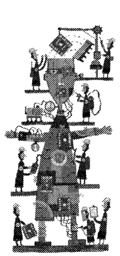

Communicating with autonomous systems using fractal patterns

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For autonomous systems, human-machine communication should be reduced to a minimum. However, prediction of machine actions should still be possible. We propose to solve this problem by using the representation space provided by aesthetics, where we express the inner state of the system by fractal patterns. As an example, we present an interface which has been realized for the EXPO.02-project "Ada".

1 Introduction

Autonomous machines are systems that develop according to their own dynamics, under the interaction with their environment. The physical constraints reduce the degrees of freedom. In this reduced space, the autonomous system finds the optimal solution according to the principle of least action. No explicit control, or adaptation, mechanism is needed to obtain this optimal behavior. Autonomous motion generators are computationally and economically far cheaper than the classical vector based motion descriptors, and they are capable of finding novel, by humans unanticipated, task solutions. As a consequence, the challenge is to find a minimal encoding of the inner state of the autonomous system, sufficient to allow the judgement of the current state and a prediction of the future behavior. A obvious approach is based on the observation that autonomous systems display transitions between macro-temporal multi-stable states, which could for example be expressed by natural languages. Verbal man-machine interfaces have been the subject of intensive research for some time now. However, they are generally very resource intensive and not universally understandable. We searched for alternatives to express the inner states of an autonomous system. Our claim is that aesthetics provides a minimal form of representation which is universal and immediate.

2 Quantitative aesthetics

The term aesthetics originates from the Greek *aisthesis*, which literally means the study of sensory perception. In philosophy, the focus shifted to the study of, and the experience of beauty. On the other hand, there is also a tradition to look for quantitative measures of aesthetics: At the end of the 19^{th} century, Gustav Fechner started an effort to ground this notion on an empirical-inductive ansatz [1], which led in recent times to various attempts to quantify aesthetic perception by humans, based upon mathematical [2], as well as, biological grounds [3]. One tradition uses information theory based complexity measures as a tool to quantify aesthetic experiences, some of which follow the idea that humans perceive aesthetic information as highest between the poles of order ("perfect banality") and chaos ("perfect originality") [4]. Our recently developed complexity measure C_S [5] is a measure of the complexity of prediction of the pattern in a statistical sense. In this way, to a completely random process, zero complexity is assigned. Using the thermodynamic formalism of dynamical systems as a starting point, the complexity is evaluated as the integral over difficulties in the prediction of unstable orbits of the system. In agreement with insights from theoretical biology, the measure can be shown to be finite for all measured systems, and it assigns maximal complexity to systems between order and chaos (intermittent systems).

3 Realization

For the mapping of inner states onto patterns along principles of aesthetics, fractal patterns are ideal. They come without pre-defined meaning, use simple, resource-friendly generators, and provide as a function of their parameters a large variety of patterns. Moreover, they allow multi-observable representation, by focusing on different inherent qualities: color, speed, composition, and temporal structure.

These concepts laid out above were implemented in the context of the Ada project "Ada the intelligent space" of the Swiss national exhibition "EXPO.02" [6]. Ada perceives it's environment through tracking video cameras, floor tile based weight sensors and fixed mounted microphones, and is capable of responding via music, under-tile lighting, video walls and light pointers. These actuators allow, as they provide the interaction with the visitors, Ada to evolve its "personality" autonomously. In this context, the representation of Ada's inner states should increase the audience's ability to make judgements concerning Ada's actions and reactions, and accordingly their understanding of Ada. The inner states identified in Ada were independent notions of surprise/disappointment, joy/sadness, satisfaction/frustration. They were expressed in patterns by a fractal pattern generator of the form

$$x_{(t+1)} = y_{(t)} - \sqrt{|bx - a|} \cdot \mathrm{sgn}\,(x)\,, \quad y_{(t+1)} = x_{(t)} - a,$$

where a and b are the parameters that determine the pattern generated, and care was taken to avoid the fixed-point at the origin. The mapping onto patterns follows the considerations of quantitative aesthetics (see figure below): On the first axis, "surprise" is represented by a high number of different substructures, and "disappointment" by a low number of different substructures. In the second axis, "joy" is represented by a high number of elements, "sadness" by a low number. In the third axis, "satisfaction" is represented by smooth and harmonic structures, "frustration" by broken structures. The multi-stable states that have been identified in Ada are thus mapped onto parameters a and b. Due to the limited visitor-Ada interaction time, the 27 regions of state space have been reduced to 15.

The important aspect of representation over different time-scales is realized by drawing the incoming short-time information on a ring, encircling, in the middle of the screen, the rendering of the fractal expressing the current inner state. From there, the patterns procession through time is shown by a movement of the pattern out of the circle on a ring that expands its diameter logarithmically. The pattern is immediately followed by newer, younger patterns, where the growing size of the pattern points generates the illusion of a history passing by the spectators. When applying C_S to the pattern classes produced by the expression engine, the highest values were computed for those patterns considered as most complex based on the principles of quantitative aesthetics, and vice versa for simple patterns.

4 Conclusion

Discussions on machine autonomy tend to forget that the autonomy of these systems also affects communicating with them. The principles of machine autonomy imply that these systems should be equipped with communication interfaces that take into account their autonomy, and, as they become complex in the sense of behavior, their communication interface should not presuppose the observer. In our real-world autonomous system study of Ada, a lean, basic-principles based one-way machine-man communication was designed and implemented, in order to develop a man-machine autonomous system. The approach was based on the mapping of the autonomous systems inner states onto fractal patterns, selected by principles of quantitative aesthetics, using the Stoop complexity measure (C_S). Embedding these patterns through time allowed the identification of behavior. The present contribution consists a first fundamental step into effectively and unbiasedly enabling optimal man-autonomous machine interactions.

5 Literature

[1] Gustav Theodor Fechner. Vorschule der Ästhetik. Von Breitkopf & Härtel, 1876. [2] G.D. Birkhoff. A mathematical approach to aesthetics. Scientia, 1936, pp: 133-146. [3] I. Rentschler, B. Herzberger and D. Epstein. Beauty and the Brain. Biological aspects of aesthetics. Birkhäuser, 1988. [4] W. Ebeling, J. Freud and F. Schweitzer. Komplexe Strukturen: Entropie und Information. B.G. Teubner, Stuttgart, Leipzig, 1998. [5] R. Stoop and N. Stoop. An integral measure of complexity. In: V. Shafeev (ed), Control of Oscillations. Proceedings of the Conference Progress in Nonlinear Science, in Honor of 100 Birthday of A.A. Andronov, 2001. [6] K. Eng, A. Baebler, U. Bernadet, M. Blanchard, A. Briska, M. Costa, T. Delbruck, R. Douglas, K. Hepp, D. Klein, J. Manzolli, M. Mintz, T. Netter, F. Roth, K. Wassermann, A. Whatley, A. Wittmann and P. Verschure. Ada – buildings as organisms. In: Game, Set and Match, Faculty of Architecture, TU Delft, 2001.

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