“Seeing as” and Re-representation: Their Relation to Insight, Creative Problem-Solving and Types of Creativity

Ana-Maria Olteţeanu

Cognitive Systems, Universität Bremen
Bremen, Germany
amoodu@informatik.uni-bremen.de

Abstract. Re-representation and restructuring are processes relevant to creativity research. These are related to “seeing as”, defined as the ability to represent features as different meaningful objects, and select and group objects as relevant structures for the problem at hand. Creative problem-solving, insight and the three types of creativity proposed by Boden are explored from the perspective of these terms. A set of essential questions to be answered by the cognitive systems discipline from the perspective of re-representational ability is put forward. Some of the implications of enabling re-representation and evaluating systems based on re-representation are then explored.

Keywords: Re-representation, Insight, Creative Problem-Solving, Computational Creativity, Human Creativity, Transformational creativity

1 Introduction

Let’s say you are in an art gallery, looking at an ambiguous modern art piece and ask a friend what she sees. Her answer might be very different than yours and it might surprise you. Though you might appreciate her answer as interesting, you might think of it as highly subjective and of her ability to see different things than you in art as not the most extraordinary of skills for survival.

However, the same friend might be with you in a circumstance in which you have just moved in a different place, with little furniture. Her ability to see a Cup as a potential Flowerpot, a Shoe as a Hammer to put nails in the walls with and a piece of Dental Floss as a String for attaching paintings to the nails in the walls might be very useful. Such an experience might make you realize that this “seeing as” process has some applications to the real world of problem-solving and it doesn’t come just with the aesthetical pleasure of interpreting art objects, or delving into other people’s interpretations.

Being able to recognize objects as what they are is important for perception, problem-solving, general purpose-guided behavior and survival. Being able to see objects like something else might not seem so straightforwardly useful in the real world, until connected to the ability to use things in a different way to solve problems, or see problems in a way which makes them solvable.

In the following, *"seeing as"* will be treated as:

(i) the ability to represent a group of features as a meaningful object (even if those same features have been previously seen as a different object) and
(ii) the ability to represent a group of objects as a meaningful structure which can help solve the problem at hand (even if those same features have been previously seen as a different structure).

A connection can be drawn between "seeing as"[1] and creativity literature terms like re-representation, combinatorial and transformational creativity. This paper will explore the relation between these terms, and describe the interest this class of processes presents for creative problem-solving, artificial intelligence and cognitive science.

The rest of the paper is organized as follows. Section 2 describes creative problem solving as a productive, flexible process and insight as one of its interesting empirically studied high points which sometimes reflects the "seeing as" description. Section 3 brings forth the definitions of transformational creativity and re-representation, as proposed in the literature, and shows their common ground. Important questions to be asked about re-representation are proposed in Section 4. Section 5 discusses the importance of re-representation for artificial intelligence, cognitive science, and the evaluation of creative systems.

2 Creative problem solving, insight and "seeing as"

An old philosophical thought experiment attributed to Berkeley [2] asks: *"If a tree falls in the forest, and there is no one to hear it, does it make a sound?"* If we define sound in cognitive terms (not just as physical vibration, but physical vibration which needs to reach a hearing sensor), than there is no sound unless organisms with some form of hearing sensors are around.

Similarly, problems do not exist in the physical world, they are an artefact of the cognitive processing of an agent. Problems only exist for agents that have goals or experience a discomfort between their needs and the external environment.

Thus a part of the classical view on problem-solving which defines problems as the "distance from the initial state to the goal state" (Thomas Barkowsky, personal communication) reflects much more than a computational view. It reflects the fact that the only agents which encounter "problems" are agents that: (a) are capable of having goals (not necessarily formulated as such, but as good conditions to exist in) or of feeling discomforts between their needs and the current state of affairs, and (b) have the ability to diminish such discomfort by changing their world (or their state or both).

Furthermore, well-structured problems are rarely encountered in the world [19], with ill-structured problems being the norm [18]. One can look at creative

[1] When mentioning the term "seeing as", the visual domain (visual sensory input, visual representation or visual imagination) is not the only one the authors refer to.

problem-solving as an effort made by the solver to bring productive structure to ill-structured problems [21], with multiple ways of "structuring" being possible. Such structuring becomes clear when it is an impediment to solving, like in the case of functional fixedness [7, 12] - which involves being stuck in one of the possible interpretations of the problem or of the problem's objects, with no ability to see other solutions or representations of the problem.

Thus in our understanding, the process of creative problem-solving contains:

1. the ability of a cognitive, natural or artificial system to use new objects to solve a problem, other than the ones that have been stored in its memory as tools for that specific purpose (if any), or to create those objects by putting together objects or parts of objects the system has access to. Depending on the problem, objects can be either physical or abstract/informational (concepts, problem templates, heuristics or other forms of representations).
2. the ability to see the problem in a way which makes it fit for or easy to act on with existing physical or abstract tools.

Both such abilities involve a capacity for representational change and require processes which afford fluidity in changing representations of features, objects, concepts, problems and heuristics. In the following, we will sometimes use the words *representing* and *interpreting* interchangeably. This is to show the fluid nature of the representation process, which involves interpreting a certain set of stimuli as a certain previously known concept, object or problem. "Seeing as" can thus be observed at a variety of levels, from ambiguous figures to insight problem solving.

2.1 Ambiguous figures

In the simple example of the duck-rabbit illusion, two figures can be seen in an ambiguous image, as shown in Figure 1 a). Let's say the sensory input set of an image x is S_x. Thus, all the elements of the image 1 – the duck-rabbit illusion – are sensory input set S_1. A cognitive agent A viewing the figure might recognize it as representation r_1 – a duck – or representation r_2 – a rabbit. Both r_1 and r_2 are pre-existing representations in the knowledge base of agent A (KB_A).

The same set of features S_1 is interpreted or seen as different known representations. Groups of the features in S_1 can be seen as different or same object parts. Let's say that the sensory input S_1 is split in 6 feature groups[2], where a feature group $fg_x, fg_x \in S_1$, is something which can be easily interpreted as a known concept by agent A:

$$S_1 = \{fg_1, fg_2, fg_3, fg_4, fg_5, fg_6\}$$

These feature groups can be translated into concepts for each representation, as follows:

[2] These feature groups might not be the same for the two representations r_1 and r_2, as will be seen in the girl-saxophonist illusion in Figure 1 b).

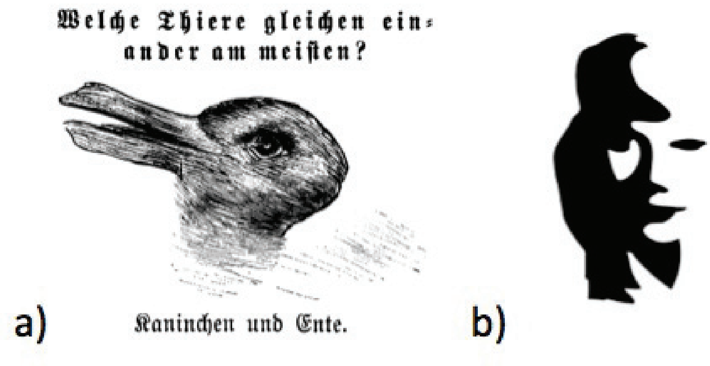

Fig. 1. Ambiguous figures: a) The duck-rabbit and b) The girl-saxophonist

(i) $r_1 \supset \{beak, head, eye, neck, feathers, back\ of\ head\}$; interpretation via r_1 – a duck;
(ii) $r_2 \supset \{ears, head, eye, neck, fur, pout\}$; interpretation via r_2 – a rabbit.

Some of these concepts might overlap, like $head, eye, neck$, while others are disparate. The *eye* might take two different inclinations depending on whether r_1 or r_2 is being produced as an overall interpretation, with the dichotomy between *beak* and *ears* and the general inclination of the head determining which figure is being seen. Thus visual groups of features are interpreted as known representations of animal body parts, with these acting as sub-representations for the overall representation as a duck or a rabbit. The visual features can be re-interpreted or re-represented at any time through the other representation parts and overall representation.

The process of re-representation in this case is a process of mapping from external stimuli to known representations, as shown in Figure 2. In this process, the external stimuli are "seen as" a figure or another. It is worth noting that parsing is a form of interpretation already. This can be seen in Figure 1 b), where the act of grouping features already makes a difference in what is ultimately seen in the figure. Thus grouping all the black features of the left side into a figure enables us to see the saxophonist, while grouping the black elliptical shapes as eyes enables us to see the girl's face.

The process of mapping the sensory elements of S_1 first or more naturally to r_1 or r_2 can depend on a variety of factors, like: (i) which elements of S_1 are interpreted first; (ii) the ease of access in KB_A from initial interpreted elements to r_1 or r_2; (iii) the strength of r_1 or r_2 interpretations over keeping together the sensory elements, etc.

It is worth remembering that neither of the two figures would be available to us in either of the ambiguous figures examples, if we wouldn't know about ducks and rabbits, about girl faces and saxophonists. Antoine de Saint-Exupéry said that *"A rock pile ceases to be a rock pile the moment a single man contemplates*

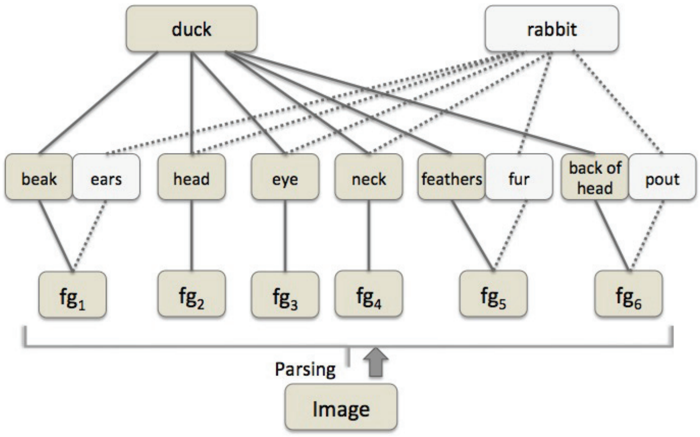

Fig. 2. Mapping sensory input to different representations in the duck-rabbit illusion.

it, bearing within him the image of a cathedral." [5]. He probably meant to emphasize the way the motivation and representations held by a human agent could shape the world. However, conversely, a cathedral is just a rock pile, when looked at by an agent that doesn't carry any concept or representation of a cathedral. The representations that an agent holds constrain the interpretations that can be bestowed upon a set of external stimuli, as they enable various forms of grouping and parsing.

Seeing as and re-representation have been shown to play a role in computational models of creative inference. A creative system for object replacement and object composition (OROC) has been shown to solve the human Alternative Uses Test [24] using re-representation strategies in which unavailable known objects are replaced with other objects that afford the same task. For example, OROC makes alternative use inferences like the following: *"Dental floss may be used to hang clothes to dry."*. This is done via ignoring the first representation of the features needed (which comes from knowledge of the initial needed object) and branching into other possible representations of the needed features. Thus needed features are re-represented as other possible objects, enabling OROC to see dental floss as a clothesline.

Thus "seeing as" or re-representation of given features as different objects (or, in the extended case, seeing groups of objects as different problems) can be applied as a tool for understanding the process of creative problem-solving at different levels.

2.2 "Seeing as" in insight problems

The problem-solving literature [16, 7, 1] describes insight as a process in four steps: Familiarization with the problem, Incubation, Illumination and Verification. The insight moment (or the illumination stage) is meant to represent a moment in which the problem is seen in a solvable way, with the path to solution becoming clear. It is still debated in the literature [17, 26, 9] whether this process proceeds in incremental ways or is the product of a "flash of insight" moment. However, some agreement exists that the solution in insight problems comes soon after discovering a suitable representation for the problem, which makes the solution seem straightforward. Whether this representation is a previously existing one, or one which needs to be created from existing parts can be used to differentiate between processes of search and composition in problem-solving [21].

Two cases of empirical object insight problems can offer an easy example of how "seeing as" and re-representation play a role in the solving process. In the candle problem [7], the participants are given a box of thumbtacks, a book of matches and a candle, as depicted in Fig. 3. The goal is to fix the lit candle unto a wall in such a way that the wax will not drip onto the table below.

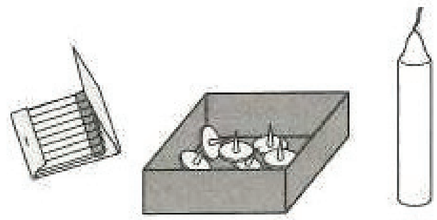

Fig. 3. Depiction of the candle problem

In the two strings problem [16], the participant is put in a room with two strings hanging from the ceiling, and a variety of other objects scattered around. A condition of the problem is that the participant cannot touch the second string while holding the first because of the distance at which they are positioned. The goal is however to tie the two strings together. These insight problems can be solved by: a) seeing the thumbtack box in the candle problem (empty and) as a candle support; b) seeing the string in the string problem as an incomplete pendulum which can be used to bring the string closer to the second string.

In both of these cases, the participants solving these problems know both objects - the initial recognized object, and the "seen as" object. Thus participants know of both thumbtacks boxes (r_1) and candle supports (r_2) for the first problem, and of strings (r_3) and pendulums (r_4) for the second problem. Solving the problem is a matter of seeing part of the feature set in the first problem (fs_1) as r_2, not just r_1, and part of the feature set in the second problem (fs_2) as r_4 rather than r_3.

Thus in such problems, the initial feature set can be represented in multiple ways, but not necessarily at the same time. Both r_1 and r_2 can be valid interpretations of fs_1, in the same way in which both figures can be discerned

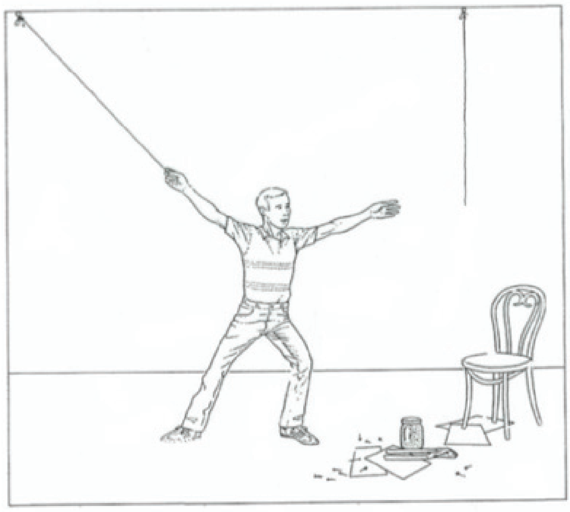

Fig. 4. Depiction of the two strings problem

in the ambiguous figure case. The thumbtack box’s interpretation as r_1, and more generally a container, is made salient by the fact that thumbtacks are stored in it, and by the way the problem is described. An interpretation of the same features as r_2 - a support for candles, requires accessing knowledge about other objects that have been previously used as candle support, and a process of re-representing the same features as that object.

The same process is applied to seeing the string as a pendulum, however the features which can be represented as a string can only be seen as an incomplete pendulum. Thus, the creation of a pendulum in the initial set-up of this problem, which brings in the problem the affordance of setting one of the strings in motion and not being required to hold on to it, requires also seeing one of the objects scattered on the floor - the pliers - as the weight which can be attached to the string to thus construct a pendulum.

Of course, the solutions shown here to these two insight problems have been anticipated by the designers of this empirical experiment. However, in an open ended world, with no predesigned solution, creative problem-solving is applied when the given features of a problem are taken as an ambiguous set, i.e. a set which can be parsed in various ways and interpreted using various representations by the agent. It is worth noting that any such interpretation under a different representation can bring forth different heuristics, implicit knowledge or ways of solving the problem, which are associated with that particular representation, in the same way in which building a pendulum brings into the problem the affordance of a certain type of motion. Thus re-representation transforms the way we should look at the problem-solving process in general.

2.3 The interpretation, representation or "seeing as" step in (creative) problem-solving

The previous examples show that the problem and its structure depend on the representations of the solver. Thus classical problem-solving, which defines a problem as:

- An initial state;
- Operators or successor functions which define reachable states f(x) from any state x;
- A state space, constituted of all the reachable states based on applying the operators to initial states in whatever sequence;
- Paths - sequences through the state space;
- Path cost - a function used to evaluate the best heuristics;
- Goal state or goal tests (to determine if the goal state has been reached) and
- Heuristics which can be appraised on their success and optimality,

can be refined as to allow for the initial interpretation or representation of the problem, and its future potential re-representations, by containing:

- An initial set of features;
- An initial set of representations in the knowledge base of the solver;
- Interpretation steps which act upon the set of features (seeing as), translating them into representations of what the objects are, what the salient elements are, what the problem is;
- This yields an initial state, with attached operators and paths (the operators known or strongly associated by the problem-solver to those representations);
- The next steps are applied as in classical problem-solving. If the process is not successful: a) restart at the interpretation step (re-represent features, objects, what the problem is) or b) change currently held representations or c) bring new features in.

A problem can thus be represented via a set of problem spaces, which can be created using the representations of the solver, where these representations can themselves be changed as to accommodate the problem. In the case of successful creative problem-solving, the representation of the problem as one of these sets brings forth the solution. Thus one set contains a path to the goal, or can be adapted such that a path is created.

Considering this, the likelihood of success might increase in the case of: a) many representations in the knowledge base of the solver; b) an ability to fluidly translate between these representations as to adaptively use different representational tools for the problem at hand and c) an ability to modify promising but incomplete/imperfect/not fully fitting representations as to suit the problem.

Thus, for any set of sensory features and objects which might constitute the problem, the objects seen and the structure (or problem templates) applied depend on the knowledge base of the solver (KB), the representations it holds (R) and its ability to navigate between a representation and another via various processes (like the ones proposed in [21]).

Furthermore, as mentioned before, "seeing as" pertains to the ability to incorporate a set of features received via sensory input in a known object, concept or representation. This can be done equally well in other domains than the visual - one can hear a particular musical theme in pianissimo with a particular pitch contour as a caress; one can hear another string of notes as someone approaching. Multimodal re-representations are thus possible as well. Finally, re-representations don't pertain to objects alone, but can apply to entire situations, groups of objects and actions, and entire mental models.

It will be an interesting challenge for artificial intelligence to enable systems with the capacity of changing the way they represent things, and the ability to see objects, concepts and problems (or parts thereof) as different possible objects, concepts and problems[3].

3 Re-representation and Boden's types of creativity

Restructuring has been proposed in theories of insightful problem solving as the process of changing the initial problem representation, as to find a productive representation which makes the solution (or solution path) obvious [4, 7, 13, 20].

Thus according to Batchelder and Alexander [1], in insight problems: *Likely initial representations are inadequate in that they fail to allow the possibility of discovering a problem solution.[...] In order to overcome such a failure, it is necessary to find an alternative productive representation of the problem.* Here we consider restructuring and re-representation as similar processes.

Boden [3] describes creativity as "the ability to come up with ideas and artefacts that are *new*, *surprising* and *valuable*". Boden proposes three styles of creativity: *combinatorial*, *exploratory* and *transformational*. The *combinatorial style*, in her words, "involves making unfamiliar combinations of familiar ideas. [...] Think of a physicist comparing an atom to the solar system [...]" *Exploratory* creativity is related to conceptual spaces as "structured styles of thought". Thus, "Within a given conceptual space, many thoughts are possible, only some of which may actually have been thought.[...] someone who comes up with a new idea within that thinking style is being creative in the second, exploratory sense.". Boden defines *transformational* creativity as "someone thinking something which, with respect to the conceptual spaces in their minds, they couldn't have thought before. [...] (the preexisting style) must be tweaked, or even radically transformed, so that thoughts are now possible which previously (within the untransformed space) were literally inconceivable".

In order to allow for a comparison between Boden's creativity styles and re-representation, all three styles will be taken into account. Thus let's say "structured styles of thought" are the norm, and these are the equivalent of the representations one has and is used to navigating in a particular manner when thinking. One might of course come up with a new idea which one has not yet thought of and is surprising. However, when a moment of combinatorial

[3] This relates to the human capacity for interpretation and to artefact interpretability, which will be further discussed in Section 5.

creativity arrives - if a physicist compares an atom to the solar system - this is a case of "seeing as" - and therefore a possibility of re-representation. What might not be so obvious is that a) some processes have already allowed this seeing as (like structure mapping, or noticing similarities); those microprocesses are representative for creativity and b) such "combinatorial creativity" moment might very well be what enables further "transformational creativity".

Thus, exploring further this re-representation of an atom as the solar system, one can transform the conceptual space of what an atom is. Initial representations and ways of thinking about those representations are transformed in the same way by exploring how the structure of the benzene molecule can be seen as an Ouroboros snake or a tibetan knot, or how one could apply form principles from preclassicism in atonal music.

Seeing the world as made of rabbits when the other people see it as made of ducks can shape the way one proceeds when dealing with the world. Thus engaging in exploratory creativity from a different set of representations might indeed transform the conceptual space, especially if the rabbit representation proves more productive (better traps are used for whatever the actual animal that is hunted is, more things can be understood and confirmed in practice with the new mental model of the atom, etc.).

The transition from one representation (of the same object, set of objects) to another allows for transformation and further exploration. Thus, in this view, re-representation is a key process in transformational creativity, be it that such re-representation happened overtly or covertly.

4 Questions to be asked

Various questions are of productive interest for the computational study of creative problem-solving. This section proposes the following:

Q1 - How can representation be changed in a cognitive system? Representation is questioned as a concept in cognitive science, in terms of types and existence. This type of inquiry studies what the neuro-cognitive reality of representation is aside from the phenomenology of it (with some authors even debating there is one).

From the general perspective of creativity, a more important question is that of how *relations* between representations are formed, how representations of formerly singular entities can be blended [8], how structures of various representations can be mapped in analogy [10] and metaphor [14, 15], or combined, searched and made to converge [21].

At the level of insight, re-representation and transformational creativity, the question of interest refers to the way a cognitive system could operate with: a) a set of sensory inputs and/or b) previous existing stored memories, in order to see them as forming different objects and different sets of problems with afferent heuristics. To further study this transition between possible interpretations requires enabling systems with fluidity in structuring and re-structuring representations of stimuli, and representations of previous representations (and also understanding the way this happens in natural systems). In the case of creative cognitive systems, representations are not to be regarded as fixed and unique, but rather as changing entities which adapt to the needs of the problem at hand, recruiting material from other existing stimuli or from previous knowledge.

Q2 - What kind of memory could efficiently support processes of productive thought and alternate representation in cognitive systems? The question of changing representations has direct implications on the way artificial cognitive systems should be planned, the design of their knowledge representation structures (and processes, as adressed in the next question). Fluid representations might require a precision trade-off on the storing information (memory) side.

This is encountered in human memory in various ways (e.g. in constructive memory, shape bias). Data structures capable of such features need to be enabled in order to efficiently allow representation change. Such memory/data structure design might be the first step in creating efficient processes which are able to transgress domain boundaries and gather different knowledge, thus lifting the burden of functional fixedness and enabling new productive solutions.

Q3 - What kind of processes can deal on a large scale with such a memory search, as to put together very disparate information ?

Mechanisms for analogy [10, 11] and metaphor [14, 15] have been proposed. Mechanisms for associative, similarity and structure-based search and replacement [21] have also been proposed. More empirical evidence needs to be gathered on (i) what such mechanisms are in natural cognitive systems and (ii) what are their different classes. More experimental settings which can investigate these processes and compare them need to be designed. From the AI perspective, various comparable mechanisms can be implemented, and help the testing of cognitive hypotheses.

Attempting to answer these questions in computational and empirical ways can yield future important lines of investigation, including: complexity in creative problem-solving, what impairs re-representation on a wider scale in humans, the relationship between representation and process in problem-solving, the relevance or irrelevance of phenomenological "aha" effects in insight, how associative and remote search processes are controlled, etc.

5 Discussion

Re-representation and "seeing as", with their relation to combinatorial and transformational creativity as defined by Boden, are important for both artificial intelligence and cognitive science, because of the foundational questions they pose. Thus, questions Q1, Q2 and Q3 are fundamental questions about the nature of representations, representation organization and processes. For artificial intelligence, they refer to the representations, data structures and algorithms we need to enable to obtain creative, creative-like or creativity assistive systems. For cognitive science, they bring us back to fundamental question of representation, process and their interdependence, allowing us to study them in a new context.

Creative computational systems are assessed in a variety of ways [3, 25, 27], be it from the perspective of process, from that of novelty, through human judges or by comparability with human responses in similar creativity tasks [23, 24].

However, in the light of the previous sections, perhaps a metric should be established which related such creative systems to "seeing as" and re-representation. In this vein, two possibilities are proposed here:

(a) a metric which measures the ability of a system to re-represent features as objects, concepts, sets of objects, scenes, problem templates;
(b) a metric which measures the possibilities of the work created by such systems to be re-represented.

Point (a) is self-explanatory after the previous reading, however a methodology would need to be put in place. Point (b) refers to supporting (natural and artificial) critics of creativity to assess creative systems, based on the breadth of interpretation their products have. All the ways in which such an artefact/product could be seen might be hard to map. However, a work which can be seen in multiple ways might offer the possibility of multiple interpretation[4], in the same way in which an object offering similar re-representation possibilities might generate multiple uses.

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[4] In temporal arts, the generativity of particular artefacts can sometimes be visible throughout the creative product: thus a well chosen melody supports many alterations, variations and modifications throughout a musical piece.

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