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Abstract Computer-aided design tools have been used in architecture and design offices for more than 30 years. It must be said that, from the beginning, they have behaved more like over-equipped drawing tools than as true supports for the creative process. In recent years, additional modules (plug-ins or dedicated libraries) make it possible to enrich the software environments already implemented in creative agencies: whether in the field of design, urban planning or architecture, these tools can generat...

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COMPUTER AIDED TOOLS FOR ARCHITECTURAL AND URBAN AUTOMATIC GENERATION

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Abstract: Computer-aided design tools have been used in architecture and design offices for more than 30 years. It must be said that, from the beginning, they have behaved more like over-equipped drawing tools than as true supports for the creative process. In recent years, additional modules (plug-ins or dedicated libraries) make it possible to enrich the software environments already implemented in creative agencies: whether in the field of design, urban planning or architecture, these tools can generate and optimize on demand an infinite number of formal or conceptual solutions whose feasibility or effectiveness in terms of input constraints can be evaluated, for example, by bio-inspired processes.
It is in this context that we put to test some generative tools able to quickly process hypothetical architectural or urban digital simulacra for a given historical period.
Whether for the restoration of the ancient city of Vienna (France), to show the inhabited slopes of the Fourvière hill during the time of Lugdunum, to illustrate the historic urban fabric of the "Vieux Lyon" district or more recently as part of the exhibition "Claude, un empereur au destin singulier", these generative tools are based on current knowledge of the architectural, constructive or stylistic constants over time: they thus make it possible to quickly produce plausible 3D images of squares, streets or buildings during the period of interest.
Former experiments raised the question of the discontinuity of the generative models used, which will have to be applied differently not only according to the scale (bay, facade, building, block, district...) but also according to the nature of the objects to be represented (vernacular islets, residential or monumental buildings etc.) or the knowledge available about them (knowledge consistency, divergent historical conjectures etc.). The MAP laboratory has developed over time some simple software tools that made it possible to question in depth the structure of generative methods involved in the production of plausible architectural and urban digital reconstructions.

Keywords: Generative tools; Formal grammars; 3D modeling; Architectural heritage.

Machines to enhance creativity.

Over the past twenty years, the considerable growth of digital tools has enabled the emergence of technologies capable of imitating and reproducing human behaviour in an increasingly autonomous way. Initially conceived as artifacts capable of repeating tedious tasks over and over again in order to give humans complete freedom to focus on more interesting activities, our contemporary societies are seeing the emergence of a large number of tools capable of assisting us in our daily actions. They are now equipped with behavioural autonomy and are increasingly able to make decisions for us. What a long way has been covered between the first automatons, designed to autonomously reproduce a sequence of predetermined actions, and the devices capable today of potentially replacing humans cognitive faculties. But although the idea of "artificial intelligence" already emerged in the early 1950s in Alan Turing's now famous paper "Computing Machinery and Intelligence" (Turing, 1950), it is certain that - even today - one wonders whether a machine is really capable of "thinking".

The MAP laboratory is regularly involved in numerous survey campaigns at many remarkable historic sites. Of course, heritage experts and researchers did not wait for the rise of digital tools to build scientifically plausible restitutions of past Oekumens. During the 2002 and 2003 campaigns in North Africa in particular, we had the opportunity to meet Jean Claude Golvin, who was very involved in the enhancement of ancient heritage through the meticulous and precise drawing of urban spread outs and buildings during antiquity; at that time, the question of the digital formalisation of the artistic and scientific process implemented became obvious to us. In view of J. C. Golvin's magnificent watercolours, it is legitimate to question the origin of such a formal variety resulting jointly from a scientific rigour and a unique creative intelligence. Certainly, the computer tool lends itself very well to the creation of all different forms from recursive or random formalisms. Nevertheless, it is difficult for them to be able to deviate from the rules introduced at the outset if a creative spark - in the true sense of the term - does not interfere somewhere in the decision-making loop and the generative process put in place has the capacity to free itself from the normative digital pitfalls anticipated by Schön (Schön, 1992) and Chupin (Chupin, 2000) some twenty years ago.

What are computers used for?

In architectural design, creativity is both a myth and a taboo. For a long time, many researchers have been interested in the inadequacy of design assistance tools in terms of creativity and autonomy. To quote J. P. Chupin who himself invokes the work of D. Shön:

> *"...architects are far from paying equal attention to process and product. If the introduction of information technology does not certainly increase the architect's creativity in his mission, most CAD software behaves like over--equipped drawing assistants: they presuppose both the maturity of the designer and that of the object of his design. To make full use of the potential of digital tools it is not enough to increase their ability to simulate materiality, but at the same time it is important to take over the relationship with the body they anaesthetize"*

The essence of the black box at the origin of the creative process cannot thus be altered other than by the mobilization of "situations to think", the only ones capable of stimulating the creative process by "successive jumps of intuition". Again according to D. Shön:

> *"This does not mean that computers are of no use, no assistance in design. Instead, we suggest that research should focus on computer environments that increase the designer's ability to capture, store, manipulate, organize and reflect on what they see."*

Beyond cognitive faculties, a question that arises today concerns precisely the ability of an artificial system to assist us in "creative" disciplines. Without wishing to supplant inspiration, we are now seeing the emergence of many tools capable of accompanying conceptual exploration, a fragile phase if ever there was one, because it comes from a set of cognitive processes that would be able to understand and produce an indefinite number of new processes. Serendipity, which is frequently used in the creative context to designate a form of intellectual availability, fortuitously brings rich teachings from unexpected discoveries or errors. Moravec's paradox establishes that often what is difficult in robotics is easier for man (and inversely, what is difficult for humans seems quite easy to computers…): we enter here into the dark space of a black box in which even the most optimistic predictions do not foresee an artificial intelligence supremacy before many decades. Let us consider instead the phenomena that are still poorly understood concerning the interpretation of intelligible data by the human brain, and in particular those with which, in our field, it is interesting to play.

Malevitch's arkhitectons.

From 1923 to the early 1930s, Kasimir Malevich produced several three-dimensional models, assemblages of abstract forms which appear similar to models of skyscrapers, called "arkhitektons". The drawings accompanying the construction of the models are called “planits“. The arkhitektons are mostly white plaster models made up by several rectangular blocks added one to another. Usually a central bigger block is the main compositional element and smaller parallelepipeds are progressively added to it. No function is shown or translated into form, the final shape being the pure result of assembling abstract masses vertically or horizontally. With their spatialization of abstraction and their formal non-objectivity, the arkhitektons embody Malevich effort to translate the suprematist principles of composition to three-dimensional forms and architecture.

> *“In a series of prismatic, quasi architectural sculptures (which he called ‘Arkhitektons’) [he] sought to demonstrate the timeless laws of architecture underlying the ever changing demands of function. (…) Malevich’s Arkhitektons resemble early De Stijl compositions in which ornament is non-figural and ‘form’ and ‘ornament’ are differentiated only by scale. These studies are purely experimental and the buildings have no function and no internal organization.“*
>
> *Alan Colquhoun: Modern Architecture (Oxford University Press – 2002).*

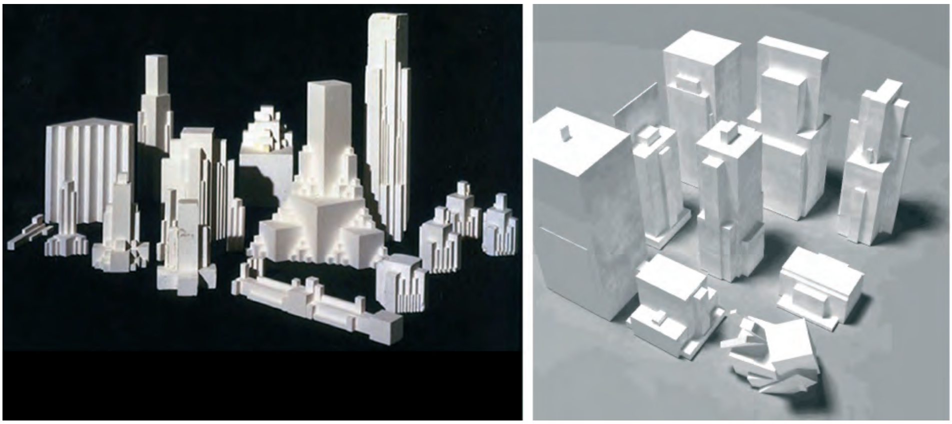

Figure 1. Comparing Malevich Arkhitektons with early generative experiments (1930 / 2002).

Responding to the issues stated by Malevitch in his supremacist manifesto, these formal games not only appeal to interpretative shifts due to their plastic ambiguity but also herald - perhaps unintentionally - the rise of those recursive formalisms that today are called “fractals“.

The game of ambiguity.

From a perceptual point of view, it is impossible to dissociate the object from its interpretation, neuroscience shows that there are mental processes that lead the individual to over-interpret external stimuli by establishing unmotivated relationships between phenomena: an apophenia is an alteration of perception that leads us to see significant figures in our environment: clouds, vegetation, mineral elements like coatings, stones... Malevich's architectonics are particularly interesting in this respect because they succeed in unambiguously orienting the observer's interpretation. We can refer here to one of the most reproduced Magritte's paintings, "La trahison des images", with the well known "Ceci n'est pas une pipe" label, which sows doubt by denying the identity of a subject represented on a painted support just as Malevitch's arkhitektons do not represent architecture. Playing on this ambiguity most of the objects shown will be able to blur the line between what is shown to be seen and what is expected to be seen.

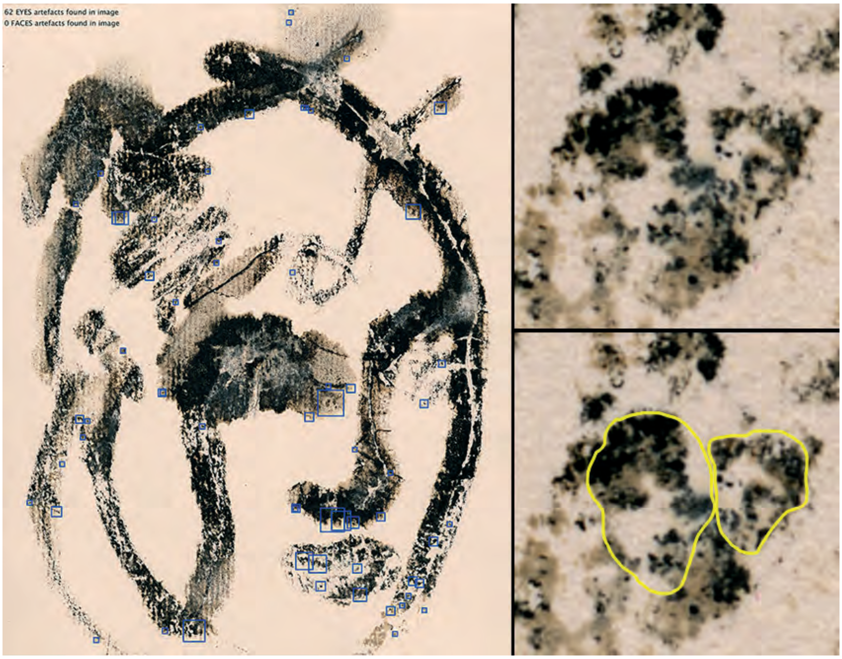

Figure 2. Our SETI (Search for Extra-intentional creaTIvity) project (2017).

To illustrate the points made above, we will focus on some researches carried out in the laboratory over the past twenty years. Some of these studies come from topics that question the relevance of generative heuristics in project or conceptual exploration situations, others illustrate the application of tools capable of validating the hypothesis of guided creativity - like Borges' literature - by the mere application of combinatorial rules.

The parametric construction of architectural objects does not necessarily follow a constructive logic, at least not in its operational expression. In some case it could follow a preliminary decomposition of semantically identifiable architectural entities - naturally responding to the lexical scope of the expressed term - and classifiable by constructive presets: these presets group together homogeneous elements from a descriptive point of view and can integrate topological descriptors that will make it possible to modify their nature.

The inflexion point of descriptive profitability

What then could be the "smallest morphological polytope" in architecture? A theoretical but also a physical object which can be transformed and recombined in order to generate the wider variety of architectural forms? Within a top-down strategy, much has been done to point out the best mechanisms able to simplify a given polygonal geometry taking advantage from most recent research in the field of mathematics and topology. Reasoning bottom-up we have highlighted (and experimented) the fact that most of the existing architectures could be decomposed, factorized and then recombined with simple geometric transformations (duplication, translation, scale or rotation) and this at different levels. This could also be useful for real-time rendering pipelines which need incremental representations of a given object to provide fast contextual representations of complex 3D-geometries depending on the distance of the observer. To contextualize the transformation an initial decomposition is made according to the three projection planes: the façade, the section and the plane.

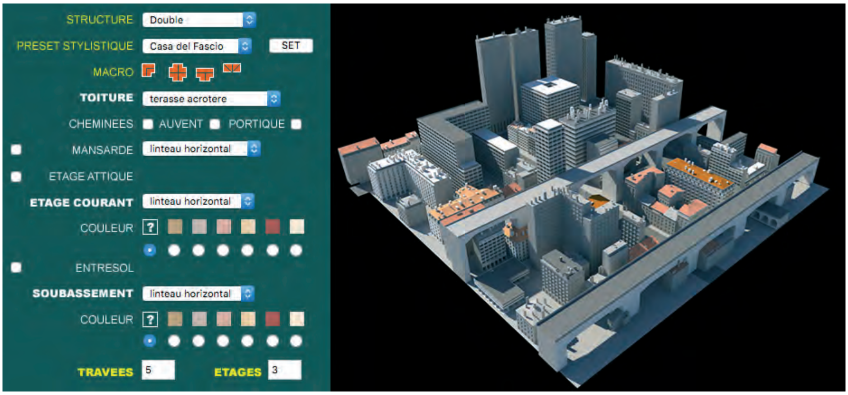

Figure 3. The non-expert mode of the building generator and some of its 3D formalizations (2007).

Based on rules, these generative assets aim to approximate as closely as possible the external aspect of the models they generate; taking advantage of contextual similarities due to historical and/or geographical proximity the studied subjects, the descriptive model could be even simplified; the underlying description model will so include a reasonably limited set of descriptors, sufficient to distinguish the most formal disparities for a given family of subjects. Thus, faced with a historically coherent fabric, it is relatively easy to produce a credible disparity through a limited set of parameters: the experience shows that to describe banal architecture, the representation of an overwhelming majority of the existing architectural corpus needs no more than ten to twelve simple rules. On the other hand, historical political or religious buildings are often made of a wider expressive disparity whose geometric depiction would probably exceed the descriptive capacities of the conceptual model defined above: it would then be necessary to multiply the descriptive rules to describe an object whose architectural singularity would require a "personal" set of rules, which would obviously be counterproductive and completely useless in this case.

". . . In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province. In time, those Unconscionable Maps no longer satisfied, and the Cartographers Guilds struck a Map of the Empire whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that that vast map was Useless, and not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.

Suárez Miranda, Viajes de varones prudentes, Libro IV, Cap. XLV, Lérida, 1658"

The cube presents the interest - beyond being one of the least demanding primitives in display resources - to be a very interesting analogon for the low--level description of architectural forms: the deformation of the cube by its vertices, edges or faces constitutes an extremely versatile matter as for the possible ergodicity of its formal possibilities; not only its geometric base can be stretched according to x, y and z but the installation of deformation operators capable of stretching its horizontal (roof) or vertical (ground development) edges make the cube an extremely interesting geometric base. The repetition by juxtaposition or tangle of similar forms at different scales makes it possible to multiply infinitely the possible formal solutions that will make it possible to mime - experience has shown - most of the formal solutions populating our cities.

If we add to this a spatially synchronous and quantified placement of plausible textures respecting a certain number of composition rules, we very quickly arrive at a combinatorial variety allowing large built surfaces to be populated without unsightly repetitions. Despite this, however, we very quickly come up against structural repetitions that can lead to formal dystopias reminiscent of certain illustrations by Quino in particular, whose inventiveness has always denounced the shortcomings of uniformity and standardization; in this case, we are only able to produce formal outcomes that are certainly all different but essentially all similar, what we call a “disparate uniformity”.

Figure 4. Left alone, the generator can produce an infinity of uniformly disparate shapes… (2007).

Infinite nonsense.

This formal distopia resonates with the issues related to the use of combinatorial formalisms that have interested our research since the beginning. Following the chimera described by Borges in his famous account “The Library of Babel”, it is tempting to imagine a device capable - in the field of architecture - of sweeping away, according to a combinatorial logic, all past, present and future architectural production of mankind. Of course, we are not at all in the same generative paradigm and it is highly likely that the vocabulary elements involved in such a generator would exceed the 24 characters used to populate the Borges library. A very modest attempt was made on the occasion of the first Lyon Architecture Biennale in 2017, during which we left a machine running for only 5 days during the event and which was responsible for randomly producing a mapped projection on the two pillars surrounding the reception area. During the exhibition, nearly 300,000 digital arkhitektons were produced in pairs, most of which went unnoticed, either because of the inattention of the spectators or because the projection took place at night during the closing of the venue.

We like the idea of these machines working tirelessly to produce images that no one will be able to see. A little in this logic, we have reproduced an artistic installation on Line that already dates back about ten years: a matrix of pixels turned on or off according to a binary logic; when a pixel has finished its cycle (turned on and off) the adjacent pixel changes state. For practical reasons all pixels are disposed in a square matrix, the logic remaining the same for the "line" pixel as for the adjacent pixel. According to this very simple rule, the occurrence of the state change for each pixel of the matrix will depend on its position in the row and will follow an exponential temporality. Nevertheless, left alone, this system will sweep away all existing binary possibilities and will eventually produce some few happier solutions beyond a universe of meaningless configurations.

Figure 5. The arkhitektones generator Biennale de l'architecture de Lyon (2017).

Bio-mimetic processes and optimization of generative strategies.

We have seen that combinatorial strategies, although capable of sweeping away an infinity of formal solutions, are not able to produce interesting solutions in a temporality compatible with human existence. According to this point, current research focuses on those mechanisms that have regulated the generative processes of our biosphere for billions of years. Some of them were theoretically described several decades ago and still constitute today a solid exploratory basis for the ongoing investigations in this very field. For example, L-systems - described during the early 60′ by an hungarian biologist, Aristide Lindenmayer - make it possible to model in space and time some growth phenomena that mimic the growth dynamics involved e.g. in plants evolution. The recursive and auto-similar properties of their structure will allow them to be displayed with incremental levels of detail able to produce evolutionary shapes that model, for example, the transformation of an architectural ensemble built over time. L-systems are based on axioms and rule mechanisms whose formal expression is easily applicable to constructed elements with redundant and self-mimetic characteristics that actually imitates evolutionary process with a recursive regeneration of auto-similar patterns. Experience shows that the structured use of shape variables with a proper set of geometric transformations make it a very efficient 2D and 3D generator. Applied to topological germs specific to architecture, an infinite number of formal varieties can be obtained. Ongoing experiments aim to demonstrate the formal versatility of this model in generating the most disparate morpho stylistic varieties.

As seen, recalling Nature with efficient generative paradigms seems to be relevant to discriminate the exponential spread-out of possible solutions of uncontrolled growth approaches. However, the drawback of such processes consists in its unpredictability or its poor response to domains where it is hard or impossible to define a computational fitness function. Interactive Genetic Algorithms (IGA) or Aesthetic Selection uses human evaluation for the fitness function, typically when the form of fitness function is not known, such as visual appearance or aesthetics evaluation. It is so possible to use well-established mechanisms that have been experimented by nature for billions of years and that have produced - needless to say - workable results in many areas. Well implemented in today's 3D tools, some inspired organic formalisms are now used in many fields: although they certainly do not deploy the same functional complexity as their living counterparts, they are extremely gifted at optimizing multi-criteria problems, supervising monitoring operations or assisting in operational decision-making. As said before, it is no longer necessary to go through the tree of possibilities in its entirety, we will be able to make drastic shortcuts in the production of optimal solutions considering set of constraints placed at the beginning and this according to a time span more compatible with the duration of our own existence.

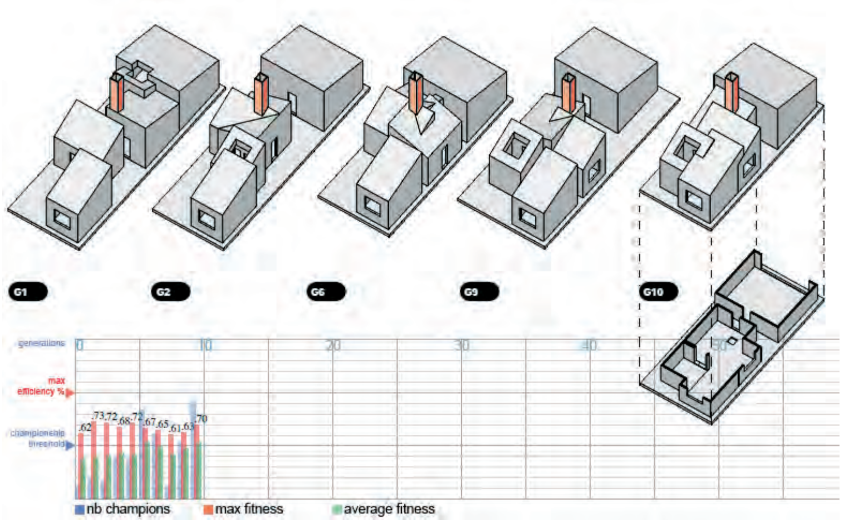

Figure 6. Some formal results rising from the IGA solver (2009).

An interesting formal experiment led us to implement a set of rectangular figures to be placed on any surface by imposing the following constraints on them: the arrangement of the figures should be as compact as possible without them overlapping. These two constraints - clearly antagonistic - do not have an absolute optimum, there are an infinite number of possible distributions that correctly respond to the constraints imposed and there is no formalism able to point out computationally the optimal configuration. One could test, according to a combinatorial logic that would find its place in the Babel library, all the possible solutions from a discrete distribution of the figures within a given perimeter but this with little chance of extracting - once again - optimal configurations within a reasonable time period. As mentioned, only the use of a bio-inspired algorithm, such as a genetic algorithm, would be able to quickly guide all solutions towards acceptable optimums with regard to the problem initially posed. In this example, we also wanted to involve a human user in the generation process in order to influence it with some subjective preferences. We know that the human user will not necessarily choose among the optimal formal solutions but among those that seem to best meet his subjectively formulated expectations. Experience shows that this action often positively rebuilds the genetic potential of existing populations by introducing - fortuitously - innovative solutions to the problem at hand. We must say that, at the end of this first generative step, the system hybridizes the process by introducing formal rules related to the implementation of architectural environments such as the layout of windows or the shape and slope of roofs.

> *"Interactive Evolutionary Computing methods include Interactive Evolution Strategy (Herdy 1997), Interactive genetic algorithm (Caldwell, Johnston 1991), Interactive Genetic Programming (Sims, 1991) and Human- based genetic algorithm (Kosorukoff, 2001).The application areas of IEC have been spread widely. IEC is a technology that joins human and evolutionary computation in order to optimize target systems based on a cooperative interaction between feature parameters and psychological spaces. Conventional approaches for these human evaluation-based systems have frequently modeled the human evaluation characteristics and embedded the substitute evaluation model in optimization systems. The analytical approach is a common approach in AI research, but it is difficult to lead a model, for example, to resemble a personal preference model." (Takagi 2001)*

Conclusion

Still today the use of computers needs to be improved when invoking creative processes. Natural behaviors wonderfully act as imagination enhancers often within the perceptive boundaries of visual or auditory perception. In this sense we still believe that most of the software is located in the user's head. Taken separately, design assistance tools are still cruelly lacking in decision-making maturity and are still forced to imitate the complex paradigms of human intentionality through formalisms that are certainly sophisticated but still far from *"the unknown border, reachable through disruption of all senses."* (Lettre d'Arthur Rimbaud à Paul Demeny, 15 mai 1871).

Besides the impossibility to solve with a single formalism the exhaustive shaping of existing architectural forms across history and cultures, we believe that an artificial creative process cannot be separated - so far - from conscious intentionality to get it out of the trap of "disparate uniformity".

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