



HAL
open science

Enactive Interfaces?

Claude Cadoz

► **To cite this version:**

Claude Cadoz. Enactive Interfaces?. The Virtual Workshop of the 7th Enactive Conference, 2004, Interdisciplines.org, European Union. pp.24. <hal-00910622>

HAL Id: hal-00910622

<https://hal.science/hal-00910622v1>

Submitted on 27 Jun 2014

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

**Enactive Interfaces?****Claude Cadoz**

Acroe-ICA

The paper proposes to discuss foundational issues in the characterization of “enactivity” and of “enactive interfaces”. Concerned with material aspects of man-environment relations, it aims at initiating a technological counterpart to the purely cognitive approach of enaction. Distinguishing ergotic, semiotic and epistemic functions, it focuses on physical objects envisaged in turn as things to be known and transformed, as tools, instruments, machines, representational objects. The computer is then considered as a symbolic representational machine allowing dynamic representation of dynamic systems, of dynamic interactions between their dynamic components and of dynamic interactions between systems and man or environment. “Enactivity” of interfaces is then related to the fundamental notion of “loop” in relations, at the various nested scales of the whole man-machine-environment system.

Date of publication: 6 December 2004

Enactive Interfaces?

by Claude Cadoz

©Copyright Claude Cadoz – ACROE-ICA

Claude Cadoz

Laboratoire ACROE-ICA – INPG/Ministère de la Culture et de la Communication

Grenoble - France

Man, Machine, Environment

André Leroi-Gourhan explains that the vertical standing position, the commonly admitted criterion for humankind, liberating simultaneously the face from alimentary prehension and the upper limbs from locomotion, opened two fields of relational developments: the one of the Tool, and the one of the Language. “*The tool (...) for hand, authentic secretion from body and brain, and the language (...) are the two poles of a single system*”¹ (Leroi-Gourhan, 1964).

I would like to start with this notion of relational fields, in the light of this double standpoint.

Let’s say, first and simply, that the human being is in a dynamic relation with its (material and human) environment and that this constitutes the global framework we need to speak of in order to be, to communicate, to transform, to create.

And being “in the mood for lexicon”, due to my concern within this Network and to a natural tendency of mine, I will build my purpose by revisiting step by step some basic terms.

Let’s assume that “human being”, “environment” and “relation” do not have to be defined.

We will call “interactions” the relations in which the human being, whatever its goal, and the material environment (at least a part of it at a given time) are mechanically linked.

A first category of basic relations of human being with its environment relates to its position and posture in this environment and to their modification or evolution (egomotion).

Modification of posture is a limit case of interaction since there is generally (for example when we turn our head) no mechanical link with environment, while when we move we actually interact (as when we climb a hill, for example).

We will simply call “objects” (physical objects) those parts of the material environment that can be, at least at a given scale (time and space) of experience, distinguishable and separable from the whole and from others entities of the same kind. At our everyday scale, interactions can be described through the physical concepts of force, deformation, displacements, and through the Newtonian laws. We will qualify as “*ergotic*” (Cadoz, 1994), whatever the other features, the physical interactions between the human being (as a physical system) and physical objects (as physical systems as well) in which there is an energetic exchange; the former being generally the source.

We will consider the human being as equipped with, distinguishably, sensory organs, motor organs and cognitive systems, and we will speak of (avoiding the pitfall of definitions for that), mental

¹ Translated from French by C.C.

states, activities and wills, just assuming for the moment that there is somewhere a link between the latter and the former.

Let's assume also that sensory organs are sensitive to "sensitive phenomena", in an obviously circular and mutual definition, and that motor organs are sources of "motor phenomena" when involved in an interaction with the physical world. But more important, let's consider 1) that (at our everyday scale) the "phenomena" are "objective" (i.e. outside of the subject) but not "objects" and 2) that they are well definable and describable by physics. So, we will speak, globally, of "sensory-motor phenomena", grouping the two in a single whole.

Going further in this primary lexicomania, we will speak of *epistemic* situation (or function) when the relation leads to increase mental "contents" with some *knowledge*, and of a *semiotic* situation (function) when it leads to create some object or "sensitive phenomena" that can be used by the subjects (ourselves or others) for any epistemic purpose.

And then, we will speak of "communication" when some more or less complex epistemic / semiotic loop is established between two (or more) subjects.

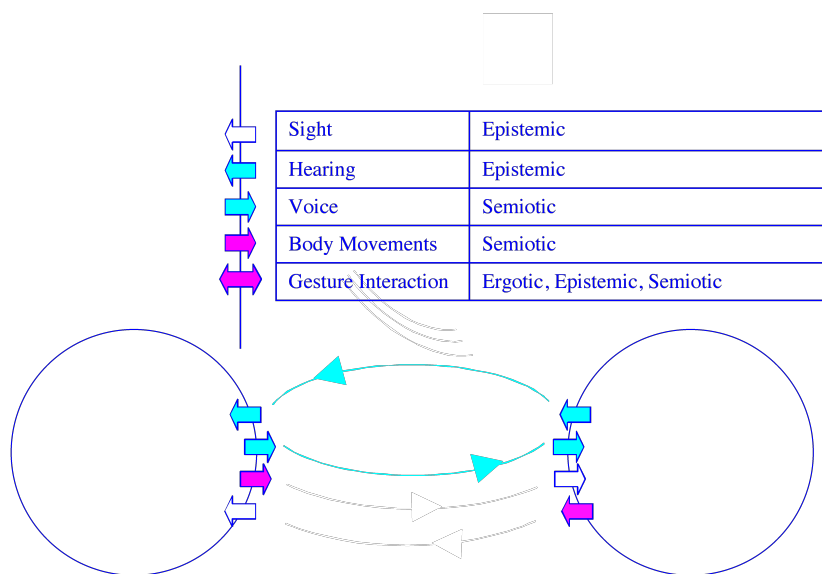
Let's notice that 1) we can interact with objects, communicate with subjects, 2) we don't communicate with objects, but we can communicate with subjects thanks to objects.

We can of course "interact" with subjects, but apart from some specific relations (direct fight, collaborative physical labour, ...), this is not a central preoccupation for our purposes.

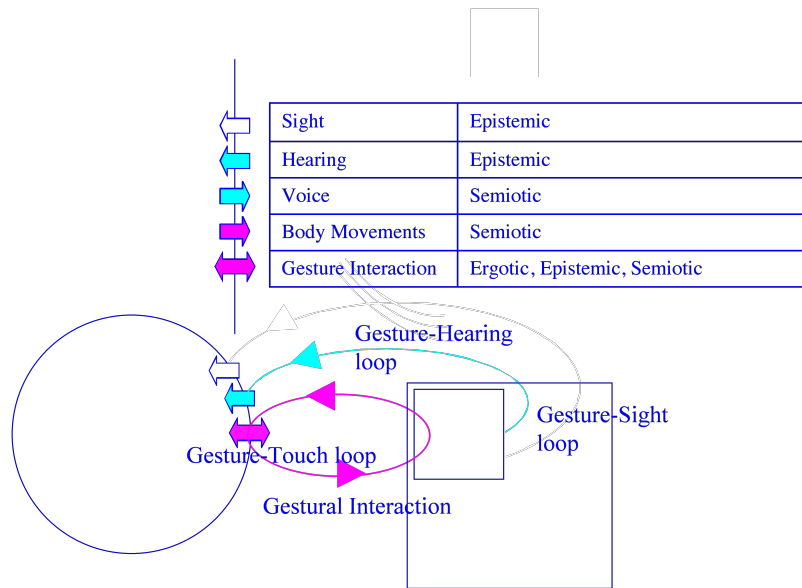
Since we are strongly concerned with technology, we will make this practical basic distinction between relations that involve only natural (biological) equipment (natural locomotion, corporal and gestural behaviours, simple modification of the physical environment, vocal emissions, natural hearing, seeing, touching etc.), and relations that involve physical objects. We will speak of "natural relations" in the first case, and of "technological (artificial) relations" (not very beautiful! but practical for the moment) in the second.

Natural relations

In natural relations with (material and human) environment, we can consider human communication (relations with human environment) and interactions (with material environment), and two basic systems of loops: communication loops and material interaction loops.



Communication loops (voice-hearing, corporal expression-sight)



Interaction loops (through gesture, with objects/material environment)

Considering the sensory-motor phenomena, we have, within interaction, three simultaneous loops: the “Gesture-Touch”, the “Gesture-Hearing” and the “Gesture-Sight” loop. In the last two, we can say that the object converts a part of the outgoing (subject viewpoint) energy from a given nature (mechanical) into another (acoustical), or into the modification of an external one (visual).

We can introduce a notion of “order” of these various loops involved in communication and in interaction:

The most intimate loop (first order) is the gestural interaction. It is the most “direct” one and one must observe that there is no direct notion of emission or reception of phenomena. Both the behaviours of humans and of objects are mutually dependant and constraint: we have to consider a mechanical system constituted of two components linked to each other, the first (the subject) being a source of mechanical energy producing forces and displacements of the whole (subject-object) system. The phenomena involved (of the same, mechanical, category) at the body-object boundary are not directly controlled but the action (will) of the subject influences them and they are “measured” by the subject through his *Tactilo-Proprio-Kinesthetic*² sense.

The two upper loops in interaction can be said to be of “second order” in the sense that:

- There is energy transformation - from mechanical to acoustical, and from mechanical to visible movements, needing an external source of (visible) energy;
- The acoustical or visual phenomena don’t react on the gestural ones without going through the subject perception and cognition. The loop is closed through the subject’s perception and cognition.

In communication, loops are of “third order” in the sense that the two flows (from subject 1 to subject 2 and conversely) are not physically related. They may be largely time delayed, even limited to a single flow, and include necessarily the two subjects in order to be closed.

Let’s notice also that in aural communication, the human being is the source of the sensitive phenomenon involved (acoustic phenomenon) and that the phenomenon is of the same nature for

² Tactilo-Proprio-Kinesthetic sense needs to be defined specifically (not in this text because it needs some substantial developments).

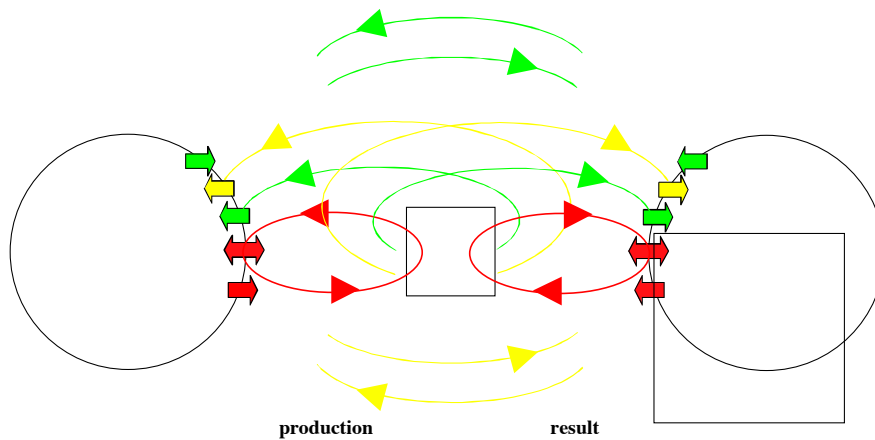
production and perception. In corporal expression, no phenomena are emitted. To be transmitted, the corporal (body and facial) expression needs an external energy (light) produced by an external source and modulated by the “expressing” subject. These features are quite important because they differently determine the “sensory-motor contingencies” within the two cases.

Technological (artificial) relations

We qualify as “technological” or “artificial” a relation (with material or human environment) as soon as it is mediated with a material object (the computer entering in this category).

We don’t take into account, for the moment, the way in which this object is built.

In such a mediated relation, we have not to consider two entities in relation but two relations with a same entity. These two relations are individually observable according to the previous. Let’s however assume a dissymmetry attributing to the first relation the status of “production”, and to the second the status of “result”.



Mediated relations

“Natural” and “artificial” relations are of course not exclusive; in the more general situations they cohabit in a global scheme that can be, in turn, described as a more or less complex set of loops of several orders.

Within these schemes we have a general framework that allows situating, from a purely objective (concrete) point of view, every situation we may encountered in our various respective purposes and domains.

Tools, Instruments, Machines

A material object, supposed to be extracted or built from the material environment in any manner, can be used according to several main purposes that we can try to classify:

- Without any relational purpose:
 - In order to be known by the subject;
 - To be modified or transformed by the subject;
- With a relational purpose:
 - For communicating;
 - To physically modify or transform the environment.

Further, we can add a notion of indirection since an object can be used as intermediary, inserted between the subject and the various objects according to the previous situations, in order to know, to modify or transform another object, or to communicate through another object. And of course to interact with another object which physically modifies or transforms the environment, etc.

These can be extended and mutually combined *ad libitum*.

Staying at a simple stage, we just propose a particular but important terminological distinction, between *Tool* and *Instrument*.

Both are material objects usable on several of the above situations. In common language, 'Instrument' is considered just as more sophisticated than 'Tool'. From our approach, we assume this first distinction but we give to *Instrument* a strongest definition that can be derived from the example of the musical instrument. A musical instrument, when sufficiently mastered by the musician, is like a "part of his body", organically extending it. This "embodiment" is only achievable if an intimate (multi-) sensory-motor loop interaction is available but also it needs 1) suitable physical conditions that can be defined from criteria like energetic adaptation (economy), good correspondences between the ranges of phenomena in the object and in the body, good correspondence between these ranges and the ranges of human sensors and actuators, and 2) to a sufficient learning through *sensory-motor experiences*.

The crucial point is then that the mechanical man/instrument system must be observed as a whole and that it is fully legitimate to introduce and take care at this point of something like "sensory-motor-instrument contingencies".

Hence, we will call in general *instrumental relations* (or situations) the relations where the subject is in relation or interaction with his environment through a multi-sensory-motor interaction with an object available for deep learning. The latter may be, in this definition, supported by the three nested sensory-motor loops or by only one or two of them, the ultimate condition being the presence, at least, of the gestural (ergotic) interaction.

We can find *instruments* for material (non communicating) tasks – a bicycle is for example an instrument for locomotion – and *instruments* for communication – musical instruments being an emblematic example. We can in the last example speak of *instrumental communication*. Unfortunately, it may be ambiguous to speak without any care of *instrumental interaction* because it is not explicit whether we speak of the interaction between the subject and his instrument or of the interaction between the subject and his material environment through the instrument.

This was often a source of confusion within the terms we habitually used; so, we may need to invent some specific terms or qualifying for this distinction (to be discussed).

Part of the body vs. part of the material environment

It is of actual interest to observe the status of the mediating object according to several points of view, in particular in relation with the question of learning.

A given object may play the role of instrument for a given purpose, but it may also remain only as an object, amongst others, in the material environment.

We will consider that the instrumental function is not given *a priori* but depends on two factors:

- Appropriate material specificities;
- Learning.

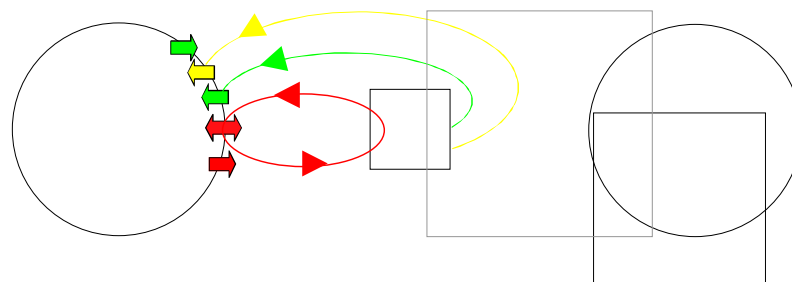
The first ones may be analyzed according to three criteria:

- Ergonomic features that assume a suitable adaptation between the human physical capabilities and the object in order to allow a consistent interaction,
- Production features that assume a suitable adaptation between the object and the addressed environment,
- Correspondences between the former and the latter.

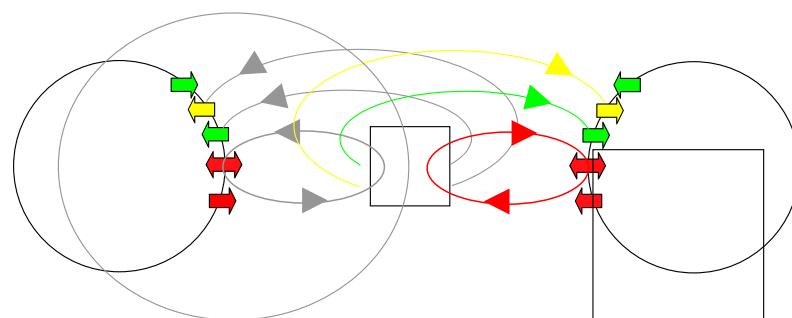
The second factor is of another order and, independently of the previous, it supposes a phase during which the object must be experienced by itself.

Hence, we can consider that before this learning phase, the subject attention is focussed on the interaction with the object considered as an “object of the external world”, a part of it with which he has a specific interaction. After the learning phase, the object is, as we said, a “part of the body”, organically extending it, allowing to speak of “sensory-motor-instrument contingencies”.

More generally the object’s status is relative, within the same material conditions, to the learning and to the action’s aim that determines the attention focus.



Interaction Man-Instrument



Relation “instrumented Man” - environment

In any case, we can generally consider that whatever the object of the environment we consider, it can be viewed either as belonging to an environment with which we interact or as a part of our body thanks to which, globally, we are in relation with our environment.

A symmetrical change in point of view, a “de-embodiment” process, can be evoked about the particular attitude a sportsman adopts when, in order to adequately understand and master his body, he tries to get and experience it as an external object.

To continue with some other terms, we can define:

- *Instrumental gesture* as this particular category of gestures that involve an interaction with an object (an instrument). It is to be distinguished from “corporal expression” or “corporal manifestations” (like in dance, mime, facial expression, gesture that accompanying speech, sign language, music conductor gestures, etc.), which are not *ergotic* since there is no physical interaction with any physical object (excepted, in a limit point of view, for the dance, where we interact with the ground). These gesture are *non-instrumental gestures*.
- *Instrumental communication* as the communication situations that use a physical object in order to achieve a *semiotic* task. Typical example is of course music, but we can consider for example marionette animation in the same way.
- *Instrumental tasks* in general may be any task (to communicate or to interact with physical environment) in which we use such a media and were we have to develop a certain skill determined as well by the first, second or third order loops, the focussing on the former or on the latter depending precisely on the learning.

Machines

The term is commonly used today about computer and digital systems in general (cf. “Man-Machine Interaction”) whereas it referred rather to mechanical devices before the advent of “New Technology”. In fact, following the technology evolution from the mastering of matter, then of energy and then of information, machines have been in turn purely mechanical and *passive* machines (without energetic added sources), *active* machines (using and converting external non-human energy) and today *informational machines* (the third category being generally combined with the two others).

A machine, whatever its function, is generally considered as more complex than a tool or an instrument. It can be described as a system, with some complex components and interactions between them.

But what is important for our purpose, avoiding to quibble about *complexity* or *system* (an instrument is also a system) is, in fact to consider that it is a material object, but that the translation from matter or energy to information, or the combination of them in our contemporary machines is not so evident in the use or the understanding we get of them.

I think that there are at this point some patent and permanent misunderstandings that are precisely to be raised if we want to build a consistent theoretical framework for “enactive interfaces”.

But in order to introduce what I feel as necessary to constitute a minimum conceptual framework for our “enactive purpose”, I would like to adopt now another entry point and spend some lines on the question of another status of objects that is not reducible to the ones previously described. In particular when we take an object for another in order to make, for various purposes, the former present and to get a relation with it that stands for the one we would have with the latter: which is, literally “re-presentation”.

Whatever the role we dedicate to this substitute, and even if such a substitute can be eventually experienced in the same sensory-motor interactions than its original, there is obviously another kind of questions in play.

Representation³

Representation is material and cognitive

The first aspect where the notion of representation is relevant and necessary is in its material form, for communication purposes. It appears when several individuals aim at getting in common something they have in mind, whatever the reason for that (to share a feeling, to advertise a danger, to coordinate actions, etc.). Since we (human beings) are separate minds, each able for ourselves to think, to feel, ... to be in individual specific mental states and activities that can't be directly shared, we need means that make these internal features objective, i.e. present outside of the subjects at least as objective "sensitive phenomena" or even as material objects for a sensory (-motor) experience.

Taking representation in a very literal sense - to take *something that stands for something else* - we can say that at least three things are in a two by two representational relation: the mental states of at least two subjects and the objective external thing: the external thing as representation of mental state of subject n° 1, the mental state of subject n°2 as representation of the external thing and the mental state of subject n°2, by transitivity, as representation of mental state of subject n° 1.

Let's notice that "*stands for*" doesn't suppose anything about the way it stands for. In particular, we have no way to verify what correspondences exist between the two last. Moreover, we are led to admit that, the mental states being or not considered as "representations" themselves, we have no way to evoke and to discuss about them other than through external, material objects or objective phenomena.

As soon as the representation in question is not dissociable from communication and, apart for natural communication, it necessarily needs objects, we can assert 1) that it is necessarily a question for Technologists (for whom a very strong concern is the object, and... communication) and 2) that it is non dissociable from the perception and cognitive questions.

We believe that, in conclusion, we can't avoid considering one more time this question, and that what is important is not so much to dispute about its polysemy but to try to understand what is its new possible meaning in the context of new technology.

But a first step, more easily practicable and concerning material issues, is to consider the material representation of material things (objects): the representational relations between objects.

And let's start for example with this statement from the French linguist Jean Paulus: "to represent is to take *something that stands for something else* in order to apply it some actions of a special kind (...) more economical and practicable, although not less gratifying than the motor actions they stand for"⁴ (Paulus, 1969).

This very general sentence holds by itself the essential questions concerning representation: what is a thing and how can a thing stand for another? What are the purposes of the actions? What are the actions? How can an action stand for another? It also points out the very important notions of *economy* and *practicability*.

Considering the representation of an object (which is less general than "thing") by another object, we can consider two "identical" objects and decide that one of them will be the *representing entity*, the other the *represented entity*. Then we can experience the former (for example in a sensory-motor interaction) for the various purposes we introduced above: to know it, to modify or transform

³ I think that, not only the question of representation should not be evaded - under the pretext that it is so common and so polysemic that it can fall on total irrelevance - but that it may be the crux of our discussions, and particularly between the people that are from the Technology side, and those that are from Psychology or Philosophy ones. The former need fundamentally this term but its sense and use are obviously not equivalent for them and for the latter.

⁴ Translation from the French by C. Cadoz

it, to communicate, to physically modify or transform the environment. If the two objects are actually identical, there is no difference between the actions we do with the represented and those we do with the representing. That can be of a certain advantage if, for any reason, the represented is absent (far away in time and/or in space). That can be also interesting because of the fact that two different subjects, in two different times and spaces, each owning one of the two objects, can perform exactly the same experiences. One can say that we get, by that, a certain extension of the experiences in time dimension (historical), space dimension (geographical), and social dimension (several subjects identically involved).

But this hypothetical experience raises a difficulty: what is the identity of two objects?

As well as we can't relate two mental states other than by relating them to an external object (or phenomenon), we can't identify two objects other than by relating them to the same mental state. There is no way to go out of this circular relation.

Identity doesn't exist

In order to avoid the pitfall of circular definitions and mutual referring, let's just consider mental states and objects as in fact both features of one and the same world that we can consider from a subjective point of view (the objects are something we have in mind) or from an objective point of view (the mental states are born by a human being who is an object in the universe...). So, coming back to the word *things* (which is more general than "objects"!), we can try to discuss about *things* in general (of course, in doing that, we necessarily use material objects – for example the words written in this page – and mental states – for example the painful efforts I do to try to make this clear).

Speaking of a *thing* implies separating it from a whole and considering that it can be independent of it. This is possible only in limited circumstances. For example, considering a given material object, extracted from its environment for a given experience, we can never maintain that a further experience should not reveal an interaction with a part of this environment we evaded. Let's just invoke the so famous "butterfly effect" from chaos theory, stipulating that a very small event can be responsible of a dramatic one, far in time and space, in an unpredictable manner.

It may be *a priori* the same for mental things (until proof of the contrary).

So, we can assert that the absolute thing of the universe is the universe itself, including living and human beings.

Let's suppose nevertheless that we succeed, for a given experience in a given time, to isolate a thing. Again, we can't be sure that the experience we get at this time is complete. A further experience, even assuming that the thing is isolated from any other thing in the world, may reveal further deeper features that escaped our first investigation. We will call that the *infinite ontology* of things, infinite not in the sense of actual infinity (which can't be verified), but in the sense of potential infinity, as do mathematicians when they say, for example: "whatever small (or great) is a value, we ever can find a smaller (or greater) value that..."

Now, speaking of identity or difference supposes identity or difference between several things, at least two. If there are two things, it means that there is at least a difference, allowing distinguishing them. Absolute identity is then equivalent to uniqueness.

In conclusion, 1) the only absolute thing in the universe is the universe itself, and 2) the absolute identity is uniqueness. So, there is no absolute possible representation. The only absolute representation is the representation of the universe, by itself.

Identification is an act

It is a strong necessity for the human being to be able to speak, to feel, to practice Identity. This is in fact something like an existential question.

So, the only way to practice identity is, somewhere, a subterfuge. We are led to consider that things have multiple aspects that we are able to separate in turn, and then, that we are able to say, between two things differing on at least one aspect, that certain other aspects are identical. In some way, we (or some material or biological device outside of our will and consciousness) decide that such features (among those we know and those we don't know) have to be taken into account and such other not.

Categorization, at a high cognitive level, filtering, discretization, etc. in biological or technological processing, refer to this identification process.

Reduction and extension in representation

Standing a thing for another in such representational attitude founded on an identification process, we can be sure, having taken into account only partial features within the two correlated objects, that features within the *represented entity* have been lost in the *representing one*, and conversely, that features are present in the latter that are not in the latter. In the first case, we get a *reduction*, in the second an *extension* of the *represented entity* by the *representing one*.

Far to be only drawbacks, these facts, inherent to representation, are conditions for economy and creation through representation.

The classical triad: *Index – Icon – Symbol*

The different ways in which the human being takes objects for others are very numerous. Thinkers of every period and from every discipline worked on their characterization, classification, critic, refunding, mutation, etc.⁵

It is actually relevant to try to describe and characterize the various representational relations, and sometime, however no so easy, necessary to eliminate dramatic misunderstandings. Nevertheless, a very basic classification is this famous triad *Index-Icon-Symbol*. However very common, it remains very practical for our present purpose.

Index

An index is a part, initially physically or organically linked to another in a whole object or phenomenon, that is, in a second situation, separated from the whole and that “stands” for the eliminated part. For example smoke is an index of fire (assuming that there is never smoke without fire!), feet traces on the ground are index of man walking on the ground, sounds may be considered as index of instrumentalist playing an instrument.

Icon

An icon, as commonly defined, is an object that presents some “analogy” with the thing it represents. For example, a portrait for a person. However, the notion of “analogy” is not so simple.

⁵ Let's just mention one of the most famous, Charles Peirce who was a compulsive taxonomist and who went to propose until 59 049 types of signes (Peirce, 1931-58). A classical reference here is also Nelson Goodman (Goodman 1976, 1968, 1990). See also, for pedagogical approach of semiology (Chandler,1994, 2001).

It may be built from the previous idea of identification (process). But we must enter some more details.

Identity of some features between the *representing entity* and the *represented one* is indeed required (unlike in *index* where, for example, there is no resemblance at all⁶ between the smoke and the fire), but the interesting question is, precisely, on what kind of features?

We will assume, for the sake of explanation (and evading the question of mental / material dualism) that we can legitimately refer to a first basic classification of the features themselves into *time*, *space*, and *quality*. Time is primary since it is at the base of our mental experience, which is the experience of changing of our mental states. *Quality* is something else of which we can just say that it can change over the time. *Space* is also fundamental at our common scale; however, it may be considered, somewhere, as built from the previous with the participation of our body (the structure of our retina, of our skin, of our two ears, ...) and of our motricity. But as well as quality can change over the time, it can also change over space and in combination over time and space.

However simplistic, and even disputable, this classification allows us to illustrate the idea of iconicity in a large acceptance. And rather than embarking in a long discussion, let's just evoke an example, from which everybody can make extrapolations.

Considering, as first thing, a tennis ball moving in the space, we can find an analogy with a second one, for example a disk having roughly the same diameter, the same colour and visible details on its surface, moving on the 2D space of a cinema screen. Some features are indeed identical and other not (the dimension of the space for example). Hence, we can say that the picture (the movie) is an iconic representation of the first thing. More, we can add that this icon preserves identity on certain visual qualities and on time/space determination.

Let's consider now a photography made during the initial scene. It is also an iconic representation, but without time determination. Looking now at the successive images on the film itself, put out of the projector, we can recognize the ball and discover in a single time several positions it had at different times in the space. Then, we get an iconic representation of time/space (linked in movement) within space: the 2D specifically structured space of the film.

Looking now at a comic strip on tennis, we can find such drawings where ball trajectories are visualised. We then have another kind of iconic representation of time and space introducing something that we never see per se (the trajectory) but that we can nevertheless identify.

Now, in every previous cases related to our first "tennis ball moving in the space", we can, in an animated drawing replace the ball, the disk, the drawing... by a simple dot, just visible, but without any particular visual details. Then, we get an iconic representation of the movement (time/space) in itself, *abstracted* from what is moving.

In such a drawing, the trajectories can also be modified (simplified or arranged) in order to emphasize a specific character. Despite strong such *anamorphosis*, we can keep in mind the initial link with the original. Anamorphosis is part of iconicity.

Let's now envisage that we are not satisfied with this (relatively) passive situation and that we wish to know and communicate about not only this event, but on tennis balls in general: how can we play tennis? what are their behaviours when we cast them like this or like that? All the previous iconic representations failed for that. But if we take a potato, even if, by that, we eliminate some important features of the tennis ball, we can at least seize and cast it. We can also experience new kinds of identities or differences: between the weigh, the deformability, the tactile aspect of the surfaces of the two objects, and then we can envisage a new dimension of iconic representation, concerning dynamic (matter, time, space) features.

⁶ One can understand that this formulation is quite succinct, for the sake of economy in this paper. But obviously, for the same reason that identity doesn't exist and is "practiced" through *identification*, conversely, difference, non-resemblance is as well practiced through an act or by a material device. We can always decide, having in front of us two objects, to choose a point of view that allows us to consider them as different or, conversely, as identical. But we can also exhibit material processes, in particular involving strong non-linear amplifiers where the correspondence between inputs and outputs can be completely arbitrary determined.

Symbol

Symbols are completely different.

There is *a priori* no analogy, no resemblance between the symbol and what it stands for, for example a circle for a human being. The core idea here is, on the contrary, on the *arbitrary* relation, ...fore the best and the worst. *A priori* any thing (object, phenomena, mental state or phenomena) can be a symbol. But, correlatively, the relation must necessarily be established, i.e. experienced in an initial learning situation making present at the same time and place both the *representing* and the *represented*, or, through a special material device achieving what we usually call a *coding*.

It is interesting to evoke these three categories together because they are notably complementary:

- Index and icon are both not arbitrary, the link within the first being physical, cognitive within the second;
- Index and symbol both link different things, physically within the first, cognitively within the second;
- Icon and symbol, both establish the link between cognitive process, the first is non arbitrary, the second is.

One can remark that at no moment in this argumentation, we were led to make any assumption on the mental or material status of the things being in representational relation. The material aspects introduced sometimes were just necessary to more easily support the explanations.

One can notice also that a given elaborated representation may combine the categories, for example when we represent on a map the summit of a mountain with a small red triangle associated with a number indicating its altitude.

Systems

We can experience a thing as constituted of several sub-things, and conversely, a thing as a part of a set of things constituting together, at an upper level, a “macro”-thing. For example, a tree constituted of a trunk, branches and leaves. We can focus on leaves and observe more details within this sub-object (veins, tissue, etc.). We can also consider the tree as a member of a forest, the forest as a constituent of the ecological system of a land, etc.

We can change our point-of-view, more precisely the *scale* of our experience, in general for reasons that are related to the goal of this experience. Doing that, we get a kind of new understanding of the things: things as *systems*, i.e. 1) constituted of sub-components, which 2) are in relation between them. The trunk wears branches, which wear leaves, etc. And what is important in this notion of system, is the intrinsic dualism between a whole considered and experienced as a whole - with *emergent* properties that must be attributed both to the properties of the components and to the specific relations linking them – and the same whole considered and experienced according to its parts.

Emergence has its dual counterpart: a given thing being generally itself a part of an upper system, its behaviour may depend both of its linked sub-parts and of the other components of the upper system.

Atoms and the Universe

Is the world constituted of ultimate minimal parts that we can't decompose in further sub-parts?

The point, here, is not so much to get an answer than to realize that getting knowledge through experience and experiences being contingent by our (time) finitude, we necessarily stop at a moment. Then, we have in front of us, at a moment, things that we can't consider differently than non-decomposed.

Is there a maximum system being the system of everything?

For the same reasons, we are led to be contented, according to the knowledge integrating all the experiences done until the present, with a global system that we can't consider differently than the whole, even if further experiences will show it as a part of a wider whole.

In both cases, we can invoke again the idea of “ontological infinitude”, not in actual, but in potential sense, and until further information.

And when we consider and experience a thing for itself, we suppose that we can, for this particular experience, break the relations within the scale of the upper system and be satisfied with the smallest things entering in its constitution.

Let's notice that “scale” is not only a matter of time and space dimensions, but more generally of including or being included.

Systemic representation

Within the system idea, we can now envisage representation in a more elaborated way, trying to distribute the previous notions (index-icon-symbol) according to this understanding in dual terms of properties, relations and emergent properties.

A complete paper dedicated to the questions raised by this point should be not sufficient to treat all its aspects.

Let's just point out some considerations:

A set of relations can be preserved in an analogical (iconic) way between two systems, independently of the nature of the representation of the linked parts. For example, we can represent a tree with a drawing where trunk, branches and leaves are replaced with a rough drawing of each parts but where the number of first order branches linked to the trunk is identical, as well as the number of second order to first order, etc. We can also get a better drawing of the trunk, branches and leaves, but neglect the exact correspondences within the numbers. And finally, we can replace trunk, branches and leaves by a symbol, for example simple straight lines. We use the latter in numerous kinds of diagrams, generally not to represent real trees, but hierarchical relationships between various things.

Fully symbolic systems are well known. Languages⁷ are of this category. Indeed, in any human language for example, there are words, which are symbols regarding the objects, feelings, events, actions... they stand for, and rules (grammar) that combine them, giving the sentences a specific emergent signification.

Words are themselves small systems linking letters. And a particular notion appears here, known under the term of “double articulation”. “Double articulation” is in fact the strongest criterion defining a representing system as a language. It means that the representational function appears only within a specific combination of lower elements that, by them, doesn't represent anything. The letter “t”, in the word “tree” doesn't refer to the trunk or any part of the tree, it is just a component (vocal or graphical) among a set of arbitrary pre-determined ones, that must not be confused with its sister letters and recognized each time it is involved in various different combinations.

With “double articulation”, we solved, in a certain way the question on “infinite ontology”, simply by deciding, within the representational system, to arbitrarily start and end at pre-given finite boundaries. Which is indeed quite practical... but unfortunately (nothing is perfect!) which also put the world in a sad finite condition. One can say also that within languages things have “finite ontology”.

The example of language allows illustrating several important ideas:

- We can use a symbolic system to represent a systemic thing;
- There is no a priori necessity of correspondences between the two detailed structures and their various nested scales, within each systems in representational relation;

⁷ Understood in a large sense, i.e. not only natural languages.

- And in particular, the lowest elements of both are absolutely not in a representational relation.

Iconic systemic representation

But let's evoke a diametrical opposite situation.

We can try, indeed, on the contrary, to give of a systemic thing, for example a systemic object, a representation preserving in the same way it preserves the sensory-motor interaction we can have with it, the physical interactions the sub-parts of the object can have between them.

For example, a child playing a toy-car (not a miniature, but a small toy-car he can enter and drive) can get sensory-motor experiences of it, in a certain extent analogous to those he could (would) have with a real car, and achieve iconic travels in iconic landscapes. But the iconic character of the representation is not only between the sensory-motor interaction and in the interaction between the toy and its environment; it is also between the *relations* (mechanical interactions) between the constituents of the toy and those between the real components of the real car. Of course with some reductions and simplifications for certain of these parts, but with genuine correspondences for others. The toy has wheels and steering wheel that are in the same mechanical relations than in reality.

The realm of toys is full of such examples but it is not unique in that respect. In architecture, machine engineering, etc. this is exactly what we do with all sorts of mock-ups.

Let's just give the name of "*integral representation*" to this case where 1) we use a system to represent a system and 2) where the iconicity conquers, beyond the pure phenomenological sensory-motor aspects, the intimacy of material systems viewed as dynamical components in dynamical interactions.

Of course no absolute integral representation is possible, according to the same reasons we invoked for systemic representation itself.

At this step, we can enlighten a great contrast between the two systemic representations that are, on one-hand *languages*, and on the other *integral representations*.

"Is cognition a representation of a pre-given world by a pre-given mind?"

A lot of argumentations funding the motivation of enactive approach from the Psychologists point of view, and very well synthesized in the "state of the art of enaction" elaborated by Elena Pasquinelli (Pasquinelli, 2004) can convince us that not.

But we can't eliminate the existence and the necessity of representation process. So, the very questions are rather: "is representation exclusively a material, objective process?" and also, "are there things, of material or mental forms, that are not representation? If yes, what are they? To what representation has to be opposed?"

We can assert that, at least in perceptual processes, linking external and internal worlds through senses organs, there are representation processes by the fact these organs produce bioelectrical phenomena that "stand", in the internal world, for the external physical phenomena they "convert". In the same way, technological transducers (for example a microphone) give representations, under a specific physical phenomena, of specific other physical phenomena. However, a difference between these two (biological and technical) examples is that a microphone - or its symmetric, a loudspeaker - achieves an iconic link between the two phenomena, while the cochlea in the internal ear gives a symbolic correspondence to the acoustical phenomena under a set of specifically structured nervous impulses. But if we consider the frequency of impulses in a given salve, it may be related in an analogous manner to the intensity of a physical stimulus. Then, we can speak of (partial) iconicity. In both cases, this reinforces the idea that there is a minimal representation

process between internal and external worlds, and more, that we can envisage, at a second order, a *technological representation of this representation process*.

Further?

Whatever the actual form and support this involves, when I am able to completely imagine what sequence of streets I have to follow to go from my home to the station before any actual walking, I necessarily have somewhere in my mind something like a representation. First according to the very basic signification we adopt before: it “stands for”. But further, this is a representation in the sense that this is, at this moment, given in my mind with a minimum set of spatial (at least topological) attributes that I can mentally inspect and experience.

If to go to the station, as I do in a town I do not know, I only follow the signs along the streets, then I can say that I have not a representation of the town but a representation of local properties of the town that are, indeed, sufficient to find my way. In this second situation, a (more) global representation is replaced by local representations and sequential actions. Very often, in order to act we don't need to know where we go, but only from where we leave. And the best case is when we have only one way to leave (but we can't deny that certain people never act without knowing where they go to!).

From this example, we can introduce at least one kind of alternative to representation: *action*, involving natural organs, tools, instrument.... (and conversely).

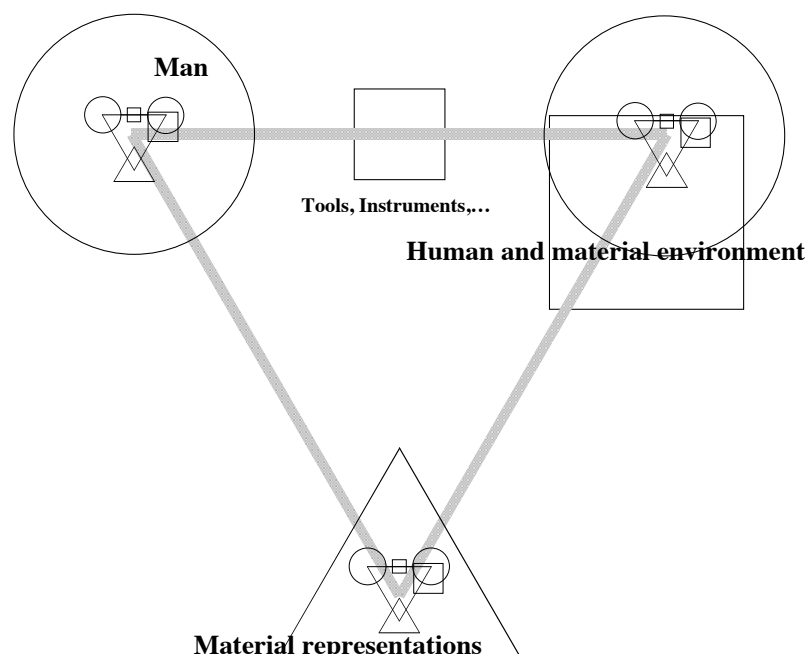
But it is yet more subtle, because an action can be a representation and conversely.

Let's say, neither to conclude, nor to summarize, just to open the next discussions, that:

- Representation is a necessity;
- It can be both mental or material;
- It can be dynamically and in a systemic way combined with action;
- Action can be representation and conversely.

And also that action and representations are not “centralized” but distributed on both sides of the human “skin”, constituting a global (social and material) system, structurally inter-related.

By this kind of proposal, we generalize the assert (Brooks 1991, quoted by E. Pasquinelli, ib.) that “the external world is its own best memory” to which we would like to add “yes! But there is no sense of external memory without internal memory”, and that the “memory” is, in fact, distributed between internal and external worlds. In the same way, let's say that the best representation of the world is the world itself, but there is no sense to external representation without internal ones, the world being the human and material world. And the representation is a matter of a triad:



In this global system, internal/external organs, tools, instruments, actions, representations can play a complex distribution. What we have to understand and/or to build may be precisely the very nature of the frontiers, their places and their roles.

Now, we can speak of...

Enactive Interfaces

Information Machines

We commonly encounter the word *interface* in the expression “Man-Machine Interface”. Starting with this, assuming that “Man” has no longer to be defined, let’s come back a few moments on “Machine”.

Currently used today (we already said) about computer and digital systems in general, we observed that it historically slipped from matter mastering to energy and then to information mastering, combined in fact in the latter with the two former.

In Information Machines or Information Technology (IT), Information refers to Shannon theory (Shannon & Weaver 1949). It includes of course computers, but adds the key notions of transmission and wide diffusion of information through the new mass-media; in particular the Internet. However, one generally plays down the fact that, with Information Technology, information is stored, treated, restored, transmitted, but also produced, created. And also, we underestimate the fact that information, for its transmission as well as for its production, needs always some energy expense, as small it can be.

Elementary entities

But first of all, a Computer (wide sense) is a physical object. Given to us as it is, we can submit it to all the experiences discussed above. Then, it appears as a material *system*, with its smallest components, internal interaction phenomena, interaction phenomena with human being and real world. But this concerns the approach of engineers that have to build or repair it. As normal users, we obviously approach it in another way. This needs some elucidation.

We commonly consider that everything in a computer is “made” of binary digits and processed by “logical” or “Boolean” operators driven by a “program”. What is the status of these things?

A digit is not an object, it is associated to the state (electric, magnetic, etc.) or a phenomenon we can observe from a physical object (semi-conductor component, magnetic support, etc.) and which can influence the state of other objects of the same kind. These components are built in such a way that they can get two, and only two different and individually identifiable states – that correspond to a physical categorization (identification) process, and need some particular physical conditions. Considering several objects showing the same (identified) states, we associate them (the states). This is an *abstraction* process. Then we give a name to this sharable state (“true”, “false”, “0”, “1”, etc.). This is a sophisticated external representation joining verbal, textual and graphical representations to an abstraction.

But the most important here, is the fact that we also get another external representation of these states. Indeed, the phenomena that concretize this abstraction within the electronic components are not sensory-motor phenomena. Even so, if we want to know or determine them, we need such sensory-motor phenomena. This is the function of these essential technological components that we call *transducers*.

Namely, and in its basic definition, a *transducer* is a physical device that can transform (as the action and perception organs did) a given physical phenomena in another one, assuming a correspondence between the two. This is actually a representation process, but physically (not humanly) achieved. Hence, as supporting a representation process, it could (should) introduce a reduction. For the usual transducers like acoustic-electric (microphones) or its symmetrical, electro-acoustic (loudspeaker), this is well characterized and quantified with the notions of bandwidth and signal / noise ratio.

However, the concept of transducer includes another specific feature when a transducer links together not only two different kind of energies, but two different scales of energy. For example an

audio amplifier can provide electrical energy at its output that evolves in the same way as its input energy, but in a completely different range. It needs for that an added external source of energy that is separated, but controlled by the input energy. This principle of *energetic relays* (which is achieved by devices such as vacuum tubes or transistors) is fundamental because it introduces the notion of *sign*, or *arbitrary sign*, in fact *symbol* within the technological systems. Indeed, particularly when they are non-linear, the amplifiers can introduce arbitrary (nevertheless absolutely controlled) relations between their input (*represented entity*) and their output (*representing entity*). Here appears the concept of *signal*. And at the same time, this fundamental property of the active transducers, which are unilateral devices: they work in a unique direction.

A transducer, in summary, is a material device achieving a representation process that can be analyzed within the same criteria than the ones we introduced before and that can be characterized as *iconic*, *symbolic*, etc.

In general, this transduction is completed with sophisticated ones achieving the correspondence with graphical, visual, textural... presentations for the machine to man path, with gestural actions from man to machine path. The complete devices are called *peripherals*.

There are in a computer some devices that memorize the digits (that are able to keep their state over the time) and some that “operate” on the digits. The last term refers to *mathematics* but it has a concrete counterpart, actually in a physical (electronic) interaction between two (electronic) components: a given state on one place of such a component (called its *input*) can imply its opposite on another place (called its *output*) of the same operating component. Operating components can present several inputs and outputs and achieved correspondence between them that we can fully abstractly describe thanks to the Boolean algebra.

Elementary entities within computer, the digits and the boolean operators, define a “language”. More, this is an “absolute” language since its symbols are just the minimum needed to get distinction (“0” is not “1” and “1” is not “0”) and the minimum multiplicity: 2; and its rules the exhaustive list of possible combinations we can get from these two elements.

Finally, we *program* computers. Very shortly said, we practice this language.

The Computer as a representing machine

System of interacting symbols

Except for strict Boolean algebra purposes, the digits and their treatments have no meaning by themselves. Of course we know that we use the digits as elementary components of much more sophisticated things, thanks to a wide variety of transducers and peripherals. Whatever could be the latter, one can say from now 1) that we will be in the *symbolic* mode since there can't be another link than *arbitrary* or *conventional* between these things and the digits, and 2) that it will be typically in *double articulation* conditions, leading us to the general language context.

But considering the computer from the representational point of view, we must emphasize a very essential novelty: computer is a representing system that includes *interaction* in its representational function.

In summary, a computer is a *system of interactive symbols* we can practice in the same way than a language, including writing, graphical supports and representations, etc.

Nevertheless, these *interactions* are not general since they are, by essence in computer as well as in every “digital technology”, *oriented*: a given component can act on its subsequent but not the contrary. This strictly *causal* situation is inherent to the very principle of digitalization and intrinsic instantaneous loops are not representable within it. Hence, the only relations that can be supported within a digital context correspond to a hierarchical tree (oriented dataflow), including however feedback, *but necessarily time-delayed* loops. And the only loops that can be supported within a

digital system are pairs of time-delayed input/output flows. Nevertheless, for certain scales of experience, this can be a sufficient representation of instantaneous loops.

Ergotic transducers

Of course, the internal phenomena (within computer) are neither sensory nor motor.

We already said that transducers and peripheral were necessary in order to establish a link with the human. So, such transducers and peripheral exist that allow receiving or sending from and to the subjects, in *epistemic* and *semiotic* ways various kinds of “knowledge”. This is the reason why we can use the computer as well for communicational (storing, treating, restoring, transmitting information) as for creation (producing information) purposes.

But, in invoking the *ergotic* relation, we need some special conditions: something that can be in a mechanical (intrinsically bidirectional) interaction with real and observable forces, displacements or deformations, and, correlatively, energetic involvements.

Before going further, let’s just remark that the same question arises if we want to assume an interaction with the material environment.

The computer being not by itself a energy producer (it just consumes it, in a completely different range than the human motricity), we need first an added source of energy that can compete with the human or material environment sources. But we need also a way to convert the mechanical phenomena in digital ones that can be then, in separate unilateral ways, received or produced by the computer.

We can here introduce and define the technological concept of *ergotic transducer*.

- ⇒ An ergotic transducer is a technical device:
- That converts an energy of a given nature (generally electrical) from an external source into a mechanical energy that can be consumed within a mechanical interaction with the human or a material object (which is no more no less than an electrical motor);
 - That, incidentally (but necessarily) gives an electrical (digital) representation of the mechanical phenomena occurring during the interaction;
 - And of which energy production is commanded, through the basic principle of *relay* (or electrical amplification) and digital/analogical conversion (representation) by digital (electrical) phenomena.
- The second and third functionalities being constrained by the digital condition: unidirectional relations.

An ergotic transducer can then be the support not of an ergotic interaction, but of a REPRESENTATION of an ergotic interaction. Indeed, we don’t physically interact with a computer since we don’t exchange mechanical energy with it. We no more communicate with a computer since it is not a living being, but just, in certain circumstances, eventually a REPRESENTATION of living or human being.

Symbol interacting system interacting with Man and Environment

Now, we can propose a (partial but essential) characterization of the Computer.

If we mean by Computer, in a wide sense, the set of machines that include central units, peripherals, transducers, ergotic transducers and energetic source, we can say that it can play the role of a *representing system* with very new fundamental characteristics. It is together:

- A symbolic system;
- A system within which the symbols can interact;
- A system that can support representations of multi-senrory-motor interaction with human;
- A system that can support representations of material interactions with material environment.

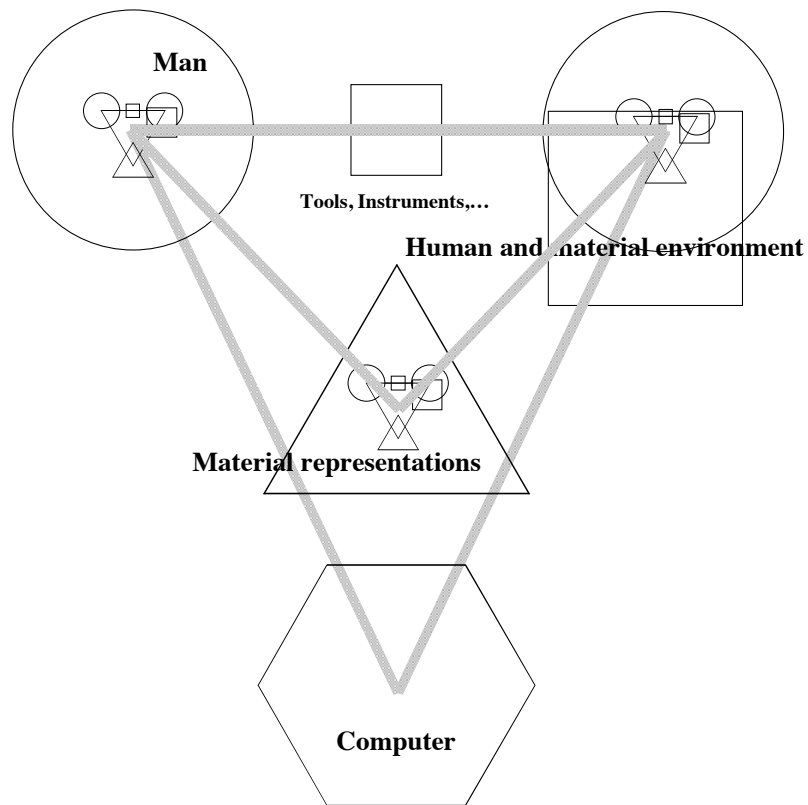
A specific application of all these features consists in using the symbolic interacting system to represent physical interacting objects in an *integral representation* attitude. *Physical modeling simulation* enter into this approach.

Far from bypassing the question of representation, we, on the contrary, give it a new and strongest perspective. Indeed, we think more fruitful to envisage now the consequences of this position enlarging representational attitude to interaction, dynamic, matter, energy, than to dispute on the legitimacy of the concept.

Now, we have to consider in what situations it plays this role, and for what purposes. What it does other than representation? what link, within representation and without representation, it has, may have with human and with (human and material) environment?

Man, computer, environment

The complete diagram representing the various protagonists and their relations is:



On each sides:

- Human being with its:
 - light sensors (sight)
 - acoustical sensors (hearing)
 - acoustical producer (voice)
 - corporal mobility (body and face expressions)
 - gesture interactivity (gestural channel)
- Material and human environment

Between the two:

- Tools, Instruments,...
- Material (non electrical) systems of representation
- Computer with its:
 - Man-machine transducers and peripherals:
 - visual displays (screens, ...)
 - acoustical displays (loudspeakers, ...)
 - acoustical sensors (microphones)
 - light sensors (cameras)
 - motion (non ergotic) sensors
 - ergotic transducers and their energy sources
 - Man-environment transducers and peripherals:
 - the same categories than above
 - Internal digital systems

To this basic diagram, we must add tele-transmission (more or less time-delayed) of internal phenomena (data) of any nature and from any place we can consider between the outputs of the sensors and the inputs of the displays; which gives spatial extension. And storing and restoring of the same features; which give temporal extension.

From there, it is possible to state a typology of the main basic situations involving computer according to the other involved entities:

		First entity	Second entity
Com.		Man	Man
		Man	Absent
		Absent	Man
Inter.		Man	Material environment
		Man	Absent
		absent	Material environment
	

Between these entities (man or material environment), the links will be of different kinds depending on:

- The relations between the outputs, viz. inputs of the computer sensors viz. displays are direct or treated through a digital process;
- The nature of the process when existing.

⇒ Communication

- Direct connection:
 - Man/Man: Direct communication; a difference with direct “natural” communication occurs as consequence of intrinsic transducers limits, constraints or anamorphosis.
 - Man/absent, absent/Man: *Tele-communication*, Time-delayed communication.
- With an internal digital process:
 - Speech, corporal expression, ... analysis / synthesis, treated or not treated, tele-transmitted or not, stored and restored or not: *Man-Machine “Communication”*

The internal process can be “human metaphor” oriented, or not (for example when the sensory-motor data are transformed into abstract ones that are used for any conceptual purpose). In the latter the computer may be nothing corresponding to a representation. But in the former case, even when

Man is absent, it is more relevant to speak of a *Man to Man communication* where the computer “represents” Man, than a Man-machine communication.

- When sophisticated digital processes trying to mime human reasoning or mental behaviour are involved, i.e. *Artificial Intelligence* are introduced, we can again consider the computer as *representing* human agents, and it is also better to speak of (sophisticated) Man-Man communication than of Man-Machine communication; which gives to the machine a confusing anthropomorphic status.

⇒ Interactions

- Direct connection:
 - Man/Environment: *assisted manipulations* where some amplifications and/or anamorphosis can adapt the capabilities and skills of the human agent to the specificities of the material task.
 - Tele-transmitted (in both directions or not): *telemanipulation, telepresence*.
- With an internal digital process:
 - Man/Environment: *Assisted manipulation and telemanipulation, assisted Robotics, Augmented Reality*;
 - Man/absent: *Artificial (or Virtual) Reality*;
 - absent/Environment: *Autonomous Robotics*.
- In these various situations we again consider two cases according to how the digital process is conceived. In any cases it can refer to nothing corresponding to human or real material features, but it can also be a *representation*, of real world in *Artificial Reality*, of human agents, in *Robotics* and *Autonomous Robotics*, both in *Augmented Reality*.

Through this very quick and incomplete overview (to be detailed further), we aim to point out the relevance of the “extended” representation paradigm to understand the role of the computer. Man and (human or material) Environments are in relation through the machine that can be, according to the various situations, viewed:

- As a representation of the (human or material) environment with which human agents “virtually” communicate or interact; the virtual relations being representations of the real ones;
- As a representation of human agents “virtually” communicating or interacting with real (human or material) environment;
- Any combination of the two.

Let’s remark that the traditional tools, instruments, etc. figuring in our global above diagram can, as well as any part of the material environment, be themselves explicitly involved in the representations.

As an echo, at this point, to the idea of complex distribution in a global system, of internal/external organs, tools, instruments, actions, representations, we can add that what we have to understand and/or to built may be precisely the very nature of the frontiers, their places and their roles in this distribution on both sides of the human “skin” and... of the “computer skin”.

And where is enactive interface?

Interface between what?

If it is between the human being and the world, the very (new) interface is the computer itself (traditional interfaces were tools, instruments, etc.).

If it concerns the relation with the computer, then we have to consider two kinds: Man-computer and Computer-environment interfaces.

In fact, we can speak of interface each time there is a discontinuity in the global non-centralized system.

So, *enactivity* of interfaces must be envisaged, for every case, as the character that allows the man-environment system to be a system of inter-related parts where parts are in relation through loops of different orders. Its achievement supposes to realize the optimal conditions that allow the two parts interfaced to exchange all they have to exchange, in the best way. For computer, it is not only the matter of the physical transducers, but also of the representing (or not representing) internal processes, models, etc. This is the very technological and conceptual challenge.

If *enactivity* is not always a necessity, we have to guaranty its possibility where it is needed.

So, in this aim, we have to 1) understand where it is needed, 2) understand how it can be achieved, 3) achieve it. This is our starting (not ending) work.

But we can assert that there is at least a place where the answer already exists: at the ultimate sensory-motor loop, where enactive interface should be equivalent to *ergotic transducer*.

Bibliography

Brooks, R. A. (1991), "Intelligence Without Representation", *Artificial Intelligence Journal* (47), pp. 139-159.

Cadoz, C. (1994), « Le geste, canal de communication homme/machine. La communication instrumentale », *Technique et science informatiques*, Volume 13 - n° 1/1994, pp. 31-61.

Chandler, D. (1994) *Semiotics for beginners* <http://www.aber.ac.uk/media/Documents/S4B>

Chandler, D. (2001), *Semiotics: The Basics*, ed. Routledge.

Goodman, N. (1976, 1968), *Languages of Art*, Ed. By the author.

Goodman, N. (1990), *Langages de l'Art*, Ed. Jacqueline Chambon – Nîmes (French version of *Languages of Art*).

Leroi-Gourhan, A (1964), *Le geste et la parole*, Ed. Albin Michel, Paris.

Pasquinelli, E (2004), *Enaction. A State of the Art*. Work in progress. Available on Enactive Website: EI_WP1_Enaction_State_of_the_art_article (041021_EPasquinelli).

Paulus, J. (1969), *La fonction symbolique et le langage*, Ch. Dessart, ed. Bruxelles.

Peirce, C.S. (1931-58), *Collected Writings* (8 Vols.). (Ed. Charles Hartshorne, Paul Weiss & Arthur, W Burks). Cambridge, MA: Harvard University Press.

Shannon, C. and Weaver, W. (1949), *The Mathematical Theory of Communication*, University of Illinois Press, Urbana.