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MACS

Multi-sensory Autonomous Cognitive Systems Interacting with Dynamic Environments for Perceiving and Using Affordances

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EU Project MACS

Deliverable D4.1.1

A Conference or Journal Article Summarizing the Results of Task 4.1

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1 Introduction

The idea of affordances, first introduced by Gibson [Gib79], has taken on a life of its own in recent years where the term has been used to denote many different ideas and concepts. Some uses of the term coincide with what Gibson had in mind, other uses are in the spirit with what Gibson had in mind but extend the ideas, and finally, some uses of the term have little to do with Gibson's original motivations. To add to the difficulty, some literature has a great deal to do with affordances without actually referring to the term and for those articles that do use the term, these are spread across a great many research disciplines. The idea of affordances and ideas which extend Gibson's thoughts have influenced many different scientific disciplines, for better and for worse.

The original intent of this deliverable was to survey the use of the idea of affordances in different disciplines and produce an integrated survey of the idea which would then be used as a basis for publication at a later date as a conference or journal article. We were quite surprised at the vast number of articles pertaining to and purported to pertain to the affordance idea and were quite simply overwhelmed with the quantity and confusion regarding the topic matters associated with affordances.

Our strategy has been to go through a great many articles, 70-100, and to choose some of those representative of the articles associated with each of the disciplines in which they arise. We do not believe it is advisable to write a cohesive survey article until all this material is digested and analyzed in the light of empirical experimentation which will be initiated in this project with robotic systems. We simply need more experience and insight into these issues before producing a final survey article. This being the case, for the deliverable in question we have chosen 30 or so articles and provided summaries of them with comments pertaining to the use of the ideas in these articles in the areas associated with the MACS project. We believe this approach provides a firm basis for pursuing the topic concretely for the duration of the project. We will continue to add to this collection as the project progresses.

The type of articles which focus on affordances as a topic can be broken down into the following general groups

- Neuroscience
- Psychology (In particular Ecological and Cognitive Psychology)
- Ethology
- Philosophy (In particular discussions concerning the representationalist/non-representationalist debates in AI and cognitive psychology)
- Design
- Perception
- Robotics
- Artificial Intelligence and Computer Science
- Machine Learning

There is obviously overlap between the groups and it is not always clear what group or groups an article should be classified under. The latter three groups are the most relevant for this survey and the first five may be viewed as offering background and intuitions about the affordance topic.

MACS-WP4 focusses on the following aspects associated with affordances

- Knowledge Representation – What type of representational structures would be required for modeling affordances in a robotics architecture? How do these structures relate to robot behaviors, actions and plans? How should a robot's embedding environment be modeled? How should the interaction between robot and environment be modeled?
- Robotic Architectures – How may the representational structures associated with affordances be integrated into robotic architectures and how may the robotic architecture support use of and inference with affordances?
- Grounding and sensing – How can affordances be grounded in a robotic system and integrated with sensor to symbol processes associated with deliberative/reactive robotic architectures?

As a first step in generating a high-quality survey of the affordance concept which focusses on robotics, knowledge representation and machine learning aspects, we have chosen to first put together an annotated bibliography of articles of interest which includes a synopsis of each article. The synopsis is intended to emphasis the three aspects mentioned. Note that we have not done justice to the great many articles published in the Journal of Ecological Psychology, primarily because we have had no subscription to the journal and it has been difficult finding many of the articles on the WWW. We will add additional material from the JEP as the project progresses. Note also, that another MACS deliverable D5.1.1, covers a number of machine learning articles pertaining to affordances that we exclude from this survey.

2 Annotated Bibliography

Article: Achieving Generalized Object Recognition through Reasoning about Association of Function to Structure
Authors: Louis Stark and Kevin Bowyer
Type: Perception, Robotics, AI
Reference: [SB89]

Synopsis:

Main idea: The main idea in the article is to define an object category in terms of the functional properties shared by all objects in the category. This is intended to contribute to generalized object recognition.

Article summary: The authors describe an implemented system for object recognition of chairs based on functional descriptions of categories and subcategories rather than structural descriptions used in model-based object recognition where paramterized CAD-like models are stored in a database. In the authors system, a boundary description of an unknown 3D polyhedral object in terms of face lists and vertex coordinates is taken as input to the system. An attempt is then made to attach functional labels to the parts of the object by traversing through a category representation graph containing procedural knowledge primitives (PKPs) representing generic functional requirements for the categoies in question. An association rating or score is provided and if it is high enough, the system recursively traverses the graph checking whether functional constraints are met. The system does quite well for the category "chair" when compared against what human users would categorize as chair among 100 or so examples.

Relation to Robotics: The paper offers a novel way to think about object recognition in terms of functional rather than structural descriptions and has some similarities with a high-level notion of affordance as the functional or use component of an object.

Relation to KR: Both the structures used for functional description and the hierarchical graph structure used to dually describe categories and serve as a control structure are useful ideas.

Relation to Machine Learning: One would obviously like to machine learn functional correlations with physical structure, but the abstractions described here are most probably specified at a too high a level.

Article: Situated Action: A Symbolic Interpretation
Authors: Alonso H. Vera and Herbert Simon
Type:
Reference: [VS93]

Synopsis:

Main idea: The authors reply to a number of claims made by the situated action (SA) movement whereby humans and their interaction with the world can not be understood using symbol systems models and methodology but only through nonsymbolic models of them. The claim is that this is simply a misunderstanding about physical symbol systems.

Article summary: This highly cited article is a response by Vera and Simon to many claims made by proponents of the situated action movement in the early 90's which the authors claim misinterprets at least their understanding of symbol systems methodology and modeling. They provide a brief summary of physical symbol systems and re-trace

the origins of the situated action approach to modeling human - environmental interaction. they cover the work of Winograd and Flores, Suchman, and Gibson (to a lesser extent). Regarding affordances, they claim that Gibson was wrong about the notion of direct perception and affordances being in the environment. They claim that the thing corresponding to an affordance is a symbol stored in central memory denoting the encoding in functional terms of a complex visual display. They show how vieweds this way, a functionalist view of objects in the environment can be modeled with such triggers as symbols in production rules. They also go on to analyze a number of then current research projects in AI: They argue that NAVLAB combines both symbolic and SA type modeling and claim that it is in fact a physical symbol system. They also argue that Brooks Creatures are and the subsumption architectures on which they are based are also physical symbol systems.

Relation to Robotics: Certainly an interesting discussion which illuminates a number of issues pertaining to direct and indirect representations. Also discusses a number of "robotics" architectures.

Relation to KR: They show how from their point of view, functionalist modeling can be represented using production rules and PSS's.

Relation to Machine Learning: No direct relation.

Article: Representations Between Internal and External
Authors: Alberto Gatti
Type: Philosophy, Cognitive Psychology
Reference: [Gat]

Synopsis:

Main idea: The author provides some reflections on the representationalist (physical symbol systems) and anti-representationalist (Brooks subsumption architecture) views towards representation and its role in cognitive robotics systems. He also compares affordances with direct representations.

Article summary: The author compares the representationalist stance epitomized by the the work of Newell and Simon with physical symbol systems and that of Brooks with his subsumption architectures. In doing this, he tries to clarify the view of symbol as proposed by Vera and Simon in an article about situated action philosophy and points out that the very general definition of symbol proposed by Simon obscures a distinction between a symbol and what it designates (the arbitrariness of the mapping) that others take for granted. If this distinction is made explicit as it is by Touretzky and Pomerleau then this would exclude as being symbolic analogical relationships with external referents since the mapping is non-arbitrary. The author than goes on to discuss Vera and Simon's view of affordances and claims that the issue of affordances involving symbolic encodings of the functional role played by physical situations is not at all as clear cut as Vera and Simon make it out to be. The author also briefly discusses the epistemic role of certain types of actions.

Relation to Robotics: No direct relation, but intuitions.

Relation to KR: No direct relation, but good intuitions regarding the status of affordances relative to symbolic systems.

Relation to Machine Learning: No direct relation.

Article: Affordances: Clarifying and Evolving a Concept

Authors: Joanna McGrenere and Wayne Ho
Type: Design
Reference: [MH00]

Synopsis:

Main idea: The authors believe that the original definition of affordance as proposed by Norman was ambiguous and has caused much confusion in the HCI community. They look more closely at Gibson's original definition and propose an extension to it with a clear distinction between usefulness and usability. They also introduce the idea of a degree of affordance.

Article summary: Norman popularized the idea of affordances in the HCI community and offered a definition which both implicitely and explicitly adjusted the meaning as given by Gibson. The authors believe that the original definition has caused much confusion and try to clarify the difference between what Gibson proposed and what Norman appropriated. Norman's shift was to state that an individual's perception of a property of an object is still an affordance even if that property is not an actual property; that affordances refer primarily to fundamental properties of objects; that there is no actor as a frame of reference for perceiving an affordance; and that the existence of an affordance is in fact dependent on an actor's experience and culture. Norman of course states that he is deviating from Gibson's original ideas and later adjusted his definition not to coincide with Gibson but to make his ideas clearer to the HCI community. The authors then analyze the different uses of the term "affordance" in papers in the HCI community. Based on work byu Gaver, the authors believe it is important to distinguish two stages in design: that of designing affordances and that of designing the information that specifies an affordance. They use the terms usefulness and usability to make the distinction, respectively. This disinction coincides nicely with Gibson's separation between the affordance in the environment and the information (in the ambient optical array) which conveys the affordance. based on this distinction, the authors propose a new twist to the definition of affordance in HCI by introducing degree of affordance distinctions.

Relation to Robotics: No direct relation.

Relation to KR: No direct relation, but a good clarification of various distinctions in use in different communities.

Relation to Machine Learning: No direct relation

Book: Introduction to AI Robotics
Authors: Robin R. Murphy
Type: Robotics, Artificial Intelligence
Reference: [Mur00]

Synopsis:

Main idea: The main idea of the book is to provide a general overview of robotics, in particular the current state of the art relative to architectures. Both reactive and hybrid architectures are considered.

Book summary: This book is intended to provide an overview of the principles behind an Artificial Intelligence approach to robotics. The part of the book that is relevant to affordances is chapter 3 on "Biological Foundations of the Reactive Paradigm". The author starts by considering animal behaviors which are defined as a mapping of sensory inputs

to a pattern of motor actions which are then used to achieve a task. Behaviors are divided into three categories; reflexive behaviors are stimulus-response (S-R); reactive behaviors are learned; and conscious behaviors are deliberative. The reactive robotic paradigm primarily uses reflexive and to a lesser extent reactive behaviors. The author discusses the work of Lorenz and Tinbergen, in particular their study of the coordination and control of animal behaviors which they named *innate releasing mechanisms*. An IRM assumes a specific stimulus which releases or triggers a stereotypical pattern of action. A releaser activates a behavior and sets into motion the sensory input to motor action coupling. Consequently perception plays two functional roles, releasing a behavior and perceiving the information needed to accomplish behavior. Gibson's affordances are then discussed and defined as "perceivable potentialities of the environment for action". Finally, schema theory is introduced, in particular that used by Arbib. A behavior is then defined as a schema which consists of a perceptual schema embodying the sensing, a motor schema representing the template for physical activity and a releaser which triggers the behavior. The author then argues that affordances may be used for both releasing behaviors and as the sensory input to the perceptual schema. Neisser's distinction between direct perception (Gibson) and recognition is also briefly discussed.

Relation to Robotics: Direct and strong relation to robotics although the book is scarce on details since it is an overview.

Relation to KR: Some relation to KR in that hybrid deliberative/reactive architectures are considered and traditional sense-plan-act pardigms are played off against reactive paradigms.

Relation to Machine Learning: Some discussions of ML associated with robotics are discussed.

Article: Affordances, Conventions, and Design
Authors: Donald A. Norman
Type: Design
Reference: [Nor99]

Synopsis:

Main idea: The main idea of the article is to shed light on the great variety of confusion in the HCI community concerning what an affordance is and is not. Norman makes an important distinction between affordances (a la Gibson) and perceived affordances which he has in mind as being most important for design and which although related to real affordances add a new twist on the topic in the the context of design.

Article summary: In this short article, Norman tries to clarify what he actually means by affordances, conventions and constraints, since he has observed much confusion as to the meaning of the terms in the design community. The first point made is that a distinction should be made between "real" and "perceived" affordances. In the sense of Gibson, "real" affordances refer to actionable properties between world and actor. These exist naturally and do not have to be visible, known or desirable. In "The Psychology of Everyday Things", a theme proposed by Norman was that the physical appearance of of devices provide critical clues required for its proper operation. Perceived affordances are the visual feedback which advertise affordances (whether they are their or not). It is this concept that Norman is most concerned with. In Gibson's work, a similar implicit distinction is made between the affordance which is out there in the physical world and the

visual feedback (associated with the ambient optical array) that advertises the feedback for those actor's that have the sensory and physical capabilities to pick-up on these cues. Norman tries to clarify this distinction by taking examples from screen-based interfaces. He concludes that in the next revision of POET, all references to affordances will be replaced by "perceived" affordances to avoid any confusion with terminology.

Relation to Robotics: Indirect.

Relation to KR: There is some relevance here since Norman's considerations move beyond standard Gibsonien affordances and directly attack the problem of real objects and their relation to actors via both affordances and perceived affordances.

Relation to Machine Learning: No direct relation.

Article: Automatic Object Recognition within an Offics Environment
Authors: Michael Wünstel and Reinhard Moratz
Type: Robotics, Perception
Reference: [WM04]

Synopsis:

Main idea: The authors use the idea of deriving function from form and using that function/form association for object recognition. The work is based on the concept of affordances and uses laser scanning technology.

Article summary: The authors relate the work of Stark and Bowyer [SB89] to object recognition using a SICK laser range scanner as main sensor. The objective is to do object recognition in an office environment. They introduce a system ORCC (Object Recognition using Cognitive Computing) with three fundamental processes. There is a data acquisition phase which generates a 2.5D scanning pictue of a scene which is then converted into 3D data using the position and resolution information of the scanner. In the object modelling step, the 3D data is sliced into several layers with each then being segmented. The object classification stage then tries to relate segments within and across levels to object models defined as DAGs where each node is a segment and each weighted edge represent relation between segments such as isLower, isHigher, minDistCenter, etc. Segments are classified functionally, such as "sitting surface" and these functional segements are related to each other through the models. This work is preliminary, but interesting in that it combines affordances with functional descriptions to do higher level object recognition.

Relation to Robotics: Certainly, the perceptual component is related, but their SICK laser is not integrated with a robotics system.

Relation to KR: There is an interesting relation to KR in terms of the model structures used to represent objects in terms of functional components.

Relation to Machine Learning: There is little direct relation to machine learning.

Article: Formalizing Affordance
Authors: Mark Steedman
Type: Artificial Intelligence
Reference: [Ste00]

Synopsis:

Main idea: The author uses a logical formalism for reasoning about action and change and the use of combinatory systems to take a stab at modeling the affordances associated with objects in a formal manner.

Article summary: This article has two parts: formally modeling affordances as coupled to objects via action or event description, and secondly, showing that this technique has some interest to natural language syntactic and semantic composition as postulated by combinatory categorical grammar. We will focus on the first aspect. Steedman first summarizes linear dynamic event calculus which is a combination of Kowalski and Sergot's event calculus and Girard's linear logic. His claim is that this is a useful basis for modeling action and change. He then shows a relation between this formalism and Curry's notation for combinators. He then proposes a formal means of attaching affordances to objects by using the LDEC as a basis for modeling actions or events normally associated with particular objects. An affordance is then defined as a higher order function which maps the object (class) into (2nd-order) functions from their associated affordances to their results. For example, one can associate the actions of pushing and going-through with a door. Both pushing and going through can be defined in terms of sets of linear logic formulas each with a context and result. For example push would be associated with shut(d) resulting in open(d) and open(d) resulting in shut(d). The set of such functions, constitutes the affordances for doors. An affordance based door schema can then be defined as a function mapping doors into (2nd-order) functions from their affordances such as pushing and going-through to their results. Although it uses some intuitions from Gibson, the ideas and techniques considered are not necessarily strongly related to what Gibson is out after. There is a possibility that these techniques make sense for higher-order affordances unrelated to direct perception.

Relation to Robotics: No direct relation, but this is a representational technique which could serve as a basis for implementing affordances attached to objects.

Relation to KR: There is a direct relation as this approach provides a connection between some well-known logics for action and change and their use in modeling affordances.

Relation to Machine Learning: No relation.

Article: Characterization of Affordances
Authors: Jiajiie Zhang
Type: Perception, Psychology
Reference: [Zha03]

Synopsis:

Main idea: The author uses the theory of distributed representations to extend Gibson's affordances to a variety of domains and introduces affordance categories.

Article summary: The article summarizes briefly Gibson's ecological approach, extends it to domains that involve internal representations, develops a taxonomy of affordances, and explores the roles of distributed representations. Affordances are distributed into an external (environment) and internal (organism) representational space forming the affordance space. It can be characterized by a disjunction of constraints or conjunction of actions. There are several levels of representations in each space and there is a correspondence between the levels of both spaces. Zhang distinguishes biological (food), physical (terrain features, shelters, water, fire, objects), perceptual affordances (pictorial signs), cognitive (meaning of traffic lights, light switches), and mixed affordances (combination of more than one). The article is unfinished.

Relation to Robotics: No direct relation

Relation to KR: Suggestion of a representation and taxonomy of affordances.

Relation to Machine Learning: No direct relation

Article: Graspable objects grab attention when the potential for action is recognized
Authors: T. Handy and S. Grafton and N. Shroff and S. Ketay and M. Gazzaniga
Type: Neuroscience
Reference: [PFM03]

Synopsis:

Main idea: The authors conclude from neurophysioligical experiments with human subjects that the focus of attention is shifted to objects even if they are irrelevant to current behavioral goals. Attention at the feature level interacts with motor affordance recognition. Once a motor affordance is recognized, attentional selection can be affected at the level of whole objects.

Article summary: In the first part of the article, the authors describe three neurophysiological experiments with human subjects to investigate the problem how perception of action-related objects (tools) is related to visual-spatial attention and motor programs. In the second part, insights from the experiments related to behavioral goals, attention, and recognition are discussed. Some of the conclusions still need experimental verification.

Relation to Robotics: The results of this paper give some ideas how to build attention mechanisms.

Relation to KR: No direct relation

Relation to Machine Learning: No direct relation

Article: Case Studies of Applying Gibson's Ecological Approach to Mobile Robots
Authors: R. Murphy
Type: Robotics
Reference: [Mur99]

Synopsis:

Main idea: The author shows that for some behavior-based systems the use of the concept of affordances is beneficial and suggests a methodology how to design these systems. The key issues are the identification and application of affordances for a desired behavior.

Article summary: After giving a short overview of Gibson's ecological approach, Murphy describes a methodology for deciding whether an affordance-based approach should be implemented for a specific behavior and how to isolate a reliable affordance. She presents three robotic tasks where the approach has been applied successfully.

Relation to Robotics: Three mobile robots for the following tasks are described: fine positioning, picking-up trash and path following. The first two robots use vision-based affordances, the third ultrasonics in conjunction with vision.

Relation to KR: All behaviors are hardwired and directly controlled by affordances. There is no planning, no inference and no explicit modeling. Systems may have a common structure due to the isolation of affordances in their design.

Relation to Machine Learning: No direct relation

Article: Unsupervised Classification of Sensory-Motor states in a Real World Artifact Using a Temporal Kohonen Map
Authors: D. Lambrinos and C. Scheier and R. Pfeifer
Type: Machine Learning, Perception, Robotics
Reference: [LSP95]

Synopsis:

Main idea: A robot learns to grasp only pegs which are graspable without trying. It classifies pegs based on information about its sensory-motory state, i.e. classification is viewed as a process which also involves the robot's action. While wandering around, the robot avoids a peg if it is not graspable otherwise it will grasp it. Graspability is defined by the size of a peg.

Article summary: The authors motivate to include information of an agent's action in classification processes. They describe their experimental setup using a Khepara robot, the control architecture based on a self-organizing map, and the learning rules that were used for the peg classification task. Experimental results are given showing the global performance of the learning scheme.

Relation to Robotics: Description of an experimental setup with a Khepara robot equipped with infrared sensors and a wire loop as a gripper for learning the graspability affordance.

Relation to KR: No direct relation

Relation to Machine Learning: Implementation of a Temporal Kohonen Map for unsupervised classification based on sensory-motor state information. Introduction of a new local learning rule.

Article: Perception-Action Coupling via Imitation and Attention
Authors: G. Maistros and Y. Marom and G. Hayes
Type: Robotics, Perception, Machine Learning
Reference: [MMH01]

Synopsis:

Main idea: A bottom-up attention mechanism based on a modified Self Organizing Feature Map (SOFM) is combined with a schema network for achieving imitation capabilities of a robot.

Article summary: The authors describe a schema network, an attention system, and the integration in a simulated robot. The robot learns the focus of attention and the motor schemas by observing a demonstrator robot. Two experiments in simulation are presented. For each the setup, the learning phase, and the recall phase is described in detail and experimental results are shown.

Relation to Robotics: Description of two experimental setups for demonstration the imitation capability in simulation: The first shows postural imitation using two eleven degrees of freedom robots (humanoid, waist upwards) with explicit access to his and the state of the demonstrator and object information (visual perception). The second demonstrates imitation by following using a Khepera mobile robot simulator with six infrared sensors. A learner agent follows behind a teacher agent.

Relation to KR: The proposed system is capable of creating and maintaining representations of perceptual experiences with respect to the actions that they afford.

Relation to Machine Learning: Implementation of a variation of a SOFM. Motor schemas are learned with a simple method.

Article: From visual affordances in monkey parietal cortex to hippocampo-parietal interactions underlying rat navigation
Authors: M. Arbib

Type: Neuroscience, Ethology
Reference: [Arb97]

Synopsis:

Main idea: The author proposes biological based models for parts of the monkey and rat brain related to control of eye movement, object grasping, and navigation.

Article summary: The article presents system models based on neurophysiological data for execution of voluntary saccades in primates, the grasping behavior of monkeys, and a conceptual model for rat navigation based on cognitive maps. The models address parietal-premotor interactions involved in grasping and describe how various constraints may resolve the problem of several action opportunities provided by multiple affordances. An implemented model for object grasping is mentioned which computes affordances from visual input corresponding to the various ways in which an object may be grasped. The author describes the relation between taxis and affordance.

Relation to Robotics: No direct relation

Relation to KR: The author shows the information flow of grasping behavior and describes a biological based model for motion planning.

Relation to Machine Learning: Implementation of biologically based neural network models reported.

Article: What the brain's mind tells the mind's eye
Authors: A. Sloman
Type: Perception, Psychology
Reference: [Slo03]

Synopsis:

Main idea: Sloman understands human vision as a combination of a perceptual architecture and a rich central architecture. Vision is more than reversing the process of image formation on the retina. Spatial structure and affordances play an important role for modeling human visual perception.

Article summary: The author points out that we are a long way from Human-Machine Symmetry (HMS) and analysis why. He describes typical problems of perceiving structures, such as recognizing objects from dot patterns in cluttered scenes and occlusions, and addresses the problem of ambiguity. In his opinion Marr's view on vision has to be extended with functions related to the needs and capabilities of organisms. He suggests to apply the concept of affordances. Vision involves the detection of a variety of possibilities associated with various locations in the perceived scene. The author describes an experiment with a crow being able to form a hook from a piece of wire in order to lift some food from a tube. It seems the crow perceives affordances and reasons about their possibilities for and constraints on actions. In the remaining paper he claims that humans are able to think with visual spatial structures and points out why it's important that machine understand what they see. The article is an incomplete draft.

Relation to Robotics: The author suggests to integrate affordance recognition and reasoning mechanisms into machine vision systems.

Relation to KR: Physical, geometric information from a visual sub-system has to be coupled to inference and deduction mechanisms to understand visual information. Affordances help to provide possibilities and constraints.

Relation to Machine Learning: No direct relation

Article: An Affordance-Based Model of Place in GIS
Authors: Jordan, T., M. Raubal, B. Gartrell, et al.
Type: Artificial Intelligence and Computer Science
Reference: [JRGE98]

Synopsis:

Main idea: The main idea of this article is to improve the representation of place within a digital environment. This is intended to make it easier to add meaning structures to places in geographic information systems (GIS).

Article summary: Authors find it important to enhance the notion of place in GIS. Instead of modeling space with reference to coordinates of a location,they want to add flexibility to be able to match the way people think about their world i.e. assign complex meaning structures to places and based on such meaning decide about subsequent activities done in places. Authors claim that integrating a model of how people conceptualize and perceive places into GIS will increase their usefulness.

Relation to Robotics: Adding functional place description in a robotic system might make a process of map building and navigation more effective.

Relation to KR: The article presents methodology to model places with affordances in GIS. Three important elements of affordance-based model of place are: agents, tasks, and environments. Authors use Rasmussen's means-end abstraction hierarchy as a method of representing the environment, along with object aggregation model. In that way they get two dimensional mechanism to determine a set of possible purposes or functions of some configuration of objects (in GIS those are locations and feature attributes). The original abstraction levels of Rasmussen's model are (from top): functional purpose, abstract function, generalized function, physical function, and physical form. At each level, there exists an important relationship between upper and lower levels. The level above suggest intended function for the level, the level below suggests how the function of this level are to be implemented. The use of object aggregation model allows describing object using the same abstraction level, reducing complexity of the model at the same time. Finally, authors suggest 6 aspects of place that if integrated in GIS, would greatly improve them: physical features, actions, narrative, symbolic representation/names, socioeconomic and cultural factors, typologies. In a GIS such representations would allow to access important features of places in support of user place-based quarries.

Relation to Machine Learning: No direct relation.

Article: Perception Driven Robot Locomotion
Authors: Lewis, M. A.
Type: Robotics, ethology, machine learning
Reference: [Lew02]

Synopsis:

Main idea: Perception, more then control, is the key to achieving smooth and robust robot locomotion.

Article summary: Author argues that more emphasis should be put on the problem of perception and less on control in robotics in tasks as for example walking. The key role of Central Pattern Generator (CPG - neural circuit that produces self-sustaining patterns

of behavior) is to coordinate the fusion of the influence of perception in the step cycle. Perception is defined as the process of computing percepts, or an element of knowledge about the robot-environment relationship. Percepts are derived from sensor information and once formed, the original sensor information is lost. Author claims that many problems unique for walking machines are tied to the need to discover an appropriate set of percepts needed for control.

Relation to Robotics: Author suggests a novel way to think about robot locomotion. Percepts are supposed to be helpful in achieving smooth locomotion. First example of a useful percept is the one indicating an impending fall which requires a certain kind of correction (it can be derived from the point called Center of Pressure or Foot Rotator Index). Second example is an affordance, which assists and inhibits movement and is explicitly connected to action. According to some neurophysiological studies, there exist areas in brain, which deal with spatial perception and may compute movement affordances. The third example of a useful percept is a reflex. The example given explains that if top of a cat's paw is touched during walk, the paw by reflex swings just as to avoid obstacle. Such reflexive behavior can obviously help in robotic system. To deal with perceptual overload a predictive mechanism is employed to "cancel" optical flow caused by self-movement.

Relation to KR: No direct relation.

Relation to Machine Learning: To account for disturbances in locomotion (f.g. caused by obstacles) anomalies in perception stream must be detected and correcting actions must be associated. Occurrence of stumble reflex can be an indication of destabilizing event. Using reinforcement learning an association between novel stimuli and the reflex is acquired. Next time the robot encounters the same anomalous stimuli pattern, the appropriate reflex is launched before reaching the obstacle.

Article: Motor representations in memory and mental models: The Embodied Zork
Authors: Richardson, D. C., M. J. Spivey and J. Cheung
Type: Neuroscience

Synopsis:

Main idea: Richardson et al. following a suggestion that motor systems can participate in what were thought to be purely perceptual tasks, show that a representation of a visual stimulus accessed from memory can activate potential motor interactions.

Article summary: Authors perform two experiments to show that the representation of a visual stimulus generated from pictures or from purely linguistic description can activate motor affordances, i.e. even a glimpse of an object or an image of an object or hearing about an object can result in activation of motor patterns needed to interact with it. First experiment is to show if affordances can be stored in, or reactivated by, short term visual memory. Second experiment investigates the role of motor systems in conceptual tasks - listening to a story.

Relation to Robotics: No direct relation.

Relation to KR: Authors state that object representations (in form of memories of visual stimuli or generated from linguistic description) contain motor representation. "Internal worlds we create do not form maps of external space per se, but of perceptual and behavioral affordances within space."

Relation to Machine Learning: No direct relation.

Article: A Method for Studying Representation of Action and Cognitive Distance

Authors: Bugmann, D. V. and K. R. Coventry
Type: Psychology
Reference: [BC04]

Synopsis:

Main idea: Bugmann et al. present new methodology to investigate the involvement of action on the representation of route distance information.

Article summary: Investigation of the relationship between physical distance and cognitive distance shows that humans often do not give accurate distance estimation. Authors present a test setup in which they test how the number of turns on a path and performing of an action influences peoples' distance estimation in a guided tour environment. Subjects wearing blindfolds heard linguistic descriptions of environments over headphones, and had to imagine themselves walking around the environment in time with series of metronome clicks present to control for speed of walk and size of step. During the simulated navigation through the environment participants performed an action (e.g. put an object into a box) which occurred at mid-route. The influence of number of turns and segments' length is explained be the segmentation hypothesis (paths with more right angle turns are perceived as longer) but also a different cognitive mechanism is uncovered in the study. This mechanism involves attention processes, which are involved in remembering walking distances, i.e. focusing attention on turns not on segments themselves. The absence of the effect of performing an action is explained by the salience of the action itself. The movement of dispatching an object into a box may be perceived as a simple task and therefore is not salient enough to put an effect on spatial representation.

Relation to Robotics: No direct relation.

Relation to KR: No direct relation.

Relation to Machine Learning: No direct relation.

Article: Recognition-by-Components: A Theory of Human Image Understanding.
Authors: Biederman, I.
Type: Psychology, perception
Reference: [Bie87]

Synopsis:

Main idea: The author proposes a theory about human image understanding called recognition-by-components (RBC) and gives experimental result confirming the hypothesis.

Article summary: According to the RBC theory object are composed of modest number of simple geometric components such as cylinders, blocks, wedges, and cones. Objects are segmented, typically at regions of sharp concavity and compared against best fitting primitives, which have convex and volumetric character. Relations among the volumes are critical for object recognition. Presented examples show that the suggested theory supports rapid recognition of objects, when viewed from novel orientation, under moderate levels of visual noise, when partially occluded, and when it is a new exemplar of a category. The theory's contribution is realized by its "proposal for a particular vocabulary of components derived from perceptual mechanism and its account of how an arrangement of these components can access a representation of an object in memory". Author uses a name *geon* (geometric ion or volumetric primitive) to describe the primitive elements of

objects. Geons can be modeled by generalized cones and specification of the nonaccidental properties of the three attributes of a cross section and one of the axis is sufficient to uniquely classify a given arrangement of edges as one of the 36 geons. Examples show that deletion of a contour in region that makes it impossible to recover a geon made it impossible to identify the object. Similarly, deletion of a contour that did not make it impossible to recover a geon did not influence the object recognition. Often missing contours were reconstructed according to Gestalt laws. Additionally, experiments showed that according to RBC theory, complex objects do not require more time for their identification than simpler objects. This result opposes a theory of object recognition which employs tracing of contours.

Relation to Robotics: No direct relation.

Relation to KR: Object recognition is hypothesized to be a process in which perceptual input is matched against representation that can be described by a few simple categorized volumes in specified relations to each other.

Relation to Machine Learning: No direct relation.

Article: Cognitive, Physical and Perceptual Affordances in Interaction Design
Authors: H. Rex Hartson
Type: Design
Reference: [Har03]

Synopsis:

Main idea: As reaction to Norman's [Nor99] essay about misuse of the term affordances in human-computer interaction community, the author defines four complementary types of affordances to be considered in interaction design and evaluation. Additionally, the author presents the outcome of work on usability engineering support tools built on theory-based framework called the User Action Framework (UAF), which is a structured knowledge base of usability concepts and issues.

Article summary: The author defines the four types of affordances as follows: A physical affordance is a design feature that helps, aids, supports, facilitates, or enables *physically doing something.* A cognitive affordance is a design feature that helps, aids, supports, facilitates, or enables *thinking and/or it knowing about something.* A perceptual affordance is a design feature that helps, aids, supports, facilitates, or enables *the user in perception.* The fourth type comes from the belief that physical affordances carry a mandatory component of *purposeful action* called functional affordance. It is important to notice that Hartson renames concepts presented by Norman. Norman's perceived affordances become cognitive affordances and Norman's real affordances are renamed to physical affordances. The presented UAF knowledge base connects affordance based and other design concepts in the domain of design and analysis for usability.

Relation to Robotics: No direct relation.

Relation to KR: No direct relation.

Relation to Machine Learning: No direct relation.

Article: Attentional processes link perception and action
Authors: Stephen J. Anderson, Noriko Yamagishi, Vivian Karavia
Type: Cognitive Psychology
Reference: [SA02]

Synopsis:

Main Idea: The authors try to determine whether the action-related properties of an object (or its elements) are responsible for the generation of motor signals in the brain.

Article summary: Paper describes a series of experiments. In each experiment the observer's reaction time for judging orientation of an object was measured. As a visual stimuli computer-generated white-on-grey images were used. The images showed everyday objects and non-objects that either afforded grasping action or not. The size of all stimuli was approximately the same and additionally images were either asymmetrical or symmetrical about the vertical axis. The results of the experiments showed that the affordances of visual objects are not the cause of generating motor signals. Instead, directed visual attention is the reason for the activation of motor signals. Those signals are associated with the spatial characteristics of perceived object- and non-object patterns.

Relation to Robotics: No direct relation

Relation to KR: No direct relation

Relation to Machine Learning: No direct relation

Article: Artifact Intelligence: Yet Another Approach for Intelligent Robots
Authors: Hideaki Takeda, Kazunori Terada, Tatsuyuki Kawamura
Type: Robotics, AI
Reference: [HKT02]

Synopsis:

Main Idea: The authors propose a new concept for intelligence called Artifact Intelligence. The approach focuses on artifacts that fit their embodiment i.e. structures and functions of artifacts.

Article summary: The main idea of Artifact Intelligence is to maximize functionality of the artifacts. The authors claim that the level of intelligence should be adapted to the complexity of the artifacts' structure and functions. To realize the idea they propose active affordances and emergent affordances that establish intentional/physical relationship between the human and the artifacts. Intentional relationship allows humans to use artifacts in order to achieve some goal while the artifacts provide adequate functionalities. In the concept of active affordances, the artifacts participate to establish affordances by actions. The artifact should comprehend the user's intention so that it can afford its functions appropriately. As an experiment autonomous mobile chair was developed. The communication with user was implemented by gesture recognition. The chair minimizes Affordance Distance that corresponds to the cost of the action, which is required for the chair to move close to the user.
The emergent affordance idea is to combine affordances and active affordances so the agent and the artifact interact cooperatively to find the artifact's role. The authors presented the AgentBox which is hardware that can discover its role through interaction with human.

Relation to Robotics: The authors claim that robots are more suitable as extension of intelligent artifacts rather than imitation of creatures. They describe autonomous mobile chair as well as the simulation environment.

Relation to KR: They propose the model to represent the intentional/physical relationship between the human and the artifact using affordances concept.

Relation to Machine Learning: Learning is not mentioned but one can imagine that learning would be an important issue in artifact intelligence.

Article: Grounding Symbols through Sensorimotor Integration
Authors: Karl F. MacDorman
Type: Robotics, AI
Reference: [K.F99]

Synopsis:

Main Idea: The author proposes the perception architecture for a robot that would be capable of discovering and learning of affordances.

Article summary: The main idea is to use embodied predictions for affordances. The predictions are spatiotemporal correlations in robot's sensory projections, motor signals and internal variables that are effect of robot's interaction with the environment. Currently active predictions constitute the robot's affordances model. The consequences a robot predicts for its potential actions depend on its perceived circumstances. Thus only a subset of the robot's learned predictions will be active at a given time.
The robot revises old predictions and develops new once to account for the unexpected occurrence. Predictions that support routine patterns of behavior become parallelized, automatic and non-conscious to free up conscious resources. MacDorman does not explicitly refer to function in his model.

Relation to Robotics: An interesting architecture is presented with description of few modules.

Relation to KR: The author discusses the grounding symbols problem and the frame problem. The proposed module for robot navigation is done by using learned sensorimotor model to plan paths to potential affordances in a cluttered environments.

Relation to Machine Learning: Learning of sensorimotor model is done by developing predictions concerning how robot's motor signals transform sensory projections. This is realized using k-D tree to represent these experiences as points in multidimensional phase space. Second learning mechanism is learning of affordance categories. It is based on wavelet transform, or other multiresolution techniques with a parameterized family of two dimensional Gabor filters. Later robot creates a *categorical representation* by statistical filtering mechanism.

Article: A Comparison of Affordance Concepts and Product Semantics
Authors: Hsiao-chen You, Kuohsiang Chen
Type: Design
Reference: [HcY02]

Synopsis:

Main Idea: The authors convey a literature survey on use of affordance concept in design fields and point out directions for the application of affordance concept in product or interface design.

Article summary: The aim of the paper is to clarify misunderstanding and misuse of affordance concept in product design, especially confusing affordance concept with product semantics. The authors describe affordance idea viewed from different perspectives: the original concept from Gibson, affordance in design from cognitive engineering perspective and affordance in design from semiotics perspective. They compare affordance theory with product semantics and show main differences between them. They indicate that in Gibson's work there is no direct hint for design community to gain benefits from his

concept. Therefore, the methods that are combination of those design theories are still waiting to be developed.

Relation to Robotics: No direct relation

Relation to KR: No direct relation, although they point out how misused the idea of affordances in design is, which can be a useful warning for other communities.

Relation to Machine Learning: No direct relation

Article: Events as Changes in the Layout of Affordances
Authors: Anthony Chemero, Colin Klein, William Cordeiro
Type: Ecological Psychology
Reference: [CA03]

Synopsis:

Main Idea: The authors claim that events are changes in the layout of affordances. They also distinguish this concept from earlier definitions of event, which they refer to as physical events. They present empirical results in favor of their thesis.

Article summary: The article is a response to [T.A00] article where Stoffregen questions the possibility of ecological event perception research. The authors describe the results of an experiment concerning the perception of affordances and events while gap crossing. Based on the results they claim that ecological events are perceivable. In the experiment they examined how precisely participants could judged the point at which the gap did no longer afforded stepping across. They used dimensionless π numbers to characterize the affordance of static step across. π numbers are ratios between properties of the environment and properties of the animal. The results confirm authors' thesis that events are changes in the layout of affordances. There was one unexpected result: participants judged that ecological events occurred at distances shorter than they judged in the static task.

Relation to Robotics: Indirect relation - influence of terminology on: how we can view robotics system and design of its architecture.

Relation to KR: Indirect relation.

Relation to Machine Learning: Indirect relation.

Article: Affordances Are Enough: Reply to Chemero et al. (2003)
Authors: Thomas A. Stoffregen
Type: Ecological Psychology
Reference: [T.A03]

Synopsis:

Main Idea: This article is a continuation in a discussion about events and affordances issues that started in 2000 in ecological psychology community. It is a direct answer to [T.A03].

Article summary: The author agrees that the changes in the layout of affordances can be perceived. Chemero et al. in [T.A03] showed an empirical demonstration where the participants could perceive the disappearance of the affordance for gap crossing. But he argues about conceptual issues, namely use of definition of event. He disagrees that there is a need for additional category of perceivables, i.e. ecological events since the category of affordances includes everything that is perceived. He gives an example of nested affordances. Nesting involves time and space levels. He gives an intuitive example

of nested affordances in baseball. He claims that whether something is an affordance or a change in the layout depends on the level of analysis. That is because changes in the layout of affordances (Chemero et al. - ecological events) are part of the nesting of affordances within levels.

Relation to Robotics: Indirect relation.

Relation to KR: Indirect relation. Good discussion on clarifying the terminology which can have direct influence on design of knowledge representation structures.

Relation to Machine Learning: Indirect relation.

3 Conclusions

We think it is safe to conclude that the ideas of Gibson have had widespread influence in a great many different research disciplines as judged by the survey of articles. Not only have they had widespread influence, but one can make the claim that Gibson's ideas in some sense laid the modern foundation for the situated activity/robotics movements. Implicit in many of the approaches to modern behavior-based robotics is the tight coupling between sensor and motoric activity, the functional view of objects in the world and the non-representational stance regarding perception, where meaning is taken to be a relation between an agent and its embedding environment and internal representations are deemed unnecessary for base behaviors in a robotic system.

Although Gibson's work is often referenced in the context of this work, the explicit use of affordances in robotics architectures and in specification of behaviors is not present in the strong sense. Meaning theories based on a relational view of agent-environment symbiosis, although discussed quite vigorously in the philosophical literature, have not been used to any great extent in laying the foundations for meaning theories which may provide new ways to think about representation at higher-levels in a robotic architecture. This in fact, is one of the main insights resulting from this deliverable. In essence, one has to think about robot ontologies in a new way and build up both perception, behavioral and representational mechanisms within these constraints. This is quite a challenge, but we do believe that gains in terms of robustness of behaviors and more efficient use of environmental cues in solving problems could very well be the result of viewing robotic architectures in this new perspective.

This workpackage (WP4) has the task of proposing representational mechanisms which could be used in a robotics architecture based on the affordance idea. Although the idea of internal representation appears to be inconsistent with Gibson's original ideas, we would claim that this is not the case at all. Gibson focussed primarily on vision as a means of developing his theories of direct perception and affordances. Post-Gibsonian research has begun to view affordances in a wider sense and in a sense which focusses on use at higher cognitive layers in systems. Although this wider view will continue to influence many different research disciplines and application areas, we now believe that in the context of this project, the real issue for this workpackage is to bridge the gap between the traditional Gibsonien view of affordances as non-representational with this more modern view of affordances as representational. There is no inconsistency in this respect and this places the problem specification well in line with one of the great open problems in robotics research today; this is the question of how to integrate behavior-based and representational approaches to cognitive robotics while at the same time tightly grounding robotic systems

through perception right up to complex representational structures which are intentional in nature . In this sense, the problem is not new. What is new is the shift in perspective and the new space of solutions that is opened up by viewing the problem through the lense of Gibsonian affordances.

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