and incomplete concepts in the formalization. Second, consideration of a new real case, where it could be demonstrated that creativity enhanced by introducing the methodology described in this paper.

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References

[1] Ahn, Y.-Y.; Ahnert, S. E.; Bagrow, J. P.; and Barabasi, A.-L.. Flavor network and the principles of food pairing. Sci.Reports 1:196.(2011)

[2] C.J. Thornton, How thinking inside the box can become thinking outside the box. *In Proceedings of the 4th international Joint Workshop on Computational Creativity*, (2007).

[3] B. Shneiderman, Creating Creativity: User Interfaces for Supporting Innovation, *ACM Transactions on Computer-Human Interaction* **7**,1 (2000), 114-138.

[4] B. Shneiderman. Creativity Support Tools. Accelerating Discovery and Innovation. *Communications of the ACM*, vol 50, nº 12 (2007).

[5] M.A. Boden, *The Creative Mind: Myths and Mechanism.* Weidenfiel and Nicholson, London, (1990).

[6] M.A. Boden, What is creativity? In M.A.Boden, editor, *Dimensions of Creativity*. MIT Press (1996), 75-118.

[7] G. Wiggins, A preliminary framework for description, analysis and comparison of creative systems. *Knowledge-Based Systems* **19** (2006), 449-458.

[8] G. Ritchie, Some empirical criteria for attributing creativity to a computer program. *Minds and Machines* **17** (1) (2007), 67-69 (2007).

[9] G. Ritchie, A closer look at creativity as search, *In Proceedings of the 3rd International Conference on Computational Creativity* (2012).

[10] J. Charnley, A. Pease and S. Colton. On the Notion of Framing in Computational Creativity, *In Proccedings of the 3rd International Conference on Computational Creativity* (2012).

[11] R. Manurung, G. Ritchie and H. Thompson. Using a genetic algorithms to create meaningful poetic text. *Journal of Experimental & Theoretical Artificial Intelligence* **24**(1), pp43-64. (2012),

[12] N. Agell, G. Sánchez, M. Sánchez, F. Ruiz, Group decision-making system based on a qualitative location function. An application to chocolates design, *In Proceedings of the 27th International Workshop on Qualitative Reasoning* (2013).

[13] Heston Blumenthal. The Big Fat Duck Cookbook. Bloomsbury, London, United Kingdom, 2008.

[14] Langton, N., Robbins, S.P., Judge, T. A.. *Organizational Behaviour: Concepts, Controversies, Applications.* Pearson (2012)

[15] Mumford, M. D. Where have we been, where are we going? Taking stock in creativity research. Creativity Research Journal, 15, pp 107-120 (2003)

[16] R Development Core Team. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria, URL http://www.R-project.org. (2008)

[17] L. González-Abril, H. Núñez, C. Angulo and F. Velasco. *GSVM:* An SVM for handling imbalanced accuracy between classes in bi-classification problems. *Applied Soft Computing*, **7** pp 23-31 (2014),

[18] Sawyer, R. K. 2012. Explaining Creativity: The Science of Human Innovation. Oxford: Oxford University Press.

[19] Varshney, L. R.; Pinel, F.; Varshney, K. R.; Bhattacharjya, D.; Schöergendorfer, A.; and Chee, Y. M.. A big data approach to computational creativity. (2013).

[20] Jordanous, A. 2011. Evaluating evaluation: Assessing progress in computational creativity research. Proc. Int. Conf. Comput. Creativity 102 – 107.

[21] Chang, Chih-Chung and Lin, Chih-Jen: *LIBSVM: a library for Support Vector Machines* http://www.csie.ntu.edu.tw/~cjlin/libsvm (last updated 2013)