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THEORETICAL PERSPECTIVE

Enactive Systems and Enactive Media: Embodied Human-Machine Coupling beyond Interfaces

Mauri Kaipainen, Niklas Ravaja, Pia Tikka, Rasmus Vuori, Roberto Pugliese, Marco Rapino and Tapio Takala

ABSTRACT

This paper proposes the concept of *enactive system* as an alternative to the standard human-computer system and elaborates the idea of content mediation as *enactive media.* The authors' system consists of the two elements coupled in a holistic manner by means of bodily and spatial involvement, or *enactment*. Such a system is *recursive* by nature, involving the impact of the technology on the human agent as well as the effect of the human experience on the technology. Instead of the standard explicit interface, there is an implicit connecting surface, based on *unconscious* psycho-physiological reactions. The aim is not only to point out an analytic approach to existing media systems but also to develop radically novel media concepts implied by the enactive systems.

ENACTIVE SYSTEM AND ENACTIVE MEDIA

The classical simplification of two separate systems in technological interaction, that is, those of man and machine, is in conflict both with the holistic conceptualizations discussed by 20th-century philosophy, for example that of Merleau-Ponty, as well as with those implied by today's ubiquitous technologies. The aim of this paper is to draw the outline of a multidisciplinary research agenda that challenges previous assumptions and proposes ways to go beyond them. The core concept, an *enactive system,* is constituted by dynamically coupled human and technological processes, that is, *a dynamic mind-technology* embodiment. An enactive system does not assume a standard interface with goal-targeted conscious interaction; rather the function of interfacing is driven by bodily involvement and spatial presence of the human agent without the assumption of conscious control of the system.

A recent discourse referring to *enactment*, led by the Enactive Network of Excellence [1], has largely focused on human-computer interaction (HCI) under the label of "enactive interfaces." However, we wish to challenge the very concept of interface, suggesting a more dynamics-oriented perspective on humans and machines. We propose the human agent to be regarded as a *participant* in a process rather than as a user of tools.

Traditionally the human agent is regarded as playing a goal-targeting role by means of conscious actions mediated by an interface. In such a setting a user would expect deterministic behavior by a tool. In contrast, in an enactive setting, technology is a part of a two-way feedback system with self-controlling recursive properties, and the role of an interface becomes implicit, perhaps even to the degree of being nonconscious or directly hooked up to the participant's physiology. This evokes the Brunerian idea of enactment as learning by doing [2], to be discussed below.

As a contrast to the standard conceptualization of human-computer interaction, the enactive relationship conceives the underlying technology as continuous, ubiquitous and "intelligent" accompaniment to the human actor, or a direct extension of the user's perceptual and cognitive apparatus involved in participation in the system—living and acting with the system instead of just using it. We will give an example of an enactive system by means of an experimental setup that couples human facial expressions and animated avatar expressions to a two-way feedback system.

Further*, enactive media* are enactive systems involved in mediation of meaning through dynamic articulation of content and active engagement of the user. Enactive media assume enactive systems as their core, but also a repertoire of content elements that can be used to generate a range of meanings in terms of narrative recombinations in real time. The elements can be pre-recorded film footage, audio tracks or text excerpts or, alternatively, real-time generated behaviors. In digital systems this repertoire typically assumes a database [3], but it is useful also to consider analog enactive systems that involve a repertoire of expressive patterns, such as different ways of playing a musical instrument. Examples will be given below.

We must limit the present discussion with respect to culture and community. For simplicity's sake we begin by considering only a system of a single human agent and her technological extension [4].

In fact, there is no need to make an absolute distinction between enactive and interactive systems. We rather believe that even many existing systems can be conceived of as one or the other, depending on the level of discourse. The proposed approach assumes a meta-level inquiry with the focus on holistic system dynamics, whereas interactive systems are typically

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discussed on the level of component dynamics. The component-level view does not reveal the complexity of the system seen as a whole and therefore misses the potential of identifying recursively emergent behavior therein.

Enactive Mediation

Although McLuhan did write about media as extensions of man, he was talking rather about technology generally, including even light bulbs, as media [5]. Known for many prophetic visions concerning media and technology, he still did not foresee anything amounting to *dynamic embodied media systems,* involving the mediation of meanings, or even emotions, beyond messages alone. Beyond McLuhan, our approach relates to the more recent discourse on the *embodied mind,* consisting of brain, body and world in constant dynamic and mutually constituent interaction [6]. The discussion also has to do with the reconsideration of the relations of cognition and emotions based on recent neuroscience, for example, Damasio [7]. As to the relation of humans and technology, the present view is in harmony with the *radical embodiment* approach [8].

The attribute *enactive* was originally associated with cognition by the developmental psychologist Jerome Bruner, who used it to refer to bodily and spatial activity as an aspect of cognitive development—"learning by doing," in distinction to the *iconic*, that is, the aspect of visual processing, and the *symbolic*, by which he referred to the aspect of abstract thinking [9]. In the big picture of the last century's science, Bruner's conceptualization can be associated with the tendency of holistic naturalization of the humanities. Within this development, Merleau-Ponty's holistic phenomenology [10] is a notable landmark. An important foundation of the present discussion is the *autopoiesis* theory [11], the formulation of self-contained and self-organizing systems, a kind of bio- or ecosystemic approach. The emerging idea of *enactive cognitive sciences* considers the human mind in a systemic context, not only in the scale of the body, but also in the scope of active *enactment in* and *with* the world [12].

This also opens the view of media systems as *complex systems* that are characterized by *self-organization* and *emergence of meaningful patterns.* The enactive media approach constitutes a break in the tradition of seeing a medium as a mere conveyor of messages in an information chain [13]. Instead it assumes an enactive medium, including its human and technological agencies, as the very brewery of meaning and "messages."

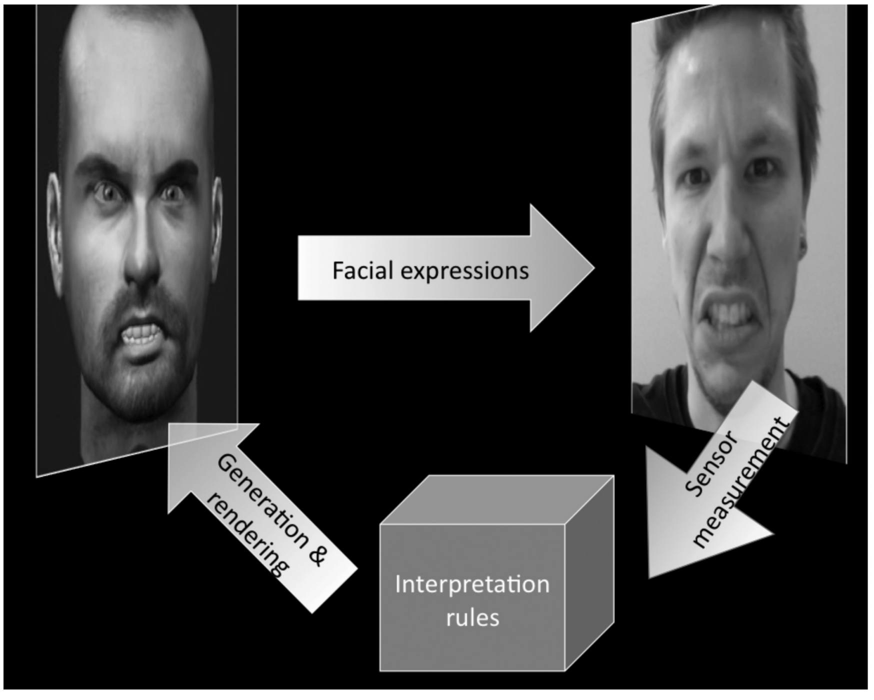
Enactive Creativity

Besides learning about the behavior of such systems, it is important to understand more about how to design such enactive involvement by the participant. Also necessary is the reconsideration of the role of the media creator (e.g. author, designer, filmmaker). While it may be necessary for the media creator to give up some explicit control, enactive media implies the level of *second-order authorship* [14], comparable to the role of an architect of a space who does not determine the behavior of the people accommodated but only the spatial framework, which only implicitly suggests or constrains activities.

A practical aspect of the project is to develop tools to facilitate the design of such systems. We will propose a conceptual model to concretize this. In the process of ongoing work, we are collecting a set of design and editing tools for authoring enactive systems, partly from existing components developed by the team [15,16] and partly from those being elaborated for present purposes.

This discussion also has to do with modeling *creativity* in general. Creativity can be seen as an enactive process where pattern synthesis and recognition work in tight reciprocal interaction. For example, hand motion and visual perception form an enactive loop in the activity of drawing. As a further elaboration, one may follow Freedberg and Gallese, who assume that, when viewing an artwork, the creator's embodiment is *neurally mirrored* by the viewer, who can "feel" the brushstrokes of the artist [17]. Emotional involvement, essentially enactment, is probably also necessary to find creative solutions in problem solving [18].

Fig. 1. An angry facial expression on a human participant and a computer's mirroring response in the enactive system. (© Mauri Kaipainen)



Objectives

The objectives of the enactive media approach are not limited to articulating the analytical concept of enactive media with respect to philosophical and media theoretical frameworks. Another concrete objective is to implement a modular open source software library that allows a range of media systems to serve experimental setups with the following elements:

a. A repertoire (database or generative rule set) of content elements to allow rich and meaningful narrative combinatoria, each element annotated with an ontology that allows meaningful montage, or alternatively the generation of behavior in real time;
b. Enaction technologies with necessary sensors and detectors to track different aspects of the participants' psycho-physiological behavior;
c. Presentation technologies for montages of content and behavior;
d. Mappings between psycho-physio-

Fig. 2. A mobile psycho-physiological data collection system. (© Mauri Kaipainen)

logical indicators and meaningful dimensions of the content, as expressed by the associated metadata;

e. An algorithmic model that drives the narrative montage in real time; and

f. Analysis of the nature of design and authorship of enactive media systems and the respective implications for professional practices and creativity.

METHODS

The enactive media approach frames a number of topics into an interdisciplinary set of concepts and implies an integrated research agenda of media technology and physio-cognitive sciences. The main method can be described as *experimental design*, merging with common practices in media art. It proceeds as a sequence of installations or experiments, each presented to an audience of visitors. The experiences of the participants are observed and evaluated against criteria including:

- perceivability of changes in system behavior in response to changes in enactive behavior
- relevance of changes in system behavior with respect to involved emotions
- meaningfulness of the montage generated
- effectiveness of implementation
- reliability of implementation.

Evaluations with respect to these lead to iterative improvements in system design and implementation.

ENACTIVE SYSTEM

Instead of explicit conscious control by means of interfaces, the enactive approach implies a focus on settings that allow participation by embodied action, that is, *enactive systems*. In them, the interaction involved can be tacit or unconscious [19,20], controlled by psycho-physiological reactions of the participant. The challenges lie on the side of mapping of the measured psycho-physiological data to meaningful behavioral, semantic or emotional entities that can be applied to control enactive systems.

To begin with, the *dimensional theory of emotions* holds that all emotions can be located in a 2D space as coordinates of *valence* and *arousal* (or bodily activation) [21]. The *valence* dimension reflects the degree to which an affective experience is positive (pleasant) or negative (unpleasant). The *arousal* dimension indicates the level of activation associated with the emotional experience and ranges from excited or energized at one extreme to calm or sleepy at the other.

Based on this, we have constructed a minimalistic *enactive system* that involves tracking (a) psycho-physiological data to infer the emotional state of the participant and (b) a computer-generated character, the facial expression of which is dependent on the participant's emotional state and vice versa, i.e. the emotional state is also dependent on expression (Fig. 1).

It is well established that psycho-physiological measurements, such as facial electromyography (EMG), heart rate (HR) and electrodermal activity (EDA), index emotional processes [22]. EMG is the primary psycho-physiological index of hedonic valence. That is, activity increases with the contraction of the facial muscle groups of *zygomaticus major* (cheek), *corrugator supercilii* (brow) and *orbicularis oculi* (periocular), which have been found responsible for positive and negative emotional expressions [23]. EDA, commonly skin conductance, is a measure of sympathetic nervous system activity. EDA is innervated entirely by the sympathetic nervous system [24]. Several studies using the picture-viewing paradigm have shown that EDA is highly correlated with self-reported emotional arousal [25]. Our mobile setup for detecting physiological data is depicted in Fig. 2.

With information on both valence and arousal it is possible, to some degree of precision, to determine more specific emotional states. In our system, the emotional state of the user is defined in terms of four different combinations: (a) high-arousal negative state (anger), (b) low-arousal negative state (sadness/depression), (c) high-arousal positive state (joy), and (d) low-arousal positive state (pleasant drowsiness). The system chooses one among five different facial expressions, including anger, sadness/depression, joy, pleasant drowsiness and a neutral expression, on the basis of psycho-physiologically measured activity of the participant (see Fig. 2).

As a starting point for understanding the mediation of meanings that constitute enactive media, this system provides a laboratory of the most fundamental means of communication—facial expressions, whose interpretation appears to be built into the neural system [26,27].

ENACTIVE MEDIA

Mapping Content

Technically, we generally assume enactive media to include a database of content (video, audio, still images, text, etc.), annotated with metadata to allow selective retrieval of content elements for dynamic montage. The bridge between enactive systems and meaningful montage is a metadata *ontology*, *a specification of a conceptualization* [28], such that supports the dynamic nature of enactive media systems. Obviously, the development of ontologies for more effective and "intelligent" linking of content is ongoing throughout the entire field of information and communication technology. The general assumption is that an ontology should be relatively stable and stick to a hierarchical structure fixed a priori.

Fig. 3. A scheme of the enactive cinema installation *Obsession*. The viewer's perception and cognition of the cinema are reflected by psycho-physiological reactions. Sensors monitoring the reactions control a montage machine that dynamically recombines content elements from a database into a narrative, which is presented as a cinematic composition. This in turn has an impact on the perception and cognition of the viewer. (© Mauri Kaipainen)

However, the requirements of enactive media differ significantly from the above. While in typical HCI systems deterministic behavior is expected and the ontology of content is correspondingly assumed to reflect unambiguous a priori hierarchical taxonomies, the recursively two-directional enactive systems addressed here are characterized by emergent behaviors. The dilemma is that one cannot expect a fixed a priori ontology to represent such behaviors. Our suggestion is to give up the "single authoritative interpretation" [29] and adopt ontologies that can be dynamically updated and restructured.

We propose the *spatial ontology* (ontospace) approach by Kaipainen et al. [30] as a solution. An ontospace is defined by *n* ontological dimensions (ontodimensions) that correspond to descriptive properties of the content repertoire. They may originate from some kind of annotation that can be either a part of the design or authoring process, or some automated analysis embedded in the enactive system. Importantly, *n* may be dynamically incremented or decremented during the process.

For a single content element, for example a video clip, the values of the n dimensions constitute the element's *ontocoordinates,* specifying its position in the ontospace. They may describe subjective judgments, physiological responses that are related to emotional experience, technical properties (color, duration or time-stamps) or any other descriptive characteristics with the potential of meaning-mediation. Several theoretical frameworks can be referred to as groundings of meaning in this context, including spatio-embodied metaphors [31], emotion metaphors [32], image-schematic structures [33,34] and embodied theory of concepts [35].

Multiple Perspectives on Content

It is assumed that enactive participation involves *continuous exploration of different points of view* on the ontospace, modelable as taking spatial *perspectives* [36]. From a particular perspective, certain content elements appear close (similar) to each other while some seem distant (different) from each other. The perspective-exploring activity contributes to knowledge acquisition about the content in a manner reminiscent to how Neisser [37] describes visual perception with his perceptual cycle. Here, however, the explorative activity is generalized to involve even abstract meaning-descriptive dimensions of the content.

It can be generally assumed that the dimensionality of the content ontospace is high, generally n > 3, so that no single unambiguous visualization of the ontospace exists, but any perspective is rather one of many equally justified alternatives. It is visualizable only by means of some dimensionality-reducing algorithm, such as multidimensional scaling [38]. A perspective can also be understood as a particular prioritization that allows the conceptualization of the content by means of an emergent hierarchy [39].

Perspective-Specific Montage

While there is a vast history of generative and montage algorithms, they do not typically allow the kind of explorability required by continuous enactment. The ontospace formalism [40] can be applied as a general groundwork for real-time montage of content elements retrieved from the database in response to every perspective taken. The simplest solution is to sort the content elements one-dimensionally by their perspective-weighted ontodimensions to compose a list in ascending or descending order. While there is no way to guarantee narrative continuity with respect to all ontodimensions simultaneously, continuity-conservation can be prioritized by perspective, so that the most solid continuity is conserved for the highest-prioritized ontodimension.

The spatial metaphor implies even further elaboration of the physical analogies. For example, it is quite natural to introduce some physical properties in terms of *inertia*, that is, simulating narrative continuity with mass, speed and direction, the latter two varying as functions of the *perspective*. Inertia introduces resistance to variations of the trajectory of the navigation through the ontospace. This means that perspective changes do not directly translate to changes of narrative direction but are "smoothed" proportionally to narrative mass and speed, constituting a kind of dynamic memory that will, according to the hypothesis, contribute to narrative coherence.

Examples of Enactive Media

To envision what enactive media might mean, one may assume an enactive system that involves content elements that are recombined in terms of real-time montage in response to varying perspectives corresponding to measurements of the participant's psycho-physiological enactment in the media system. Musical instruments with embodied control are inherently enactive, as there is continuous feedback between player action on an instrument and perception of the produced sound [41], constituting a meaning-producing mediating system. More generally, the role of gestures in music embraces dimensions related to both body and sound. In the *embodied music cognition* approach [42], sensorimotor activities in action during music perception and the role of corporeal involvement in music are the focus. Multisensory perception, perception of movement (kinesthesia) and active involvement of the musician on one hand and the expressiveness of music on the other can be considered to constitute the enactive coupling of perception and action in musical activity [43,44].

As a pioneering example of enactive cinema, one can mention Tikka's installation *Obsession* [45,46]. In it, the bio-emotional enactment of the spectator controls the narrative flow, which, in turn, influences the bio-emotional enactment, as schematized in Fig. 3. This constitutes a departure from the standard paradigm of interactive storytelling concepts, starting from Murray's *story-worlds* [47] or the Korsakow project [48], in which the narrative navigation is explicit and conscious.

In addition, we recognize that there are a number of media systems that are not deliberately articulated as "enactive" but can be interpreted as such. They include, for example, *FEEL* and *CHAMELEON* by Tina Gonsalves, which explore participants' physiological responses in the context of emotionally loaded audiovisual imagery [49]. The Multimodal Brain Orchestra project demonstrated how real-time interaction between an audience member (the "emotional conductor") and performing musicians can be created by tracking brain states, resulting in synthetic music composition with orchestrated screening of visual images [50]. Further, the "Enactive Dialectics" of Dumitriu et al. [51] may be considered a critical philosophical statement related to the participant's psycho-physiological enactment. They introduce the concepts of "augmented" or "false" feedback loops through art, thus describing the processes by which the author(s) may modify the interpretation of the raw physiological data in favor of artistic expressiveness. This reinterpretation brings about a synthesis of the intellectual and embodied aspects of human experience.

Conclusions

This approach suggests reconsidering the role of technology beyond that of tools, reaching as far as ubiquitous accompaniment of sense-making. A research agenda has been outlined that aims at deepening the analysis of interactive media and human-computer interaction by asking how the nature of interaction would change if the standard assumptions about human-computer interaction were lifted: What if the interaction were not conscious but instead driven by psycho-physiological reflections of a media experience? And what if this experience, in turn, would modify the content, thus constituting a self-controlling system? What would be the proper metadata ontologies to account not only for pre-existent content categories but also for those that can emerge in such a recursive system dynamics? And what would be the nature of designing or authoring such media?

We have introduced an example enactive system based on the psycho-physiology of facial expressions and avatars that mirror them, as well as a few other examples of what we consider enactive media. Further studies are required to observe properties of such a system in general and to validate the hypothesis of emerging patterns in meaningful narrative contexts.

We can foresee a number of innovative application areas beyond the purely experimental that may draw directly from the concept of enactive media. They include music videos, animations, audiovisual landscapes or even health care applications that are adaptive to physiological states, as well as multiplayer games in which the player's psycho-physiological states influence her status in the game.

Finally, the concept of enactive media is not just a futuristic vision but is already implementable with commonplace digital technologies, as has been pointed out.

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