Interpretation as driver for psychological creativity

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ABSTRACT
This paper describes some acts of psychological creativity as phenomena arising from changes to a situation, brought about through interpretation. It presents a way of representing a situation as a schema of concepts made up from perceptual dimensions. It shows the utility of concepts as being changed by the situation within which they are used. An example of this is described, in which the information within a concept is unchanged yet its use becomes different through salience weighting. A computational implemented example is presented as a generate-and-interpret model that produces country growth indicators and then interprets them and repeats this process. The situation, and the space of possible designs, is changed through the act of interpretation. It is suggested that interpretation can be a driver for changing situations – something that looks like P-creativity to an outside observer.

Keywords
Situated cognition, interpretation, situated design, P-creativity

INTRODUCTION
When a designer has an idea that is both new and useful, an act of psychological creativity (P-creativity) has occurred [1]. Work on *situated design*, in both theory [2,3] and cognitive studies [4] describes the movement of a designer from one situation to another during the design process, a movement that forms the basis of P-creativity. This paper suggests that *interpretation* can be a driver for this P-creativity. When the expectations of interpretation cannot be met a change of situation can occur. The claim is that a change of situation is an act of P-creativity and that interpretation can cause a change of situation. A method for achieving this is described and implemented and suggestions made for future development of this model of computational creativity.

In this paper we use a design framework for explaining the way that interpretation can cause a change of situation and then present an implemented example of how it works in a model of synthesis.

P-creativity, changing situations, and spaces of designs
A state within a computational model can be associated with a space of possible designs [5]. P-creativity occurs when the space of possible designs changes so that designs not previously available become available.

In this work, situations are taken to be structured schemas of related concepts and acts of P-creativity can occur through changes to this schema. Consider two types of models in which the space of designs is a function of:

1. The concepts that the agent holds. Learning new concepts can result in new designs being available.
2. Attention to some concepts at the expense of others. The space of possible designs can change through learning and also through a shift in attention with no learning.

Movement between situations is an example of the second of these and typically results in a change to the space of possible designs [6]. Schön and Wiggins [7] describe an architect with an idea of what they are doing, sketching using this idea, and then interpreting; in such a way that they have seen more within the sketch than they intentionally put there. This fits well with the description of a change of situation (a different schema of concepts before and after interpretation) that is an act of P-creativity (new designs or design actions are possible within this new schema of concepts). The point of departure of this work are the questions:

1. How can we represent the situation as a schema of concepts?
2. We observe that the act of a designer interpreting seems to change a situation. How does this occur and how can we model it?

Based upon cognitive studies [4,7] interpretation is seen to be an activity that changes a designer's notion of what they are doing – if you were to ask them "what are you doing now?" before and after interpretation you would get different responses [8]. A similar phenomenon to a change of situation is that of *insight* following which a designer is able to see what they are working on in a new light [9].

In this work we describe a way of representing situations as well as how situations can become changed through interpretation. An example is provided in a model that uses a method of *generate-and-interpret*.

REPRESENTING SITUATIONS IN CONCEPTUAL SPACE

Background

When we say that a designer 'knows about A' it can be considered the equivalent of saying that a designer 'holds a concept about A that has its basis in abstractions from the world' [10].

Concepts are generalizations about the world that can be used for inference. No experience is exactly identical to a previous experience, but because we hold concepts our world has some stability [11]. By learning concepts we can acquire and then re-use knowledge from experience in the world. Concepts allow for inferences to be made about the world [12]. For example, by interpreting a novel object as a PEPPER GRINDER we have an idea of how it is used (most likely there is a part to be twisted in order to crush a peppercorn) and what it is used for (to add pepper to food for taste).

There are many different theories about concepts that have in common the notion of abstraction, that 'knowledge of a specific category has been abstracted out of the buzzing and blooming confusion of experience' [10]. Concepts are created from invariance over experience.

The space of possible designs within a situation made up from concepts can be explained through a framework for representing concepts known as *conceptual spaces* [13]. This framework is used because it gives a formal mathematical model for representing concepts.

Conceptual Spaces

An agent has sensors which produce data during interaction with the external world. For example, an eye can sense changes in light, an ear changes in air pressure [13]. The different things about the world that can be sensed make up *dimensions* which represent the qualities of an object. Some examples of quality dimensions that humans sense are: height, width, depth, brightness, pitch, temperature and weight. A dimension is a one-dimensional space within which stimuli can be located.

Dimensions that are inseparable create a perceptual *domain*. Inseparable means that the agent cannot get information for one of the dimensions without getting information for all of them. For example, three dimensions of visual perception are hue, brightness and chromaticity. The way the eye is structured, we do not get information for hue without also getting information about brightness and chromaticity. A perceptual domain (e.g. texture, and color) is a space with dimensions of those things that the agent can sense. In the example of color being sensed by hue, brightness and chromaticity, this results in a three-dimensional domain. A stimulus could be located within this domain based on a set of three values.

A concept is a convergence zone that brings together spaces within perceptual domains that experience has shown to be related. For example, the concept for BANANA might bring together areas in the color domain that we might call yellow, green and brown with areas in a shape domain that we associate with the Lady Finger and Cavendish banana varieties. Gärdenfors [13] implicitly adopts a prototype theory of concepts where the most typical perceptual regions (e.g. the colors and shapes above for a BANANA) are associated and less typical instances of a concept have some distance (measured in conceptual space) from a prototype [13,14]. Figure 1 shows the way that dimensions create the space of a perceptual domain, and the way that a concept associates regions in domains with each other. A part of the meaning of a concept comes from its relationship with other concepts.

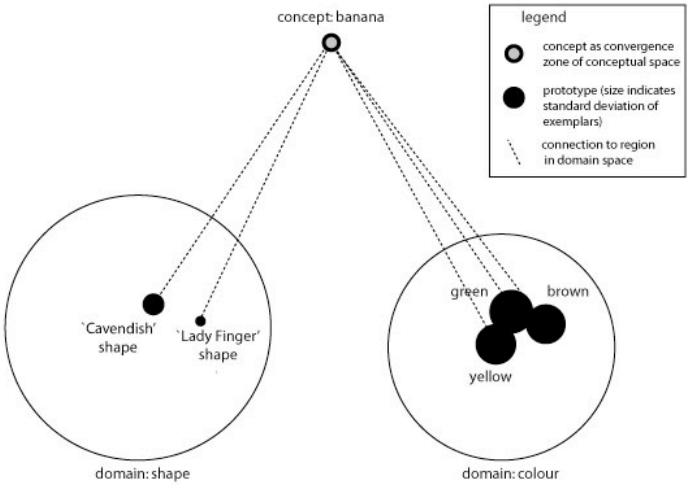

Figure 1 A concept is represented as a convergence zone of points in conceptual space.

Conceptual spaces can be extended to represent situations. In a situation a number of concepts are brought together; some concepts held by an agent are inside the current situation and some are not. Further, these concepts are not discrete units of knowledge, but rather perturb the use of each other. One such way that they perturb each other is through salience weighting. The significance of adopting this framework is that concepts are grounded in perceptual data [15].

Salience weighting within conceptual space

Within a concept, dimensions can be scaled on the basis that some dimensions are more salient within a concept than others. Goldstone [16] suggests that dimension x is more sensitized when categorization depends only on dimension x than when it depends on both dimensions x and y. In other words, it is not simply that concepts bring together dimensions within domains to create a concept, but that the categorization is more sensitive to some of these dimensions than others. The asymmetry of similarity can be taken as an indicator of this [17]. For example, people say that Tel Aviv is more like New York than New York is like Tel Aviv [13]. Following on from Goldstone [16] we can hypothesize that this is because some of the dimensions that are used to categorize Tel Aviv also apply to New York, whilst some of the dimensions that are used to classify New York are not held by Tel Aviv. The point of the example is that despite concepts being based upon

similar dimensions, a concept will be more sensitive to some of these dimensions than to others, and a good indicator of this is the spread of exemplars within that dimension. For example, the number of sides is a very sensitive dimension in the concept of a SQUARE.

This is represented in the conceptual spaces framework as a distortion of measurements in the space. When a dimension is more salient within a concept (i.e. more important to that concept) then it causes the dimension to be scaled. This is achieved by measuring distance within the space as a weighted Minkowski metric, Equation 1, where d_E refers to the distance between a concept and an external object being interpreted, k the number of dimensions and w the weighting for each dimension. A higher degree of salience corresponds to a higher weighting on a dimension.

$$d_E(x,y) = \sqrt[k]{\sum_i w_i |x_i - y_i|^k} \qquad (1)$$

In this way dimensional scaling distorts the measurements carried out within conceptual space. Because similarity is based upon distance within the space, it can change the way that an external object is interpreted.

Figure 2 shows an example of three concepts in conceptual space before and after dimensional scaling. The conceptual space has been partitioned using Voronoi tessellation to indicate which regions of the space are associated with each concept [13].

In the partitioning of space before scaling, the point q would be interpreted as an example of the concept at p_1. However, if the x dimension is scaled due to a greater salience than the y dimension then it leads to a different partitioning of space, such that the same point q is now classified as an example of the concept defined by p_3.

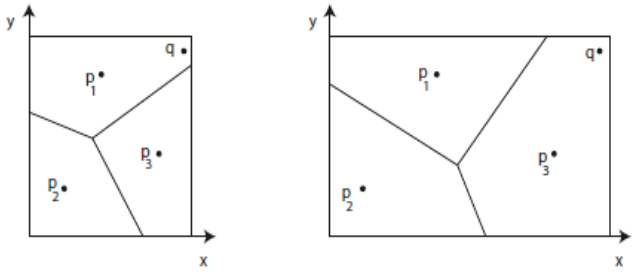

Figure 2 Voronoi tessellation of a space before and after salience weighting, resulting in different classification of the external object q (after [13])

Extending salience weighting for situations

We extend the notion of salience weighting from dimensions within a concept to apply also to concepts within a situation. Some concepts are more important to the situation than others. For example, in a situation of designing a home, the concept of a HOUSE might be particularly salient. Consider a situation as a schema of concepts, each distorting the conceptual space in their own way. In this way, a situation is more than just the sum of a number of discrete concepts; each concept is actually changed by the situation through this warping of space. In the model implemented here this is calculated as a cumulative scaling upon perceptual dimensions.

An example of a situation is shown in Figure 3, as a number of weighted concepts, each with their own weighting of perceptual spaces. Within this situation the salience of each perceptual dimension can be calculated as the cumulative scaled weight of all concepts linked to this domain.

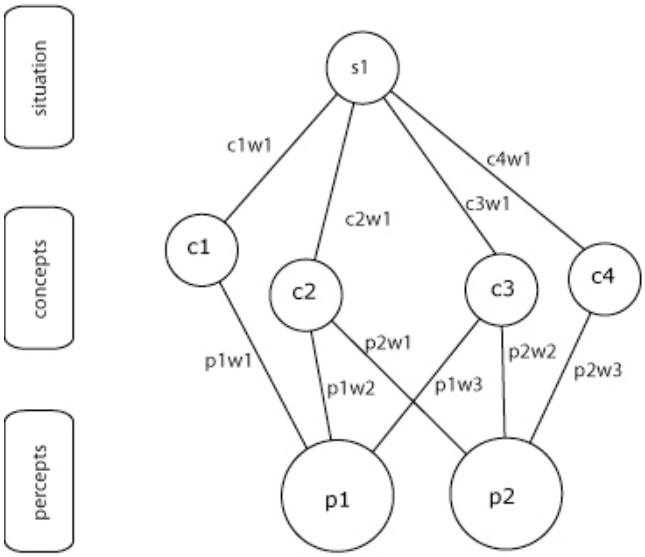

Figure 3 An example of salience weighting in a situation through representation of a schema of concepts

An example of this is calculated for Figure 3 by Equations 2 and 3:

$$p1 = c1w1*p1w1 + c2w1*p1w2 + c3w1*p1w3 \qquad (2)$$

$$p2 = c2w1*p2w1 + c3w1*p2w2 + c4w1*p2w3 \qquad (3)$$

Representing Situations

Situations can be represented as a schema of concepts within conceptual spaces. Concepts are identified as units of knowledge within the agent; but their use within a situation allows for concepts to change the use of other concepts. In this way knowledge within the agent is never static and always situated. Salience weighting is identified here as one way in which the use of concepts can be situated.

In this paper we focus only on one aspect of changing situations, associated with interpretation from an agent's experience. Figure 4 shows three questions that are linked in a circular fashion. If interpretation is about construction from expectation, one can ask where expectations come from. Models of grounded cognition hold that expectations are based upon the use of memory. Memory is based in the experiences of an agent. The point is that interpretation

cannot be teased apart from this loop of experience and expectation. In this work we bypass questions about knowledge and experience to focus upon the role played by interpretation in changes to the situation.

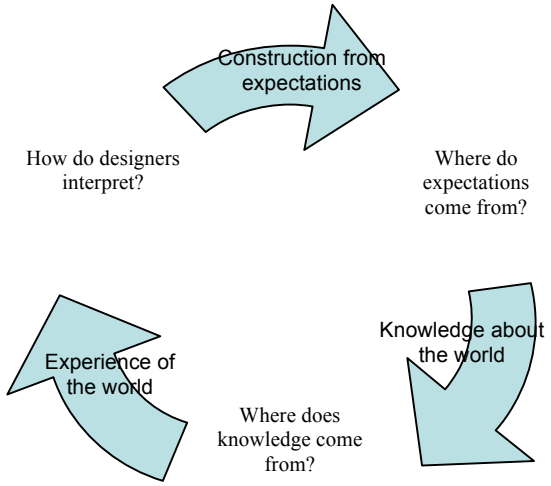

Figure 4 The cyclical nature of questions and broad responses within the paradigm of situated design

INTERPRETATION AND CHANGING SITUATIONS

During design activity, designers interpret by constructing from expectations. Whenever a designer brings something from the external world into their internal world, interpretation occurs. For example, when a designer reads a design brief, considers their own work whilst sketching or observes behaviors of a model, there is some relationship between the meaning that they construct and what they have experienced; they do not experience the world *tabula rasa*. What then can be said about the nature of this relationship between interpretation and experience? We propose that designers interpret from a set of expectations about the world, constructing from what they expect to find. These expectations arise within the current situation; they can be considered a function of the conceptual schema held by the agent and the conceptual space resulting from this schema.

Interpretation for the purpose of this work is about the 'construction of meaning' as distinguished from interpretation as the 'processing of information' [18]. Whilst this work argues that human designers always interpret in a constructive way, the term *constructive interpretation* will be used to differentiate it from other types of interpretation that do not involve construction from expectations [19]. The experiences of a designer and the way that these experiences are organized and used, in the form of expectations that come from the situation all contribute to the construction of an interpretation.

As Henry David Thoreau put it "It's not what you look at that matters, it's what you see" [20]. What you see is based on the situation active at the time of interpretation. There is a well-known children's game that can be used to illustrate the construction of an interpretation: one player scribbles some lines on a page such as that seen in Figure 5. The second player then has to draw a picture using the lines in the scribble. In order to do this they need to interpret the lines in the scribble 'as' something. For the scribble in Figure 5, as with any representation, there are many possible interpretations. In Figure 5 a drawing could be made using the lines of the scribble in which the circle becomes the wheel of a car, the eye of a bison or a hole in a cliff face - in each case the player has seen the drawing in such a way that an action is suggested by the situation that is active for them at that time. There are no limits to possible interpretations within the representation, only within the mind of the viewer. The example demonstrates that the meaning lies not in the representation itself but rather is constructed by the player looking at the scribble. Each player will likely construct something different from the lines and the same player can construct something different to the last time if their situation has changed. In doing this, the player is making use of their knowledge from experience in the world to construct an interpretation.

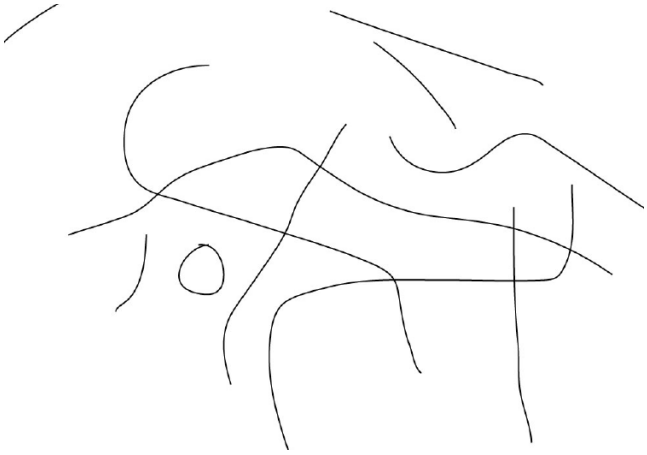

Figure 5 A scribble; what can you construct from it?

Interpretation is a two way process where: (i) the expectations of a designer affect their interpretation of their own work; and (ii) the act of interpreting can change the designer's situation.

A change of situation is triggered when something within the current situation stops working. Consider two examples of this:

1. The agent brings together disparate concepts and produces something that it was not expecting. The interpretation of this unexpected data requires other concepts to be brought into the situation.
2. The agent is not making progress on the design task (e.g. the space of designs is not changing) and so less predictable interpretations are found.

In both circumstances the change of situation is triggered by the act of interpreting. As Schön [21] describes it, the act of seeing itself changes things; here we have identified

the situation and shown a representation of it. We suggest that interpretation can change this constructed schema of concepts, to both bring in other concepts, change concepts and – in doing so – change the meaning of concepts already in the situation. In this way interpretation becomes a driver for acts of P-creativity.

Summary

We have described one way of representing situations through conceptual spaces and salience weighting, and one way in which situations can change through interpretation. A situation has been described as implying a space of possible designs and a change of situation has been described as a change of this space in a way that looks like P-creativity to an external observer. We can summarize the four main theoretical points as:

1. *Concepts are changed by the situation within which they are used:* A concept might be represented as a discrete unit of knowledge, but these units of knowledge are never used in isolation. Their use is tied to the situation and other concepts being used at the same time.
2. *Interpretation begins with construction from expectations and can lead to a change of situation when construction is not possible:* When interpreting, designers attempt to construct from their expectations. When expectations cannot be met then interpretation leads to either learning or a change of expectations. In either case the situation can change, potentially resulting in: (i) a change in the concepts in the situation; and (ii) a change in the way that each concept in the situation is used.
3. *A change of situation through interpretation can be a driver for creativity:* When conceptual expectations cannot account for perceptual data new concepts can be brought into a situation, changing it.

IMPLEMENTING P-CREATIVITY FROM SITUATIONAL CHANGE

A model was implemented that uses an iterative process of generation and interpretation in producing a set of growth indicators for a country. The model uses an agent that was primed with data that were obtained from the World Bank (http://data.worldbank.org/data-catalog). Within the frame of this activity of generation and testing (without a fitness function) we show how interpretation can change the situation. This is not claimed to be an act of P-creativity as the agent is not given a notion of utility, but it shows the way that situational change through constructive interpretation can drive P-creativity in such an agent. It demonstrates situational salience weighting and the way that it affects the movement between different situations. An example of the kind of data used is shown in Figure 6.

In the model, the agent engages in a cycle of *generate-and-interpret* [22]. Rather than the typical application of a fitness function in each phase of interpretation, the agent is simply concerned with the way that its situation changes. The agent is generating within a cycle of synthesis that is not guided towards any particular purpose – it continues this loop indefinitely. Applied to a domain, and with the addition of a fitness function, the technique could become a part of designing or of problem solving. The specific data used here (that of growth indicators) is not essential but serves the purpose of making the ideas more concrete. One way to conceive of the model is as an agent that has an idea of a problem (perhaps synthesizing a set of growth indicators that it would be good for an country to have), is playing with ideas (generating) and then seeing what is produced (interpreting within a situation, with the potential for this interpretation to change the situation).

Country Name	Electricity production from oil sources (% of total)	CO2 emissions (metric tons per capita)	Population density (people per sq. km)
Canada	1.539086802	16.88755556	3.626322509
Angola	15.51860649	1.40948886	14.08084142
Eritrea	99.30555556	0.121081685	47.33830693
Oman	18.00180018	13.6773335	8.808726979
Albania	2.517482517	1.353329558	114.3232847
Cote d'Ivoire	0.31965903	0.317004854	63.2792327
Nigeria	4.948211333	0.644416439	162.1944541
Sudan	68.04668575	0.284730009	17.0169596
United Arab Emirates	1.86450477	31.03379192	52.19991627

Figure 6 Examples of the growth indicator data that were used in the experiment

Figure 7 shows an example of four concepts held by the agent. Each square represents one of the growth indicators, normalised to a value between 0 and 255 so that it can be represented as a greyscale swatch.

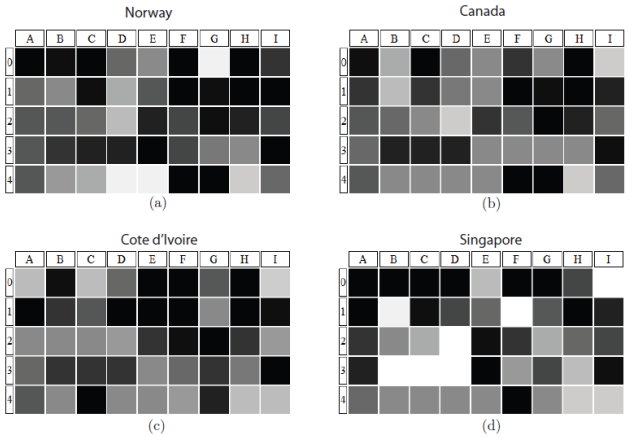

Figure 7 The 45 growth indicators represented as grayscale swatches for four different countries: (a) Norway; (b) Canada; (c) Cote d'Ivoire; and (d) Singapore

Figure 8 shows the way that the model moves from one situation to another situation. The three arrows labelled (a), (b) and (c) are examples of three different movements that can occur as a result of interpretation. In (a) the space of possible designs within the situation has not changed, but

the specific designs being generated have changed. In (b) the space of designs has changed so that some designs that were previously available are still available but so are some new designs. In (c) a complete paradigm shift has occurred such that entirely new designs are conceived.

When the model commences the agent 'knows' about 121 countries, and has 45 perceptual dimensions for each (the specific growth indicators). The model commences its activity with a situation consisting of four randomly determined concepts. It then goes through an iterative cycle of generate and interpret.

Each concept in the model (each country) can be considered as a genotype, with the value of each percept a gene. By taking some genes from each of the explicit concepts within the situation, a new concept can be generated through *genetic crossover* [23]. The specific method for generation is not as important as the fact that concepts are perturbed by the act of externalizing them, either through interaction with other concepts or through imperfect representation. For example, in other models random layout of concepts can be used as the method for generation.

When the agent interprets it is expecting to find the concepts that it held prior to generating. Sometimes these expectations will be met and at other times they will not. Referring to Figure 8 we can see that when expectations are met, movement within the space of possible designs of type (a) occurs; the four concepts do not change, but the specific designs produced do. However, when expectations cannot be met (it cannot interpret the product of its generation within the current situation) then the situation changes, resulting in type (b) and (c).

The success of construction from expectations implemented in the model as a threshold of distance within conceptual space, using the Minkowski metric described in Equation 1. If the interpreted concept is sufficiently far from the expected concepts then it cannot be interpreted within the situation and the situation changes.

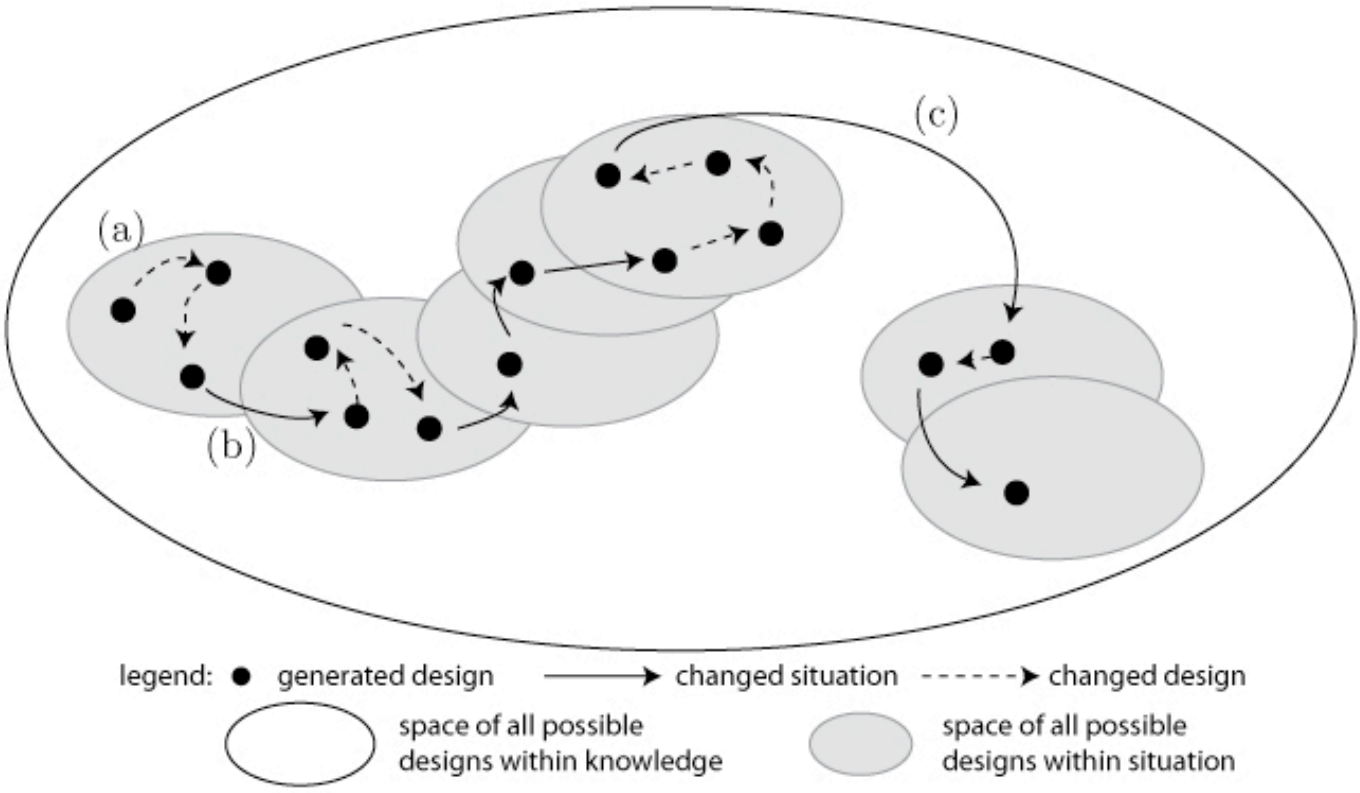

Figure 8 Generated designs and spaces of possible designs within changing situations in the model: (a) new generations within the same situation; (b) movement to an overlapping space of possible designs; and (c) movement to an entirely new space of possible designs

If we took all 121 countries in the experiment and allowed for genetic crossover at all points to create a final result then each feature could be one of 121 possible values. There are 45 features, meaning that there are $121^{45} \approx 5 \times 10^{93}$ possible designs, which is a very large space of possible results.

Within a situation of 4 concepts (4 countries) there are $4^{45} \approx 1 \times 10^{27}$ possible results which is a much smaller space of possible results. Through changes of situation, this smaller space of results moves around within the larger space of possible results. To an external observer this looks

like P-creativitiy: the system looks like it is operating within a constrained space and is then breaking out into a new space.

An example of results from the experiment

We help to explain the model by going through how we get the results step by step as the agent generates and interprets:

1. The agent begins with a situation that holds explicit concepts of Namibia, Botswana, South Africa and Zambia.

2. The agent generates results within the space created by the situation. These results are crossovers between the four countries in the situation, Figure 9(a), (b), (c) and (d). This is an example of a Figure 8(a) type change.

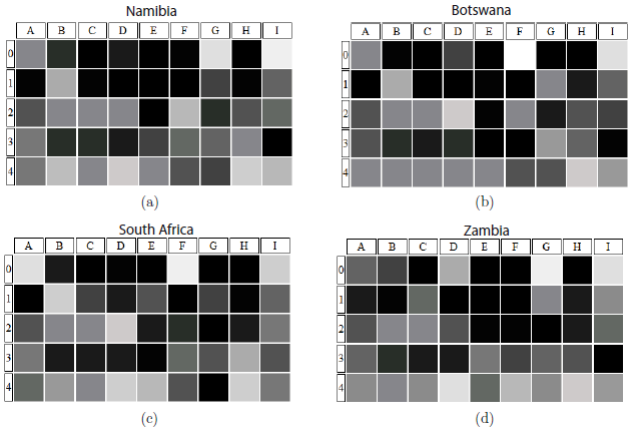

Figure 9 Four concepts in a situation: (a) Namibia; (b) Botswanal; (c) South Africa; and (d) Zambia

3. In the 8th result that it generates, Figure 10(a), none of the explicit concepts can be constructed. However, one of the implicit concepts is able to be constructed, Bangladesh, Figure 10(b). The result is that the situation is changed. This change is of the type (b) represented in Figure 8.

4. The agent generates results within the space of the new situation, further examples of type (a) movement.

5. The 31st result is generated, Figure 11(a), cannot be interpreted as one of the countries within the situation. This results in the situation changing. In the model, this results in use of the closest situation within conceptual space (based upon the primed experiences of previous situations) within which an interpretation can be constructed. An interpretation is then made, of this data interpreted as Uruguay, Figure 11(b). However, the situation has now changed to one of Uruguay, Chile, Paraguay and Bolivia; the conceptual schema has been altered by the act of interpreting. This is an example of a change of situation represented in Figure 8 as (c).

6. The agent continues to generate results within the space created by the new situation.

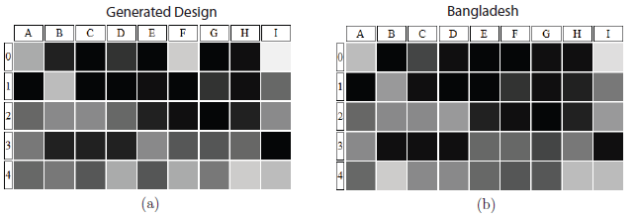

Figure 10 The agent produces: (a) a generated result; which is interpreted as (b) Bangladesh

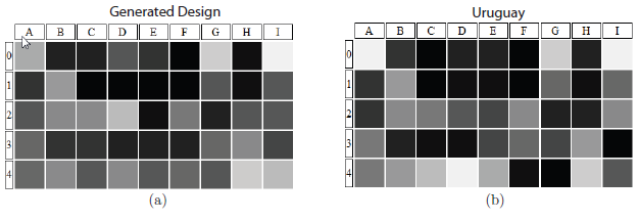

Figure 11 The agent produces (a) a generated result; which is interpreted as (b) Uruguay

The effects of salience weighting

Salience weighting requires conception to be linked to a number of perceptual domains. The 45 features of conceptual space are each linked to one of four perceptual categories. In this model four domains related to the data are identified as: agricultural, financial, environmental and demographical.

Within a situation there are four explicitly expected concepts. Each one of these concepts has a link to all four perceptual domains. The suggestion of salience weighting is that the values within perceptual domains can be a guide to where attention follows within the model. In this model salience weighting is calculated using the average distance from the median for the features within the domain. Each vector within conceptual space can be described as the convergence of four vectors from perceptual space.

The salience within the situation is then a ratio of the relative weightings of the four domains within the model. All measurements of similarity within conceptual space are then weighted depending upon the perceptual domain that the features are related to.

The interpretation of the results produced within the model is affected by this salience weighting. Consider two different situations that have a concept in common which is Switzerland: (i) Germany, Luxembourg, Netherlands and Switzerland; and (ii) Spain, Portugal, Ireland and Switzerland. Both situations include Switzerland. Through salience weighting, the use of this concept occurs differently in the two different situations. Table 2 shows the four perceptual domains and the salience that each has within the two different situations.

	category				Switzerland to Gen. Des.	
situation	*AG*	*EN*	*FI*	*DE*	*distance*	*similarity*
Spain, Portugal, Ireland and Switzerland	0.252736	0.237908	0.294205	0.215152	0.326146465	0.899090559
Germany, Luxembourg, Netherlands, Switzerland	0.258768	0.246918	0.273833	0.220482	0.324084232	0.900296983

Table 2 Situational salience weighting effects within the generate-and-interpret model

Consider then that a result is generated within each of these situations, Figure 12(b). In one situation, the similarity is sufficient for the generated result to be interpreted as Switzerland whilst in the other situation it cannot be interpreted as Switzerland.

This demonstrates the way that the situation changes the use of a concept. The concept was unchanged, the source being interpreted was unchanged, but the resulting interpretation was different because of the situation.

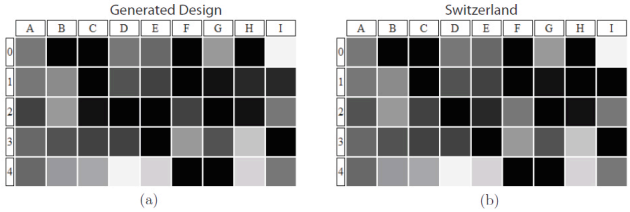

Figure 12 The agent produces: (a) a generated result; which in one situation is interpreted as (b) Switzerland

DISCUSSION

The claim made in this paper is that a change of situation appears to be or be like P-creativity to an external observer and that interpretation can trigger this change of situation. This work has focused upon using a generate-and-interpret model to demonstrate the representation of a situation and the way that interpretation can be a trigger for a change of situation.

Future work will focus upon the way that a change of situation in this manner can be a model for P-creativity. One way to do this would be to take an existing model of computational creativity and alter it to include the ideas described here, specifically that:

1. However concepts in the model are represented, their use is not simply a function of this representation but rather is constructed within the situation. Salience weighting has been provided as an example of one way to achieve this.
2. However the situation is represented the act of interpreting is able to change this situation when expectations are no longer useful. A threshold of distance within conceptual space from the expectations has been provided as an example of one trigger for changing the situation through interpretation.

This work has presented a framework within which P-creativity is claimed to occur but is limited in the way that it has implemented this framework. The attraction of a situated approach to computational P-creativity is that it focuses upon changing the space of possible designs in a way that is useful to the agent. The work produces a link between the grounded experiences of an agent and the way in which it navigates its own knowledge during a task. It is a movement from identification of a phenomenon in studies of design cognition to models that exhibit this same phenomenon.

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