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Embodied Intelligence in Physical, Social and Technological Environments

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Abstract. The aim of this contribution is to highlight different aspects of embodied intelligence that add to a broader interdisciplinary perspective on this phenomenon. This article intends to bring together three forms of embodied intelligence from the fields of technology and social research, starting from robotics research that deals with the technical replication of organic bodies, to insights from the sociology of the body outlining the relevance of corporeality in social encounters, and finally to the forms of embodied intelligence in the connection of technical forms with organic bodies and their effects on the perception of self and others within the hybrid research field of "Bodies of Technologies". This tripartite division of embodied intelligence deals with the biophysiological properties of an organism in self-environment relationships (the subject of robotics research), the interaction of a being or system with other beings in self-environment relationships (the subject of the sociology of bodies), and finally, as a third, new level of embodied intelligence, the technically mediated experience of (virtual) self-environment relationships through the somatechnical fusion of bio- and socio-physical properties in human-machine hybrids is presented. Accordingly, the article will name the specificity of each form of embodied intelligence and trace the conditions and peculiarities in the gradual increase of complexity from simple to interactive and finally to virtual bodily intelligence.

1. Introduction

A basic prerequisite for organic life is the organism's relationship to its environment as well as to other living beings as part of its experienced world. In this context, living beings with their properties do not buzz through the world as immaterial life forms, but are equipped with bodies that enable them to harmonise their needs with the challenges of the world, according to their perceptual and sensory specifications.

The research field of embodied intelligence has set itself the task of getting to the bottom of precisely these properties of organisms and recreating them in all their nuances through artificial life forms. The research field of embodied intelligence is a relatively young field that made its first attempts in the 1990s [1] and has gradually established itself as an inter- and transdisciplinary branch of research between computer science, biology, engineering, philosophy, and neuroscience. Parallel to the development in the technical sciences, a "body turn" took place in the humanities and social sciences, starting from the prevailing linguistic paradigm, where the body increasingly became the focus of consideration of entities that physically interact with each other or form practices in dealing with objects. Thus, here too, the pure consideration of language and linguistic idiosyncrasies or the focus on cognitive mechanisms of social relations was brought back to the foundation of bodily materiality, and in sociology the field of sociology of the body was established. As in so many areas of the natural and social sciences, the results of the

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two fields, which are intensively worked on in their own fields of research, have not been merged, although this merging of findings would be a great gain for the disciplines involved. As Pfeifer & Iida state, it can therefore be assumed that a bringing together of the findings from the different disciplines would lead to both a more sophisticated theoretical level and a more advanced practical knowledge for the application of the concepts in embodied intelligence research.

"With the fundamental paradigm shift from a computational to an embodied perspective, the nature of research topics, the theoretical and technical issues, and the disciplines involved have changed dramatically, or in other words, the "landscape" has changed completely." (Pfeifer & Iida 2003:1)

In their contribution "Embodied Artificial Intelligence: Trends and Challenges," Pfeifer and Iida [2] point to a paradigm shift from emulating information processes of higher cognition in computer science to an embodied perspective on intelligence through imitation of organic beings. Similarly, this article highlights the implications of the sociology of the body for robotics research and new findings on bodily properties for the technical imitation of embodied beings in environmental relationships. Insights into the fit of embodied technologies to everyday, socially habituated life situations reveal, on the one hand, undiscovered bodily as well as corporeal capacities for theorizing corporeal actors and, on the other hand, contribute to recognizing somatechnical hybrids as part of the body, the self, the alter ego, and even as part of society, from which new social practices emerge.

A step towards merging concepts of robotics and social research is taken in this contribution by extracting the basic levels of embodied intelligence research from the various research findings at this point and systematically relating them to each other. Accordingly, an overview of the basic forms of embodied intelligence research is given, followed by a proposal for determining their characteristics up to a leveling of their degrees of abstraction. In this way, it becomes visible to what extent embodied intelligence increases in complexity from lower order to higher order intelligence analogously to the degrees of cognitive intelligence and even keeps pace with the degree of abstraction of symbol processing in cognitive systems.

In the following pages, three levels of embodied intelligence are considered: first, *physical embodied intelligence* as reflecting a self-environment relationship in robotics; second, *socially embodied intelligence* as reflecting a co-world relationship in social encounters; and third, *embodied intelligence with somatechnically integrated objects* in terms of new embodied qualities emerging in the hybrid relationship between physical human-technology interfaces through effects of controllable technical extensions on the self-environment relationship and the co-world relationship.

2. Embodied Intelligence in Self-Environment Relations

In order to tap the potentials of controllable human-robot constellations as technical body extensions for the discovery of hitherto unrecognized basic capabilities of embodied intelligence in human actors, it is first necessary to gain an impression of the physical properties of organisms acting in the world. Therefore, the conditions for a stable self-environment relationship, which is aimed at in robotics research as a basis for imitating living beings, will be reproduced first. The approaches discussed in the workshop illustrate the detailed development of embodied entities acting in variable, local environmental situations, from the selection of materials for the flexibility of shape change (morphology) as the emulation of simple physical intelligence, to the selection of relevant information for obstacle-free navigation in the terrain (locomotion), to the estimation of distances, velocities, or pressure compensation, e.g., as forms of advanced bodily estimations of local situations with embodied intelligence. Robotics research draws on results from a broad inter- or transdisciplinary field of biology, neuroscience, engineering, biomechanics, material science, and dynamical systems to emulate living beings (cf. Pfeifer & Iida 2003:10) in order to understand the physical properties of system-environment relationships in everyday, real-world situations: "The reason for the strongly transdisciplinary character of Embodied Artificial Intelligence is that intelligence, especially embodied intelligence, has to do with behaviour, with interaction in the real world, and since we are dealing with physical agents, many aspects and components are involved: Materials, morphology, sensors, actuators, energy supply, control, planning, cognition and perhaps even consciousness." (Iida 2003:V) [3].

To successfully develop animated machines based on biophysiology, robotics advocates the "physical intelligence" (PI) or "embodied intelligence" (EI) approach and focuses on biomimetic simulations of living beings. Researchers in embodied intelligence research primarily refer to Pfeifer and Bongard [4] for the definition of embodied intelligence, who name a connection between the morphology of the body and the environment in relation to the action to be performed and propose the emergence of bodily-based intelligence from movement, locomotion, and manipulation abilities. Sitti [5] characterizes intelligence in autonomous machines in general as "(...) ability to perceive (sense, interpret), control (decide, plan, predict, regulate), act (move, change, affect, coordinate) and learn (adapt, evolve, acquire experience, infer) continuously and automatically" (2021:1) and physical/bodily intelligence in particular as "(...) physically encoding sensing, actuation, control, memory, logic, computation, adaptation, learning and decision-making into the body of an agent." (ibid.).

While Sitti names gestalt morphology as "physical intelligence" (PI) and thus a condition for the formation of embodied intelligence (EI), Pfeifer and Bongard as well as Howard et al.'s [6] definition of "embodied intelligence" includes the effect of bodily information processing on cognitive functions of e.g. decision making: "Natural life strives in unstructured environments through a specific type of intelligence known as 'embodied cognition'. Intelligent behaviour arises from a close connection between an agent's body and brain and the environment, not just the brain." [6]. This definition attributes intelligent behavior in unstructured environments to the coupling of body, cognition, and environment, and contrasts with top-down approaches to symbol processing that focus on behavioral instructions starting from higher cognitive process architectures to accomplish tasks. Kramer-Bottiglio defines the emergence of embodied intelligence as a bottom-up learning process in interaction with the entity's body constitution using the concept of "morphological computing" as follows: "Embodied intelligence is the idea of embodying an ability to learn or apply knowledge, which might include the adaptive morphology of agents." [7].

This requires a close relationship of the system to the events in the environment. The main principle of robotics research for modeling AI is thus: *True intelligence requires bodily interaction of the system with the real world*. Robotics aims to understand and reproduce the fundamental physical conditions that enable an actor to orient itself spatiotemporally and to adapt its shape and behavior to material environments, as well as to autonomously perform tasks in unstructured and complex real-world environments. To this end, it follows both ontogenetic and phylogenetic approaches as applied in the sub-disciplines of (evolutionary) developmental robotics, biorobotics, biomechanics, and morphogenesis. Together with developmental robotics, biorobotics or biomechanics strive to create viable organisms adapted to the environment. These branches study how certain behaviors and physical characteristics of real-world living creatures can be transferred to artificial agents. The research area includes studies on the distribution of tasks between materials of the body structure as well as on their morphology in the self-control of the organism in interaction with the environment. From this perspective, the basic behavior of organisms in self-environment relationships depends on the morphology, locomotion dynamics, self-organization by energy supply, and the forms of gestalt based on material properties of the organism that enable the engineered system to flexibly deal with complex environmental obstacles based on varying gestalt adaptations. Examples include obstacle avoidance through environmental mapping as well as autonomous responses, effortless navigation, orientation and path planning in rough terrain, or purposeful reaching for objects. A living organism surrounded by objects performs local interactions that are aligned with biological and physical laws of nature and can therefore be accurately measured and calculated for technical implementation. The challenge for robotics research in this area is to mimic a self-regulating and self-configuring entity at the level of low-threshold sensorimotor processes in order to achieve a basis for successful practical access to the world via flexible gestalt formations. If the robot is supposed to have the shape as well as the range of action of a human being, this requires a balance between the multilayered components of the sensorimotor control system, which in its totality of sensory stimuli must be regarded as a complex multimodal and multisensory system.

For example, an everyday task that is simple by our standards and that we perform automatically on the basis of habitualized action sequences, such as removing a water bottle from the refrigerator and

then filling a glass with water, requires a complex interaction between multisensory data: These are required to detect the refrigerator as a target object, to move to the refrigerator and open it, to maintain balance while opening and closing the refrigerator, to estimate the pressure balance while opening the refrigerator door, to visually detect and locate the water bottle, to perform an arm movement in the direction of the desired object, tactile fine motor skills in grasping the object, pressure equalization and resistance in grasping the object according to the weight and texture of the material of the bottle, observing the environment to avoid hitting a) the bottle or b) one's body against a fixed or moving obstacle when lifting out and stepping back, and other small-step, complex actions to put the water in a glass. It is this multimodal body-based system that links, processes, and mediates sensory stimuli with motor signals that, in its nature and function for the whole organism in relation to the environment, can be cited as a crucial moment for a next higher level of multisensory embodied intelligence. The more sensors are involved in the information acquisition, the more complex becomes the consolidation and evaluation of the data to be processed in parallel as well as the algorithmic calculation of the system reaction in the form of an environmentally appropriate action.

To relieve the limited computational capacity and energy supply, intelligent behavior should already be incorporated in the design of the form as well as the material structure (PI): Thus, sustainable smart materials are embedded in the hardware (the body) of the robot. This includes robust exoskeletons against collisions with the environment as well as a multi-functional and adaptable body morphology that interacts with the environment and, for example, draws its energy from the environment based on stimulus-responsive and programmable smart materials (Sitti 2021:3). Further, at the level of physical intelligence that is embedded in the gestalt, a flexible system can respond to environmental stimuli, including changes in material properties such as shape, volume, strength, density, thermal conductivity, or adhesion, and subsequently derive its own self-localization based on the self-position, self-motion, and self-awareness (proprioception) of body parts in relation to environmental conditions and translate this into subsequent actions (cf. Sitti 2021:5). The initial motto of robotics, "True intelligence requires interaction with the real world," is joined by an increase in embodied intelligence through the linking of diverse multisensory information, which AI researchers assume is the source of the emergence of consciousness in a further step. The combination of the variety of sensory information from self-environmental events should finally lead to the generation of possible subjective qualities as "qualia" in the form of lived experiences, emotions or motivations in technical systems [8].

From the above discussion of the sensitivities of body-based intelligence that prove to be obstacles in the attempt to technically reproduce living organisms, the foundations of a) basal physical embodied intelligence, based on the materials of gestalt, and b) embodied intelligence, based on the ability of the system to operate in environments, can be named.

Embodied intelligence manifests itself on a basic physical level in successful goal-directed action through autonomous and flexible adaptation of the gestalt to possibly resistant or changing environmental conditions (a). Here, the assumption becomes clear that a being has embodied intelligence when it, on the basis of diverse sensory information, acts autonomously in relation to its environment and, in doing so, is able to differentiate and regulate itself as a multisensory proactive self from what is happening in the environment (b) [9]. Thus, the degree of embodied intelligence required here is at a fundamental level in the interplay of multiple sensorimotor processes for self-control of an embodied sensory unit with the material world and shall be termed as *physical embodied intelligence*.

As explained above, the adaptation of organic and technical actors to dynamic environmental conditions is in itself a highly complex endeavor involving the support of physical-material properties, the evaluation of multisensory information, the design and capabilities of successful navigation, etc. Once the environment is populated by other self-moving actors, it means that the system is confronted with other systems acting with unpredictable route, speed, intensity or direction in the environment. This greatly increases the complexity of multisensory path computations. Moreover, these self-moving actors may not only present additional obstacles in the environment, but also interact with the computing system. This circumstance creates additional interfaces and necessities for linking self-regulating systems as interactive action systems or as multi-agent systems capable of acting collectively and generating

higher levels of embodied intelligence. The corresponding skills of embodied intelligence will be discussed in the next section on the embodied intelligence in co-world relations, making visible another component of subtle body-based knowledge.

3. Embodied Intelligence in Co-World Relations

As has become clear in the section above, the requirements for implementing embodied intelligence increase with the amount of sensory data, i.e., multimodal and multisensory data collection. Another component that points to an additional multi-layered form of embodied intelligence is social encounter. Based on rules for local system-environment interactions, embodied intelligence reaches its next level of complexity in co-environmental multi-agent systems or multi-party interactions. Here, the system shares the local environment with other systems with which it is able to perform relations or corporeal interactions. By focusing on physically co-present systems, which are themselves multisensory and can interact a) with the environment and b) with the system itself, additional further information for navigation as well as interaction activities of the system with the co-world arise, which include understanding of the social context and group dynamics for extended context perception and sense making. Through the social theoretical discussion of the physical-communicative conditions of social encounters, embodied intelligence will be addressed in the following section at a next-higher level of local physical environmental orientation. To this end, we will make comparisons with social beings living in the social world, elaborate the particularities of embodied intelligence in social worlds, and identify the bodily capacities that should be considered in the construction of socially acting technical beings. In doing so, the qualities of embodied intelligence in social beings are divided into the following: 1) subject-object differentiation, 2) perspective expansion to a common sense of world experience through a reciprocal expansion of the senses in interaction, and 3) a habituated sense for interaction.

3.1. Subject-Object Differentiation

While the replication of “physical embodied intelligence” focuses primarily on the analysis and reproduction of form, materiality, and successful navigation in the self-environment relationship of organisms, everyday experience shows that embodied intelligence comes into play not only in environmental actions, but also in social encounters and thus in co-worlds. If, for example, dogs meet each other on a dog run, they often approach each other, circle around each other or run together towards a goal. Further it does not remain with the four-legged friends to sniff each other or to bark to each other. In joint play, such as tugging on a stick, the rich detail of coordinated behavioral sequences becomes apparent, as does the coordinated action of an individual and the shifting of emphasis from movements to joint behavioral coordination. Structurally identical forms are observable in everyday interpersonal encounters between human such as moments of interaction and coordination, although the type of encounter differs from animal encounters [9]. Overall, the behavior between organisms that can relate to each other differs from moments of orientation of an actor to a purely material environment. For adequate acting in co-worldly relations, correspondingly further specific abilities of embodied intelligence are required than in the case of local interactions of embodied entities with the material world. Simply the skill to distinguish and recognize other potential social partners from mere objects in the environment, in order to then extend the self-environment reference to a self-co-world reference that includes the social partner, requires additional specific abilities of embodied intelligence through divergent discretionary powers of sense processing of perceptions. This distinction between a self, an external object, and another acting subject can be mentioned as an essential feature of embodied intelligence in the co-world relation.

The moment of (inter)bodily encounter is the basis for social processes in local co-worlds and thus crucial for the further analysis of embodied intelligence practiced in co-worlds. Lindemann calls this subject-object-differentiating moment of (interbodily) encounter with another bodily self in a shared situation “moment of touch” [10] and Breyer [11] speaks of “embodied empathy” when it comes to interpreting the other as a potential social partner in the “moment of touch” based on shape and bodily expressive behavior. The “moment of touch” refers less to the tactile touch of the actors, but rather to the initiating moment of contact, which, through the social and personal presence of an actor, evokes a

form of "affectation" on a social-perceptual level. This "moment of touch" is crucial when the ego encounters a social actor in the local situation (alter ego), i.e., in shared presence, and distinguishes him as a social partner from objects. In doing so, he can perceive the alter ego unilaterally as a being that is able to separate itself from the environment (indirect touch) - e.g., a searching animal in the forest - or to initiate a reciprocal perceptual relationship (direct touch). The latter, for example, in that the alter ego appears as a figure beckoning to him. Here ego recognizes this as a bodily expressive movement directed at itself, by which ego is "directly touched" and which it can follow up with further actions based on a bodily expression directed at the alter ego [10]. This moment of direct touch is subliminal and bodily inherently mediated, thus it is not grounded in a reflexive-cognitive thematization for sensuously locating the appearing gestalt as a social being. It is rather a form of tangible certainty as a drive for spontaneous bodily actions oriented to alter ego. Accordingly, direct perception in social encounters analogous to the mutual perception of bodily selves and the resulting possibility to influence each other is a key feature of social encounters. This ability to differentiate between subject and object is an essential moment of embodied intelligence in socially acting beings, which has to be implemented in the body architecture of social robots. In the next section, we will show to what extent the requirements for the implementation of embodied intelligence change in the transition from environments to co-worlds with respect to perspectival diversity, perceptual synergies, and the resulting common sense once the actors act as the "intermediate body" of ego and alter ego.

3.2. Co-Sensoriality, Con-Sensoriality, and Common-Sensoriality

According to Merleau-Ponty, the primacy of the social encounter lies in the dual aspect of perceptible and perceptual physicality as the basis of expression [12]. For example, by seeing that alter ego sees me, by feeling that he touches me, I can assume that alter ego perceives me, as it were. So, in this situation I feel myself as touching and by my touching I also feel alter ego and I know further about his foreign and self-perception towards me. With the awareness of the mutual touch, mutual orientation as well as reference to each other, the "double aspectivity" of the bodily perception is given. Even more, Merleau-Ponty explains the "living body" (Leib) as the foundation of "intercorporality", as a bodily analogue to an intersubjectivity based on sensory-mental processes [12].

Understanding thus becomes bodily understanding via shared (knowledge of) bodily perceptual practices. Intercorporality thus represents the bodily counterpart to intersubjectivity, which, in contrast to mental processes, derives its meaning from the praxeology of bodily co-world relations based on shared perceptions and their interpretations. The dual aspectivity of bodies creates the basic condition for a shared sense of the experienced material world and, together with the fusion into an intervening "interbody," is a feature of embodied intelligence in social encounters. Especially this fused co-world experience has to be technically realized in the implementation of robots in interaction settings, which is why a detailed social-theoretical elaboration of the perceptual convergences necessary to achieve "interbodyness" follows at this point.

So how exactly does such a bodily fusion of shared perceptions into a shared body proceed? Meyer [13] addresses subtleties of shared bodily perceptions in moments of incorporation by co-sensoriality, con-sensoriality, and common-sensoriality, underscoring essential bodily experiences in co-worlds. With these nuances, differences from physical embodied intelligence and the complexity for replicating embodied intelligence in social bodily encounters in technical gestalts become apparent. Co- and con-sensoriality in social encounters illustrate a) *multiplicity of perspectives* through alternating perceptual positions of actors, b) *synaesthetic perception* as an amalgamation of perceptual expectations, knowledge, and practice, and lead to c) agreement on shared (co-)semantics of co-/con-sensorial incorporated perceptions in *common-sensoriality* [12, 13]. Because of their potential for differentiation from the contents of incorporeal experiences of co-worlds as an essential point of socially embodied intelligence, the three aspects are briefly presented below.

Meyer emphasizes the co-sensory nature of the participants in social encounters, whereby the multi-sensory impressions of the individual actors complement each other and the situation can be experienced from a "multiplicity of perspectives" [12, 13]. For example, the perspectives of several parties on a

landscape complement each other during a hike or during communal work such as screwing on an engine or the like. The different, spatial standpoints of the actors towards the material environment mutually reinforce each other through the perspectives of the alter egos and lead to sensory intersubjectivity via perceptions of "kinesthetic, equilibrioceptive and proprioceptive dimensions, (...) thermoception, chronoperception, and (...) the presence or absence of body-internal aerial, liquid, or solid 'objects'" responsible for "'moods' and 'atmospheres', or the perceived 'sense of agency' and 'self-efficacy'" (Meyer 2021:3). Shared perception extends the first-person perspective and multimodal perception of situatedness to include the multiperceptivity of sensory impressions brought to bear through the encounter structure with alter ego, leading to a supervenient form of shared world-perception. On the one hand, this concerns the perception of the environment as a co-world as well as the shared sense of social experience. Aware that the alter ego is thirsty or in pain, for example, the overriding sense of the participant and the mood of the action is directed toward remedying the deficiency based on bodily realizations (finding something to drink or taking a break to rest the leg). In the co-sensorial dimension of intercorporality, the integration and adoption of alter ego's perspective into an overall picture of the social situation succeeds through (bodily) perspective adoption with alter ego as well as the shared and complementary world perception.

In addition to co-sensoriality, Meyer refers to con-sensoriality as the fusion of local-situational perceptions about physical experiences that participate in the situational apprehension of the world. This con-sensoriality is a kind of "apperceptive addition" (orig. "apperzeptive Ergänzung" [14]) to the given sensory impressions of the environment, in which one adds "cross-sensorial stocks of knowledge" [13] to what is perceived. "(...) when I perceive an object, such as a house from the front, the back is involved in this perception not merely as a possible perception which I judge could be produced if I walked around the house, nor as a necessary implication of the concept 'house.' Instead, the back is experienced as actually co-present—concealed but suggested by the appearance of the front" [Meyer 2021:5).

Similarly, Piaget's object permanence in children [15] establishes an apperceptive completion of world perception through knowledge of the constant presence of objects. Here the child learns; that an object is still present even when it is out of sight, e.g. in the case of a nutshell game, where a ball - hidden under a nutshell - is moved. Even when an object is occluded, knowledge of the permanence of objects in the world in the presence and absence of perception, as well as in changing spatial positioning, plays a prominent role in planning or actively executing individual or communal movements, and in understanding absent facts. With reference to Merleau-Ponty, Meyer further refers to "synesthesia," in which a sensory stimulus in one sensory modality triggers an additional perception in at least one other sensory modality and, in our cases, con-sensorially links the perceptions [13]. This means that when we look at an object, e.g., a steel measuring blade, the sharpness of the blade, the coolness of the metal, or the softness of the wooden handle are simultaneously delivered to us as con-sensory perceptions and appear to guide our actions. At the same time, the motor knowledge and memory about the required hand posture, grip technique, grip intensity and lifting force of the weight in the hand is given, which is different from the motor requirements, when picking a daisy. "We see a piece of glass, and our hand immediately knows how it must grasp it to raise it. We see its hardness and brittleness, and the same holds for other properties of materials. (...) Thus, our whole body is engaged in perception, preparing for taking up opportunities for action." (Meyer 2021:5). The con-sensory connection is essential for the "being ready-to-hand" [13] and for the conceivable execution of motor actions in relation to the object. More than this, through the synesthesia of perception, a knowledge of the properties of the object is conveyed that goes beyond mere current perception. Without this con-sensorial linkage of direct perception and implicit knowledge of the character of things in the world, all action would require constant re-experience of objects and the way we act with them. "Perceptual synesthesia" along with "apperceptive addition" of covert perceptual moments, when applied to robots, is already required for the physical embodied intelligence of motoric awareness and navigation, but finds further complexity of embodied intelligence in social encounters. What do such con-sensorial experiences of the world look like in social encounters? Con-sensoriality in intermediate actions enables bodily actors to act as a unity, as is evident in craft coordination work in teams, synchronized speeds in walking, or movement synchronizations or

gestalt fusions in couple dancing. In interbody connections with alter ego, we generate the atmosphere of a setting, knowledge of complementary courses of action or experience sensibilities based on con-sensory categorizations that we synaesthetically grasp and from which the situation is experienced on the multidimensional body level.

Already the co-sensorial "multiplicity of perspectives", which is fundamental for jointly coordinated actions in social encounters, illustrates the shared basis of perception and interpretation of material environments for social partners. The same is true for the communal convergence of con-sensorial perceptual synesthesia as soon as we e.g. glimpse the surface structure of an object or can estimate both the distance and the direction of a detonating object based on sounds. Co-sensorial and con-sensorial aspects illustrate that the world we relate to, as well as the expectations we have toward the interpretation of world, provide objective access to the world via shared sensory perception. The agreement on the convergence of sensory experiences via the co-sensorial addition of viewpoints to the diversity of perspectives as well as the simultaneous con-sensorial implication of perceptual synesthesias of human actors leads to an access to the environment and to the world that can be evaluated as objective. Meyer, following Hannah Arendt [13], calls this interplay of multiple perceptual implications in social interaction common-sensoriality or common sense, which offers us the objectifying basis for shared, bodily understanding. Accordingly, the interplay of co-, con-, and common-sensoriality is fundamental to embodied knowledge, the successful technical replication of which could capture essential moments of environmental and co-environmental sensoriality and provide key moments for intercorporeal encounters in interaction settings.

3.3. *Habitual Senses Of Perception In Interaction*

Following the multi-perspectival perception synesthesia, the embodied intelligence in social encounters manifests itself additionally through actively interrelated movement sequences in non-verbal and paraverbal moments of interaction. This includes spontaneous as well as ritualized encounter sequences, which are bodily realized through the application of social behavior codes such as non-verbal gestures, facial expressions, posture, personal distance through proxemics, the allocation of personal and spatial territories or also meta-linguistic properties of utterances such as tone of voice, volume or intensity of vocal utterances [16]. But how is it possible for social encounters to take place in an orderly fashion without the actors having to constantly reinterpret the social situation? In this regard, Gugutzer refers to Bourdieu's "practical sense" [17] or "Spürsinn" [18] for a situation: both mean a form of bodily intuition in which actors have the inherent ability to make right decisions according to situational requirements. Through the sense of intuition, the agent orients himself to the circumstances of the situation and succeeds in recognizing practical contexts of meaning and options for action on a bodily level. This sense of intuition acts as a pre-reflexive, bodily-practical sense guiding action and manifests itself by means of repeated routinized movements in unquestioned, everyday practices and finally results in habitual bodily knowledge. In the direct encounter of actors who are about to initiate a relation to each other, an almost automatic alignment and adaptation to the gestalt of the other takes place together with offers of interaction via expressive gestalts. In this process, actors face each other in their posture or adapt, for example, the width, or intensity of their gesture production to the distance or possible visual or auditory restrictions of the counterpart [19]. The adaptation of the individual thereby aligns itself almost bodily-intuitively with the perceptual skill of the other. This can vary from person to person due to limitations e.g. of sight, sounds or mobility and is thus bound to the social situation and the cooperative action context with an ongoing reconfiguration of kinesthetic information, e.g. by variations in the width of the gesture, the location of the sight, the volume of the address, the intensity of the grasp, walking speed or the like.

With regard to encounters with the world, the sense of intuition or "Spürsinn" is imparted as part of an existing, but historically variable cultural social order in the socialization process and serves as an instructive practical execution, for example, in that a sensitivity for socially appropriate physical proximity is present in social encounters [20]. Sociocultural imprinting forms thought patterns and knowledge stocks as habitus [17]. These habitually internalized and incorporated - in this case embodied

- bodies of knowledge now shape perceptions of the social world as well as of other- and self-bodyliness and guide decisions about action. Even though habituated bodily behaviors are learned and non-biogenetically anchored practices, at a subliminal-intuitive level they are embodied knowledge practices that are free from mental influences in their execution and help minimize the uncertainties of embodied socio-interactive behavior. In habitual, practical execution, free of reflective processes, one thus selects which objects and aspects of the situation are relevant for bodily action or in which way one interacts with the social world [17]. Accordingly, the practical sense assists in the coordinated co-worldly encounter with alter ego and the intermediate corporeality that unfolds as a result. The bodily intelligence that becomes immanent in co-world encounters is revealed in the “Spürsinn” for the motor-bodily demands of a social situation.

In accordance with sections 3.1 – 3.3 above, embodied intelligence includes, in addition to the sensorimotor level with physical self-environment reference, a “sociomotoric level” with co-world reference, found at the levels of perception (a), (b) praxeology, and (c) interaction. This on a fundamentally bodily, i.e., pre-reflexive, pre-mental level with the functions of a) perceiving other beings and distinguishing them from objects, b) experiencing the co-world in which the encountering actors meet “interbodily” and unfold shared perceptual and world interpretations through common actions, as well as c) forming an action-instructive sense for interaction units. Therefore, the question, “How do robots succeed in a) distinguishing social actors from environmental situations, b) combining multisensory self-perceptions with the complementary co- and con-sensory perspective diversity of alter egos to form a common sense with the objective world shared by human actors, and c) developing a practical “Spürsinn” to communicate with each other intuitively?” is significant for the formation of a technical, integral intercorporeality. Clearly, the simulation of social intelligence requires a sociomimetic replication of actors' capabilities that goes beyond the biomimetic construction of environmental relations. To what extent such a sociomimetic co-world could be replicated via extended embodied intelligence, is presented in the following, based on the concept of *sociomotorics* together with the principle of *suggestion of movement*, as a sense for situation-appropriate sequences of movements.

3.4. Application of Socially Embodied Intelligence to Robotics Research

The development of sociomimetic robots requires the modeling of fundamental epistemic features of socially embodied intelligence, which include at least the skills of subject-object differentiation as well as multimodal, multisensory, and multiperspectival perceptual synergies, copresence experience, intercorporeality, and a sense for normative expressions in interaction. On the basis of these criteria of embodied intelligence, a convergence of co- and con-sensory experiences to a common co-worldly context of meaning can succeed, which extends self-referential actions of physical embodied intelligence by the experience of a synergetically co-operating intermediate body.

Social actors, then, are mobile beings that are difficult to predict; they direct their movements both according to environmental conditions and their own motives, and in a coordinated way according to other beings. Encounters with other social actors thus increase the necessary complexity of a social robot's expressive behavior in situations that are now transforming from environment to co-world, and require the adaptation of embodied technologies to the follow-up actions of variable, moving bodies that, moreover, exhibit collaborative-interactive behavior. In co-worlds, the robot must now be able to extend its physical interaction not only to static environmental constants alone, but also to human-related environments (and objects of cultural value therein). Kinetic actions such as navigation, orientation, path planning, and motion control of autonomous systems accordingly require additional trajectory prediction that incorporates actor-centered “social navigation”. This includes the interpretation of bodily expressions and motion sequences like localization, the consideration of motion directions, dynamics and velocities, and many more. Consequently, sensorimotor skills, which have already played a prominent role for the self acting in an environment, expand in embodied intelligence in social encounters to a level that can be termed as “sociomotoric skills” [21]. In contrast to and in continuation of sensorimotor movement processes, which enable actors to navigate, act, and manipulate the environment as well as the surroundings and contribute to a delimiting experience of one's own body with its efficacy on

surrounding objects, etc., the orientation and coordination of movements on and with other socially enabled living beings is referred to as *sociomotoric skills* at this point. With sociomotoric skills, the sensorimotor feedback of perceptions through one's own movement is maintained, with the experiential component expanded to include experiencing through and with others - based on a social-kinetic component. The sociomotoric processes occur during the transition from the self-environment relationship to the co-world relationship and are the motor-kinetic basis for interbody cooperative actions. Sociomotoric actions include both the movements of actors with and toward each other, as well as their distances and postures, and the resulting overall gestalt that appears to the observer of social relations as "communication gestalt" [21]. The term "communication gestalt" refers to the gestalt-like wholeness that results from the interaction of the actors and is visible to the observer as a fused gestalt unit. It is the externally observable counterpart to intercorporeality.

In social robotics, it is precisely the translation from sensorimotor to sociomotor that allows the complexity of adapting motion components to be multiplied in real-time interaction scenarios. The robot must be able to act sociomotorically to cooperate in multi-agent environments, and at a subtle level of embodied intelligence to shape and coordinate its movements, body expressions, and interactions with others. At this point, the intertwining of sociomotoric skills with intercorporeality, intuitive "Spürsinn", and the necessary multisensory experience of multiperspectivity and perceptual synesthesia becomes clear. The technical realization of this extended motor activity could be the key for a convergence of sensory, bodily and world experiences to interbody sensoriality and thus for the basis of a (second level of) *socially embodied intelligence*. However, these contributions to a sense of communal "incorporation" or "compresence" still seem technically difficult to realize and model at the current state of research. Thus, for the development of social robots, the question is whether and how the intuitive "Spürsinn" and the associated sociomotor schema can be transferred to technical actors.

As a solution for modeling social involvement, which at least offers an approach to the mediation of sociomotoric sense, we would like to refer here to *suggestion of movement* (orig. "Bewegungssuggestion" [22]), which is oriented to norm-guided behavior in social situations and could contribute as a behavioral resource to select prefabricated movements. "Suggestion of movement" enables bodily engagement with environments and co-worlds, through "imposition of a movement that is felt in one's own body" [18]. It offers bodily impulses for coping with practical challenges and bridges the gap between the visible, the audible, the tactile and the bodily sensible, thus contributing to an intuitive way of dealing with the world. It is unimportant whether the suggestion comes from alter ego's movement, physical-mechanical or from something unmoved. Suggestions of movement relate directly to the inherent motor schema and guide instinctive-spontaneous bodily actions. They thus close the gap between multisensory, multiperspectival, and synesthetic-complementary perceptions to situationally appropriate actions in the surrounding and co-world, in that, following the multilayered levels of perception, movement impulses become accessible as practical solutions to local situational demands.

For successful human-robot interaction, the translation of social norms into sociomotor suggestions of movement is essential for robotic systems in human environments. Interaction is expressed in minimal physical units of action that enable culturally and collectively borrowed interpretive schemes and meaning attributions, thus providing rule-driven guidance for imitation. In other words, the normative set of rules makes it possible to select from a multitude of possible options for action and movement that follow-up behavior which is oriented to already established movement sequences. Rules that are influenced by culturally and socially accepted behaviors such as body distances, postures, length and intensity of touch or eye contact must therefore be included as sociomotoric suggestions of movement in the construction of a socially conforming robot behavior. Should this succeed, a behavioral architecture based on sociomotoric data would emerge, which could be oriented to established practices and meaning attribution by other social partners and could be updated in interaction. Accordingly, technical architectures with intuitive "Spürsinn" are needed that translate the plurality of multiperspectival and synaesthetic levels of perception into a socially-compatible world view and anchor recurrent suggestions of motion into bodily routines, a sense of behavioral norms, and ultimately bodily knowledge.

Conferring to the above, the socially embodied intelligence includes not only the conditions of the self's adaptability to complex environmental events, but also the additional inclusion of social behaviors, such as unknown movement paths and variable movement patterns of animate beings in co-worlds. Accordingly, modeling social embodied intelligence requires a perceptual and movement architecture that multiplies the complexity of environmental relations at various levels. Starting from the experience of a "moment of touch" for subject-object differentiation, we could see in sections 3.1 – 3.3 that technical systems with co-environmental references require enhanced navigation, perception and interaction capabilities and contribute to enhanced bodily experiences. Perspective variety and multisensory perceptual synesthesia provide the basis for a convergence of sensory experiences and, moreover, for inter-bodily shared world references as well as practical, situation-appropriate behaviour. Furthermore, for immediate moments of interaction, the body-intuitive "practical sense" was highlighted as 1) a selection instance of movement alternatives as well as 2) knowledge of contexts of meaning and action, and 3) sensitivities to "body arrangements" - such as the selection of nonverbal gestures from a pool of socio-motor suggestions of movement - for interaction. Finally, the sociomotoric behavioral architecture of socially embodied intelligence is highly complex and bound to the perception and realization of social events through selection processes of standardized movement sequences in interaction situations that are supposed to be technically reproduced.

4. Embodied Intelligence in Relation to Embodied Technologies

In the workshop presentations, it was emphasized that in teleoperated embodied technologies, such as robots, there is no embodied intelligence at play in the execution of movements or adaptations to the environment. In this case, there would be no autonomy and thus no intelligence provided by the mechanical algorithm for the robot's self-control. The dimension of embodied intelligence, however, manifests itself in another domain: namely, in the physical ability of the controlling teleoperator to adapt to the robot's shape, location, as well as situational requirements, and to successfully navigate it to another, distant location to meet the demands of the material and social world there. Here we see that embodied intelligence not only concerns the ability to control one's own body, but also includes the adaptation of objects up to and including virtualized bodies into one's own "body schema" [23]. These controllable somatechnical objects can thereby a) serve as extensions of one's own body parts (e.g. exoskeletons) or refer in embodied intelligence to b) a high degree of plasticity for adaptable body forms (into one's own body schema e.g. in remotely controllable robotic avatars). This becomes visible in the sensory, motor, and situational, i.e., bodily, fit of the controller to mechanical devices that operate in remote locations as independent entities [24]. Examples include controlled robots in inaccessible environments on exoplanets (e.g. Mars Rovers), in deep-sea exploration or drone operations, and social interaction robots in service or care robotics.

As explained in the section above, object recognition as well as encounters with embodied actors (be they technical or organic entities) are based on a fundamental and inherent level of embodied intelligence given in organic bodies. Both manipulations in the environment and in encounters with other social entities can therefore serve as examples of forms of embodied intelligence. The distinction between a self, an external object, and another acting subject is an essential feature of the embodied intelligence of social beings. Moreover, the distinction between an object that has no living properties and neither belongs to the self nor represents another self, and the perception of objects as part of one's own or another's body (e.g., in the case of prostheses, exoskeletons, wearables, or the like) has important consequences for the further analysis of stages and applications of embodied intelligence (e.g., in human-machine hybrids). If one considers the ability of humans to bodily adapt to the specific properties of various objects that function as a kind of "technically medialized in-between corporeality" [25], be it mere objects, tools or machines, up to prostheses, a mutability of our body in dealing with objects unfamiliar to the body becomes clear. A walking stick or a prosthetic leg change both the motor dimensions of the body, adapted to the resistance of the support, and the way the subject experiences himself and the world on the one hand, and how he is perceived by others on the other [26, 27]. At this point, another quality of embodied intelligence emerges, revealing the consequences of body-additive technologies as

additional, new and undiscovered capabilities of *embodied intelligence via somatechnically integrated objects* as well as relevant effects on the subjective and social experience of the body.

This "plasticity" as openness of the body for material extensions also allows us to adapt to the physical, sensorimotor, sociomotor, situational, and personal characteristics of teleoperated robots when controlling them [24]. Controllable robot avatars serve as surrogates for the physical presence of the controller and are intended to provide the experience of acting as a "cybernetic being" in interaction scenarios through "telepresence" or "teleexistence." They enable the controller to place himself in remote environments and to realize precise manipulations and interactions in remote scenarios by means of wearable control units or interfaces via real-time remote control.

In addition to technical applications of individual body parts (e.g., hand, arm, or leg prostheses), advanced interfaces also enable the connection of one's own body with whole-body surrogates equipped with bidirectional feedback on visual, haptic, acoustic, and kinesthetic levels, thus contributing to multisensory impressions for the user. The effects on the user resulting from the symbiosis of the technical body surrogates reveal previously unknown dimensions of embodied intelligence with somatechnically integrated objects, which can be divided into three levels: Firstly, into the effects of the physical body experience, secondly, into the subjective self-experience during the adaptation of an object-like body part, or to the shape of a body surrogate and further as an effect on the external perception as being a unique robotic identity [26]. Accordingly, the third form of "embodied intelligence with somatechnically integrated objects" experienced with technical body augmentations goes beyond the "physical embodied intelligence" as well as the "socially embodied intelligence" in social encounters, in that the altered physicality through object-like body additives or whole-body surrogates influences self-perception, self-presentation, situational perception, as well as social perception by others.

4.1. *Effects on Body, Self-Experience and Perception by Others*

Technical and neuroscientific findings on the effects of prostheses on individual body parts (see [28] for the example of the "Rubber-Hand-Illusion") or of whole-body surrogates on body experience (see e.g. "Body Ownership Transfer" [29, 30, 31]) indicate motor adaptations and multisensory integration of the mediated "body representation" into the teleoperator's own "body schema" [26], leading to the impression of "body ownership" and agency [32]. In this context, users indicate that they perceive sensory stimuli, such as touching the robot avatar a) from material environment and b) from other people touching the robot surface, as proprioceptive impulses during control. These sensory impressions, together with the synchronous movements of the robotic avatar, give the controller the impression that the avatar is an extension of his/her own body or that the touches are on/with his/her own body [33]. Others report alternating personal experience of a second body detached from one's own body, through which a self-transforming ego forms into its own telepresent actor [34, 35].

Thus, immersion in a robotic avatar already occurs at the perceptual level through the experience of synchronous sensorimotor activity of the avatar with the movements of the remote controller and expands to immersion in and identification with the robotic figure at a further interactive level together with the mediation of social-communicative resonance of the interaction partner [36, 37]. In this process, the degree of incorporation gradually increases to the point of personal transposition into the robot figure and communicative self-representations of the controller from the perspective of its own robot identity, which differs from the original identity of the controller [38]. Thus, initial technoscientific and sociological studies point to a transposition into the robotic avatar on a physical-bodily, personal, and social level: A) On the physical-bodily level, the controller experiences an inner-bodily expansion of sensory proprioception both when controlling individual limbs (e.g., prostheses) and when transferring to an avatar as a whole body, leading to a partial symbiosis of the technical apparatus with one's own body [39]. B) On the personal and social level, the technically embodied figure and the communicative staging have an additional effect on the fit of a narrative identity representation towards the interaction partner, which is oriented towards the characteristics of the technical figure [37]. This leads to a "fusion" between embodied technology and the organic body and thus to an inner corporeality that transcends the material and phenomenal "being".

This "fusion" resembles the interbody resonance between interaction partners, however, in this case it concerns a body unit between technology and organic body. Exactly this newly experienced corporeality leads again to a new body identification of the controlling person and thus to the extension of the personal identity genesis [for this concept see 40] by the new body characteristics, which leads also in teleoperated interaction scenarios to a new identity quality of the controlling person (on the basis of individual and social experience). In this case, embodied intelligence manifests itself in the incorporation of material-technical additions into bodily experiences of self, world, and other, and thus into the identity processes that originally transcend the body. Human users thereby animate the material body through their embodied knowledge, which becomes transferable between bodies with objects. This embodied intelligence with somatechnically integrated objects enables them to perform social actions towards remote interaction partners and to mediate their own form of (intermediate) corporeality via the body surrogate. In this way, an entity independent of the controller emerges for the interacting users, which conveys its own social identity [37].

To what extent the interbodily fusion of actors in human-robot interaction with technical objects succeeds and to what extent co- and con-sensibilities, common sense and a sense for sociomotor movement suggestions between the controller, the controlled robot avatar and the interaction partner emerge and are transferable cannot be dealt with here and strongly requires further empirical investigation in order to learn more details about the specifics of social encounters between controller, controlled agents and their interaction partners.

4.2. Embodied Intelligence by Technological Substitution of Selfhood

Embodied intelligence through technological body substitutions makes material augmentations accessible on two dimensions: a) inward (internal), to one's own body (e.g. through prostheses) and b) outward (external), through controllable body surrogates (avatars or wearables). Both forms of augmentation alter the phenomenally subjective experience of both the augmented body's affiliation to one's own body and the user's experience of identity to one's very own bodily identity. These results show the plasticity as multivariability of the body to material body augmentations that show effects on the bodily identification of the self [24]. This plasticity for material body extensions suggests an adaptation of bodily, personal and social spheres to remote situations within the modes of experience of one's own body and points to a third form of embodied intelligence with somatechnically integrated objects, more progressive than the physical and socially embodied intelligence, which enables bodily resonance via material body extensions and thus virtual dislocation of body, person and social encounters.

Robotic avatars irritate the bodily experience of the individual by superimposing a second body, acting in spatially distant situations, on their own corporeality. The technical surrogate enables the personal actor to extract genuine bioorganic properties of (proprio- and extero-) perception, kinesthesia as well as sensorimotor functions from his local, singular bodily environment. This allows him to perform actions according to his novel environment and co-world via the object-like embodied surrogate and to integrate these actions into his holistic bodily experience. Thus, embodied intelligence is manifested in the ability to incorporate "transbody technologies" into one's bodily structure, which is reflected in the adaptation of physiological and phenomenal experiences to the situatedness of the body surrogate.

This "immersion" in the robotic body demonstrates the plasticity of the corporeal self, which seems to be capable of accumulating subjective phenomena about distant bodily experiences by temporarily transposing itself into another body, self, situation, etc. The transference is associated with a felt presence of the self in the virtually transferred environment: Our ability to shift through other shapes enables us to experience "body transfer illusions" by technical means and to fully empathize with another body as well as to adapt to its own spatio-temporal conditions. This marks the experience of a new self-, time- and space-perception and shifts the experience of re-embodiment of the self, triggered by feeling with the other body, from a purely mental perspective-taking to an additional virtual bodily gestalt-taking and empathic-bodily dislocation. Somatechnologies dock with our unique embodied intelligence with their analog form, perceptual and expressive capacity and by mediating somatosensitive experiences. They enable us to break free from subject-centered constraints such as a single biography, an unchanging

body physiology or singular social identities through limited attributions of self-identity via a single body and simple, monolocal world references.

Thus, embodied technologies (at least temporarily) dissolve the assumption of enduring core identities [35] not only at the personal level, but also perspectives limited to monolocal corporeality, revealing that the self instead appears dynamically as a constant response to multifaceted bodily-perceptible experiences in environmental and co-environmental relations. Physically immersive technologies thus abolish monolocal subject-object relations and reveal open boundaries to the multilocally shaped genesis of the bodily and identitary self. It becomes clear that the self is able to decenter itself from its own body and to enter into an interplay with materials, which enables an autonomous self-perception that deviates from one's own body. Thereby the experience expands from the present environment to an experience of the world, which stands apart from the spatio-temporal and bodily concordance of a local co-presence and can be dispersed in mediable "multiverses".

What is otherwise made possible in reflexive cognition and communicative use of symbols capable of abstracting from the present to the absent [14], can also be experienced on a bodily level through embodied intelligence with somatechnically integrated objects. Accordingly, the body is capable of symbolic abstraction, as it were, to have bodily experiences that are removed from the here and now, and to sense decentralized, multiversal local atmospheres through body surrogates elsewhere (for the term "atmosphere" see [41]). This experience of decentralized displacement of bodily life through internal and external techno-material augmentations characterizes humans as beings capable of multibodily, multilocal, and multimaterial world experience and world adaptation, as well as multiple, alternating forms of identity. The virtual ability to move to distant places and into other bodies is thus a high-level achievement of embodied intelligence that abstracts from the "here and now" and allows us to be present and bodily involved in distant places.

4.3. *Concluding Remarks*

Through technologies that transcend the boundaries of the phenomenal self and the distinctions between one's physical and virtually simulated body as well as the local and mediated environment, we experience the paradox of being one self and simultaneously in the guise of another [35]. Here, the specificity of the gestalt for self-perception and self-presentation of a personal identity becomes clear. It is characterized by new techno-physical impressions and induces the user to adopt a personal nature analogous to the gestalt's traits (see the concept of the "Proteus effect" in [42]).

The embodied intelligence thus becomes visible on another level. In addition to the environmental and co-environmental reference, distant virtual worlds become primary realities, and through multisensory adaptation to the technical gestalt, practices of simulating ways of acting and ways of experiencing the world change. By experiencing partial material gestalts as self-originating, the plasticity of intra-structural bodily representations becomes visible through the entanglement of corporeality and materiality through controllable somatechnologies [43, 44]. The malleability of bodily experiences and their transferability to material body surrogates reveal the limits and possibilities of body technologies and map undiscovered properties of embodied intelligence in human-machine hybrids, which include a diversity of self-concepts and the formation of a new, genuine identity for the technically embodied gestalt.

Consequently, it can be postulated that the physical, personal, environmental, and social shifts of experiences and perceptions toward an external, controllable body are extended features of a higher-level embodied intelligence with somatechnically integrated objects. The teleoperation of embodied technologies is thus an example of embodied actions, which consequently cannot be reduced to purely human activities, but are realized as hybrid human-technology actions [45].

For technically mediated self-environment relations, we thus assume that the combination of organic properties with technical body surrogates leads to extended experiences of one's own body, environments as well as co-environment relations. In these bodily-technical constellations, the almost full performance potential of organic bodies and thus of embodied intelligence is revealed in the sense that a (bodily-structurally and) functionally analogous, technical body is able to suspend the immediacy of

bodily and environmental contexts in favor of manifold, bodily self-experiences. Consequently, this means that the self with all its properties can be multiplied and that the levels of embodied intelligence of organic bodies can also be transferred to material body surrogates together with their relation to self, environment, and co-world.

In this view, the potential of bodily experiences is corresponding to expanded cognitive capacities, as evident in symbol theory in the transition from representational sign use to abstracting symbol use [14, 46]. Similarly, the experience of distant environments in technically mediated bodies exceeds field perception purely related to the body in the here and now (synonymous with representations) and transcends it through technical shifts into virtual, distanced body-surroundings (synonymous with symbolic thinking). This paper thus assumes that the embodied intelligence of the human being fully unfolds in parallel with the expansive forms of the body in (technically) expanded relations to distant environments and co-worlds, where it is further extended and endowed with new properties. To what extent this gradation of forms of embodied intelligence into object-worldly, social-worldly, and virtual displacement capacities is analogous to the subdivision from lower to higher levels of cognition [47], or what further peculiarities it holds, is to be examined in more detail elsewhere. This paper, however, already shows evidence for the increase of levels of embodied intelligence from a) *physical embodied intelligence* by simple rules in "local interactions" with objects (low-level sensorimotor processes) via b) *socially embodied intelligence* as more complex adaptations to social-specific behavior and bodily experience in "moments of touch" in social encounters as well as by means of rule-based normative expectations in social interactions up to c) high-level *embodied intelligence with somatechnically integrated objects* as advanced displacement ability in technical-material bodies, operating in distant, virtual worlds where they have real-world effects on projected self-concepts, environments, and co-worlds.

This investigation of forms and properties of embodied intelligence is intended to contribute to the differentiation of various situation-specific performance potentials that should be considered in the design of social robots as well as controllable robotic avatars. The differentiation is a first step towards the multi-layered and interwoven performance characteristics that a technical system should exhibit when using embodied intelligence. Thus, this study represents a first draft of a holistic concept of inter- and transdisciplinary research on embodied intelligence, which will certainly be complemented by further results in the coming years.

References

- [1] Brooks, R.A., and Stein, L.A. (1993). Building brains for bodies. Memo 1439, Artificial Intelligence Lab, MIT, Cambridge, Mass.
- [2] Pfeifer, R. & Iida, F. (2004). Embodied Artificial Intelligence: Trends and Challenges. In F. Iida (Ed.), Embodied artificial intelligence: International seminar, Dagstuhl Castle, Germany, July 7 - 11, 2003 ; revised selected papers (S. 1–26). Springer.
- [3] Iida, F. (Hrsg.). (2004). Embodied artificial intelligence: International seminar, Dagstuhl Castle, Germany, July 7 - 11, 2003 ; revised selected papers. Springer.
- [4] Pfeifer, R., & Bongard, J. (2007). How the body shapes the way we think: A new view of intelligence. A Bradford Book. MIT Press.
- [5] Sitti, M. (2021). Physical intelligence as a new paradigm. Extreme Mechanics Letters 46, 101340.
- [6] Howard, D., Eiben, A. E., Kennedy, D. F., Mouret, J.-B., Valencia, P. & Winkler, D. (2019). Evolving embodied intelligence from materials to machines. Nature Machine Intelligence, 1(1), 12–19.
- [7] Kramer-Bottiglio, R. (2021). Is it or isn't it: Embodied Intelligence? (this volume).
- [8] Lewis, C. I. (1990). Mind and the world-order. Outline of a theory of knowledge. New York, NY, Dover Publ.
- [9] Plessner, H. (1975). Die Stufen des Organischen und der Mensch. De Gruyter.
- [10] Lindemann, G. (2014). Weltzugänge: Die mehrdimensionale Ordnung des Sozialen (1. Aufl.). Velbrück Wiss.
- [11] Breyer, T. (2015). Verkörperte Intersubjektivität und Empathie: Philosophisch-anthropologische

- Untersuchungen. Philosophische Abhandlungen: Band 110. Vittorio Klostermann.
- [12] Merleau-Ponty, M. (1974). *Phänomenologie der Wahrnehmung*: Übersetzt von Rudolf Boehm (1966. Aufl.). *Perspektiven der Humanwissenschaften*. De Gruyter.
- [13] Meyer, C. (2021). Co-sensoriality, con-sensoriality, and common-sensoriality. *Social Interaction. Video-Based Studies of Human Sociality* 4 (3).
- [14] Bühler, K. (1982). *Sprachtheorie. Die Darstellungsfunktion der Sprache*. 1934. Aufl. Stuttgart, G. Fischer.
- [15] Piaget, J. (1974). *Der Aufbau der Wirklichkeit beim Kinde*. Stuttgart, Klett.
- [16] Hall, J. A. & Knapp, M. L. (2013). *Nonverbal Communication*. De Gruyter.
- [17] Bourdieu, P. (1987). *Die feinen Unterschiede. Kritik der gesellschaftlichen Urteilskraft*. Frankfurt am Main: Suhrkamp Taschenbuch Wissenschaft.
- [18] Gugutzer, R. (2002). *Leib, Körper und Identität. Eine phänomenologisch-soziologische Untersuchung zur personalen Identität*. Wiesbaden, Westdt. Verl.
- [19] Hall, E. T. (1982). *The hidden dimension*. New York, Doubleday.
- [20] Berger, P. L. & Luckmann, T. (1980). *Die gesellschaftliche Konstruktion der Wirklichkeit: Eine Theorie der Wissenssoziologie*. Fischer-Taschenbücher: Bd. 6623. Fischer-Taschenbuch-Verl.
- [21] Straub, I. (2020). *Zur Sozialität und Entität eines androiden Roboters: Empirische Zugänge zum Objekt- und Subjektstatus*. Springer VS, Springer Fachmedien Wiesbaden.
- [22] Schmitz, H. (2005). *Situationen und Konstellationen. Wider die Ideologie totaler Vernetzung*. Freiburg/München, Verlag Karl Alber.
- [23] Gallagher, S. & Cole, J. (1995). Body Image and Body Schema in a Deafferented Subject. *The Journal of Mind and Behavior*, 16(4), 369–390.
- [24] Straub, I. (2022): Leibliche Exzentrierung über technisch einverleibte Selbste. In: Barth, J. & Henkel, A. (Eds.): *Leib. Grenze. Kritik*. Weilerswist: Velbrück Verlag, 206-215.
- [25] Meyer, C. (2020). *Intersubjektive Entfremdung: Zur Kultur- und Technikgeschichte der Zwischenleiblichkeit*. In: Kurilla, R., Kolb-Albers, K., Krämer, H., Pitsch, K. (Eds.): *Sine ira et studio. Disziplinenübergreifende Annäherungen an die zwischenmenschliche Kommunikation*. Wiesbaden: Springer VS, 187-211.
- [26] Preester, H. de (2011). Technology and the Body: The (Im)Possibilities of Re-embodiment. *Foundations of Science*, 16(2-3), 119–137.
- [27] Meyer, C., Streeck, J. & Jordan, J. S. (Eds.). (2017). *Foundations of Human Interaction. Intercorporeality: Emerging socialities in interaction*. Oxford University Press.
- [28] Botvinick, M. & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, 391 (6669),
- [29] Braun, N., Debener, S., Spychala, N., Bongartz, E., Sörös, P., Müller, H. H. O. & Philipsen, A. (2018). The Senses of Agency and Ownership: A Review. *Frontiers in psychology*, 9, 535.
- [30] Ehrsson, H. H. (2020). Multisensory processes in body ownership. In Sathian, K., Ramachandran, V. S. (Hrsg.), *Multisensory Perception: From Laboratory to Clinic* (p. 179–200). Elsevier.
- [31] Nishio, S., Taura, K., Sumioka, H. & Ishiguro, H. (2018). Body Ownership Transfer by Social Interaction. In H. Ishiguro & F. Dalla Libera (Hrsg.), *Geminoid Studies* (p. 317–328). Springer Singapore.
- [32] Jazbec, M., Nishio, S., Ishiguro, H., Kuzuoka, H., Okubo, M. & Penalosa, C. (2017). Body-swapping experiment with an android robot: Investigation of the relationship between agency and a sense of ownership toward a different body. In *2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (p. 1471–1476). IEEE.
- [33] Cole J., O. Sacks, and I. Waterman (2000). On the Immunity Principle: A View from a Robot. *Trends in Cognitive Science*, 4(5), 167–168.
- [34] Dolezal, L. (2009). The Remote Body: The Phenomenology of Telepresence and Re-Embodiment. *Human Technology: An Interdisciplinary Journal on Humanities in ICT Environments*, 5(2), 208–226.
- [35] Jarvis, L. (2019). *Immersive Embodiment: Theatres of Mislocalized Sensation*. Springer eBooks

- Literature, Cultural and Media Studies. Palgrave Macmillan.
- [36] Straub, I., Nishio, S. & Ishiguro, H. (2018). At the Café—from an Object to a Subject. In H. Ishiguro & F. Dalla Libera (Hrsg.), *Geminoid Studies* (p. 399–411). Springer Singapore.
- [37] Nishio, S., Taura, K., Sumioka, H. & Ishiguro, H. (2013). Effect of social interaction on Body Ownership Transfer to teleoperated android. In *2013 IEEE RO-MAN* (p. 565–570). IEEE.
- [38] Straub, I. (n. d.). Über die Verkörperung einer eigenen Roboter-Identität: Zur kommunikativen Emergenz einer Roboter-Identität über Teleoperierende und Interaktionspartner von sozialen androiden Robotern. Unpublished manuscript.
- [39] Ihde, Don (2010). A phenomenology of technics. In Craig Hanks (ed.), *Technology and Values: Essential Readings*. Wiley-Blackwell.
- [40] Masumori, A., Maruyama, N., & Ikegami, T. (2020). Personogenesis Through Imitating Human Behavior in a Humanoid Robot "Alter3". *Frontiers in Robotics and AI*, 7, Article 532375.
- [41] Schmitz, H. (2011). *Der Leib*. Grundthemen Philosophie. De Gruyter.
- [42] Yee, N., Bailenson, J. N. & Ducheneaut, N. (2009). The Proteus Effect. *Communication Research*, 36(2), 285–312.
- [43] Lewis, E. & Lloyd, D. M. (2010). Embodied experience: A first-person investigation of the rubber hand illusion. *Phenomenology and the Cognitive Sciences*, 9(3), 317–339.
- [44] Maister, L. & Tsakiris, M. (2016). The plasticity of self-other boundaries: From body ownership to social cognition. In M. H. Fischer & Y. Coello (Eds.), *Foundations of embodied cognition* (S. 182–199). Routledge.
- [45] Rammert, W., Schulz-Schaeffer, I. (2002). Technik und Handeln - Wenn soziales Handeln sich auf menschliches Verhalten und technische Artefakte verteilt. In: Rammert, W. & Schulz-Schaeffer, I. (Eds.), *Können Maschinen handeln? Soziologische Beiträge zum Verhältnis von Mensch und Technik*. Frankfurt am Main: Campus-Verlag, 11–64.
- [46] Peirce, Charles S. (1985): Über Zeichen. In: Charles S. Peirce (Ed.): *Die Festigung der Überzeugung und andere Schriften*. Ungekürzte Ausg. Frankfurt am Main, Berlin, Wien: Ullstein, 143–168.
- [47] Gennaro, R. J. (Ed.). (2004). *Advances in consciousness research: v. 56. Higher-order theories of consciousness: An anthology*. Benjamins.