A Unified Framework for Perception in Autonomous Systems

Ignacio López (ilopez@etsii.upm.es)
Ricardo Sanz (ricardo.sanz@upm.es)
Julita Bermejo (jbermejo@etsii.upm.es)

Autonomous Systems Laboratory (ASLab),
Universidad Politécnica de Madrid (UPM).
José Gutiérrez Abascal, 2. Madrid 28006 Spain

Abstract

This paper presents the top level goals and perception concepts of the ASys Framework. This is an unified framework for cognitive, autonomous systems to be used both in the analysis of natural phenomena and in the synthesis of artificial autonomous systems. Perception in ASys is conceived within an holonic, systemic concept, not as an isolated phenomenon. This general perspective allows: (1) Integrating the main approaches to perception developed so far (a brief comparative analysis is offered). (2) A coherent framework for system analysis and design.

Keywords: Perception; cognition; embodied cognition; autonomous systems; cognitive systems; engineering.

Introduction: Motivation and Context

In spite of the advances in artificial systems, many tasks are still out of their capacities. Advanced context recognition, decision-making, high degrees of autonomous operation (in uncontrolled environments) and efficient social interaction are examples of them. They represent major drives for the research in advanced cognitive systems and affective computing (Cañamero & et al., 2004; Picard, 1998). Bioinspired architectures, algorithms and processes were thought to allow designing more efficient, intelligent and dependable artificial systems. However, it is not the easy path that we once thought.

On one side, the substrates of natural and artificial systems present important differences of structural nature. Their properties are so diverse that overcoming the disparity of their structural constraints is extremely difficult. As a result, the type of processes that can be efficiently implemented in artificial substrates is radically different from natural ones. On the other side, biological systems are not known well enough yet. Isolated, low-level phenomena have been traced and modelled on one end, and psychological explanations for high-level phenomena have been built on the other. But there does not exist a common, unique, integrated theory explaining all.

In our view, the solution to the problem does not rely on just biomimetic approaches or on classical engineering patterns of design. An effort in building a *general theory* which integrates concepts, relations and principles must be made. A sufficient level of generality would allow analyzing and conceptualizing the natural and the artificial upon a common background. This is what we call the ASys approach. In this way bioinspiration would be possible at a conceptual level, in spite of implementational differences at lower ones.

Obviously the abstraction back-step from reality that this approach imposes will render a theory that may be missing some details of relevance in current analyses of autonomy and perception. However we believe that these details will be regained, placed in their proper place and better grounded on further elaborations of the theory for specific domains.

The approach to perception exposed here forms part of ASys and must be necessarily understood within the goals, resources, operation and constraints of a concrete observer system —a perceptor. An observer system may carry out multiple processes concurrently, share resources among them, satisfy real–time constraints, etc. We, animals, do that all the time, and many machines do so as well. Only some of all those processes will be devoted to perception. But they should correspond to the goals and capacities of the system. In fact, they should be a part of them.

The ASys perceptual framework is a general, unifying approach, within which other perception theories may be analysed. It starts from a formal notion of system, inherited from the Theory of General Systems (Klir, 1969). Hopefully, it will create a common theoretical background for natural and artificial systems upon which new bio-inspired engineering solutions can be developed.

Studies of Perception

The topic of perception has been studied from uncountable perspectives. Some explain aspects regarding specific phenomena, and some try to provide a global vision. Let us develop a brief overview. We could divide the studies of perception in three main categories.

Many lines of research, both in natural and artificial perception, focus on low-level aspects, for example the biological structure of sensors and their electrochemical behaviour or research on signal processing. Examples of ongoing work in this trend are Bengtsson and Ullén (2006) and Koelsch and Siebel (2005), which assess recognition of different aspects of auditory signals and neural correlates. Farah (2000) offers an overview of neural correlates across the different low and medium level perception processes.

A second category of studies would concentrate on the process of perceiving actual objects in the environment. Examples of this are Barth, La Mont, Lipton, and Spelke (2005), (Mandler, 2004), (Smith, Johnson, & Spelke, 2003) which assess object formation. Object perception is related to many other aspects of the observer system. Bodner and Lindsay (2003), Kensinger, Garoff-Eaton, and Schacter (2007) and Radvansky and Copeland (2006) explore memory retrieval in

relation with perceptual aspects.

A third category of studies of perception would aim at global aspects of the process, focusing on three main topics: 1) The role of perception within the observer system (natural or artificial); 2) Causes for perceptual phenomena. Systemic explanations accounting perception and also for illusions, hallucinations, particular aspects of perception (perception of movement, volumes, etc.) and 3) Cognitive (neuro–) science: Relation of concepts, concept formation and concept recognition with neurophysiological substrate.

We could summarize two fundamental perspectives within this category. First, the well-known *ecological theory*, also called *direct perception*, whose formulation can be found in Gibson (1966) and Gibson (1987). The main idea is that the senses are adapted to the needs of the system up to such a degree that they convey *meaning* directly, without intermediate deliberation or inferential process. The observer system would therefore perceive *affordances* in its environment; in other words, *what the environment can afford* the system: support, nourishment, *etc*.

Many approaches, however, adopt the opposite view, usually referred to as *mediated perception*, *indirect perception*, or the *computational approach*. These have their root in Helmholtz's initial formulation of the problem (Helmholtz, 2005), who assumed that perception was an inferential process to find the most probable explanation for the readings of the sensors. A conceptual overview and discussion related to this trend can be found in Rock (1985) and Rock (1997). As a matter of fact, current approaches allow certain degree of "directedness" within an overall inferential process (Pylyshyn, 1999; Shanahan, 2005).

Perceptual Stance of the ASys Framework

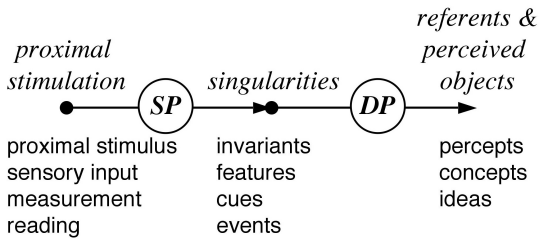
The main ideas of ASys regarding perception will be introduced in five points that are addressed in the following sections.

The Perceptive Process

Any perceptive process is based on three aspects: *proximal stimulation*, *singularities* and *objects*. The process consists in relating the three aspects. It is what is called *perceiving* or *perception*. Globally, perception always follows a sequence of two phases which will be called *fundamental sequence*, represented schematically in Figure 1.

SP and *DP* represent the two phases of the fundamental sequence. They constitute the perceptive process that is directed to recognizing certain entities in the environment, while ignoring others. These entities to which perception is referred to, shall be called *referents* of the process.

As we were saying, referents are concepts in the system, *objects*[1] which perception will strive to find in the environment. They are conceptual and cannot be found as such in the environment. If they actually exist, they will appear in a specific form and body. In other words, as a particular *instantiation* of the actual referents. It is this instantiation which will be represented by perception as a *perceived object*.



SP: Sensory processing / proximal information processing
DP: Directed processing / cognitive information processing

Figure 1: Two phases of the perceptual process.

The perceptive process might be implicit or explicitly oriented towards its referents. If the process manipulates symbolic representations of its referents, the orientation will be *explicit*; otherwise it will be *implicit*.

Singularities are patterns in the values of the proximal stimulation. This stands for any particular feature which characterizes it. It is a generalization of other similar concepts found in the literature, used with specific meanings in each context; *feature* and *cue* are the most common in both natural and artificial systems (Duda, Hart, & Stork, 2001), (Levine, 2000), (Schifmann, 2001), (Selfridge, 1959), (Ullman, 1996).

These *singularities* are attributed by DP to a certain configuration of the objects in the environment. It is this configuration which is represented into the *perceived object*.

This *attribution* consists in actually assigning an equivalence between a state of the referent and the state of the object in the environment. As we just mentioned, a perceived object is therefore a representation of a particular state of a referent which is recognized in the environment: an *instantiated referent*.

The context of perception

Perception depends on the system and its environment; it is influenced by the rest of the processes in the system, and influences the rest of the system in two ways: through the potential explicit effect of the perceived objects —their *meaning*—, and by inducing changes in the system during the process (we shall call this *implicit perception*.)

It must be understood that a specific perceptive process may be immerse in an extremely complex systemic context of operation, which will impose constraints on perception: multiple perceptive processes grounded in resources which may be mutually dependent or shared, correspondence between perceptive processes, system behaviour, system structure, system goals and other, which will largely determine the purpose, task, capacties and relevance of a specific perceptive process in the system.

[1] *Object* in the sense of idea, concept, conceptual entity.

Cognitive relevance

This point only stresses the fact that perception is referred to concepts which we have been called *referents* of the process: ideas, abstract concepts, objects. These referents establish the point of view of perception: what is interesting and what is not. In other words, they establish the *finality* of the perceptive process.

The *perceived objects* which result from perception are needed for solving problems, planning actions and monitoring the state of the system and the environment. They are the link between the real world and the operation of the system.

Operations with referents and perceived objects[2] are needed to simulate hypothetical scenarios, to refine algorithms and processes and to enhance knowledge. They are needed to create new referents which can in turn be perceived.

Perceived domain

A perceptive process perceives over a part of the universe which we shall call *perceptive environment*. It includes the outside of the observer system, *system environment*, as well as —in the general case— parts of the system itself. In other words, this means that perception can recognize referents both outside and inside the system.[3]

Perceiving externally or internally to the system —or both— is irrelevant as to the structure and nature of a perceptive process.

There may appear differences as to the grounding, level of processing or other aspects specific to a process and a system. For example, processes which perceive inside biological systems frequently operate upon richer proximal stimulation (essentially in number and nature of inputs,) given the density of nervous/chemical connections inside the system.

Interaction between sensory and directed processing

In spite of being qualitatively different, sensory and directed processing are not independent. This means that they are different parts of the same process, and therefore there exists a strong relation between them. They can be equally subject to the same operational and implementational constraints, apart from answering to the same finality.

Apart from a conceptual relation between sensory and directed processing, there can also exist a mutual influence as to their operation. Complex directed processing might eventually require specific sensory processing: re-sensing, for example. Inferential processes taking place during directed processing might eventually require scanning a region neighbouring the original focus. Simulation which might be taking place at the directed phase may depend on sensory processing.[4] These are all examples of top-down interaction. But sensory processing may also influence directed processing (bottom-up). For example, preconfiguring inference processes with heuristics as in Shanahan (2005), or indirectly through the rest of the system as in the case of emotions.[5]

Both types of processing can interact and be mutually influenced throughout a perceptive process.

This Framework in the Scientific Context

The unified vision proposed here relies on a framework on general autonomous systems which has not been described in detail yet(López & Sanz, 2006). However, some implications have been mentioned, such as the influence of system goals, resource requirements and real-time constraints on perception. They are essential to understanding the context in which perceptive processes take place in a system, whether natural or artificial, and provide generality to this approach. In fact, generality has been a strategy for unification.

It is possible to put other approaches to perception in the context of this framework, and see how it can be particularized to each case. We can develop a short comparative discussion covering the main trends.

1. **Abductive perception.** Perhaps the formalization of perception which is closest —conceptually— to this work is Shanahan (2005). The understanding of the phenomenon is similar in many aspects:

   - The understanding of the perceptive process and the *fundamental sequence* is basically shared, allowing a certain degree of *proximal information processing* and a phase of *cognitive information processing*.
   - The actual role of *singularities* is also identified not necessarily as a description of the external world, but of the state of the sensors (*sensory system* here.) This implies a certain *cognitive equivalence* between system concepts and the outside world, to be established by the inferential process (*cognitive information processing*.)
   - It also assumes that perception implies both a *bottom-up* and a *top-down* information flow, from stages within the *cognitive information processing* phase to the *proximal information processing* phase and vice-versa.

   There are, however, some points of difference:

   - This work is understood within a framework of general autonomous systems, which establishes the operational context in which perceptive processes exist: multiple processes, goals, finality, real-time etc.

     Although Shanahan (2005) refers to sensory fusion, which implies multiple perceptive processes, this is only

[2] Examples of these operations are: generalization, analogy, association and particularization of concepts.

[3] Perception inside the system gives rise to *proprioception* and *metaperception* (among many other phenomena.) Note that these types of perception are in close connection with the principles of the perceptual symbol theory (Barsalou, 1999).

[4] The field of active perception (Noë, 2004; Hurley, 2001) is actually based on this. There is evidence that sensorimotor areas of the brain have cognitive relevance. For a case in musical perception see Koelsch and Siebel (2005).

[5] For a background on emotions see Damasio (2000), H. Van Dyke Parunak, Bisson, Brueckner, Matthews, and Sauter (2006), Spinola de Freitas, Gudwin, and Queiroz (2005).

a particular case, which leaves systemic aspects uncovered: relation of perception with core and efferent processes, functional decomposition, directiveness, etc.

- Top-down information flow is assessed only in the particular case of 'expectation'. The term is understood as 'prediction', and it is described as a heuristic mechanism included in the inference carried out in the *cognitive information processing* phase. According to ASys, however, there exist multiple mechanisms of top-down flow. Implicit perception, and *re–sensing* for example.

  The context of general autonomous systems also allows the identification of other kinds of factors influencing the directed process, apart from problem–solving oriented heuristics: real-time constraints, resource constraints, coordination constraints, etc., and other factors through the interaction with the rest of the processes in the system.

The present work can be considered to follow the major ideas of abductive perception. The similarities with Shanahan (2005) and with notions and views in other works (Rock, 1985, 1997) are clear. However, it is formulated from a wider context including systemic aspects. This allows realizing their actual influence and relevance on the process and achieving a higher degree of generality.

2. Direct perception. Direct perception assumes that meaning results directly from the senses. This is supported in specific contexts by evidence in the corresponding references, mentioned above. However, we conclude that (1) it explains specific aspects of perception but lacks generality (2) in accordance with this, its scope can be determined in terms of the ASys theory. We shall now attempt this in order to comment further.

A first approach to representing direct perception in the terms of the ASys framework is shown in figure 2. Our notion of *referent* is implicit in direct perception. However, it coincides with the observer system.[6] It can be observed that, according to ecological perception, the perceptive process consists of a unique phase from proximal stimulation to the perception of affordances: surfaces as potential support, substances as nutrition, etc. (Gibson, 1987).

Figure 2: Direct Perception in Terms of this Work.

According to direct perception, the sensory systems of animals are intrinsically adapted to perceiving affordances. This is the reason why perception is direct. It means that affordances are perceived exclusively by proximal processing. In terms of the present work, this equals to saying that the stage of *cognitive information processing* proposed here has no bearing in perception. We shall say that cognitive information processing is the identity, i.e. that it yields an identical result to its input. Direct perception is thus represented in case (a) of figure 3.

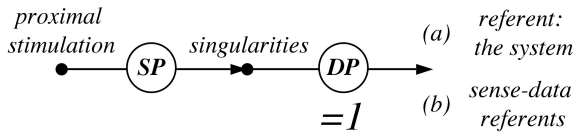


Figure 3: Fundamental Sequence of Direct Perception and Sense Data.

We might observe that this is equal to saying that direct perception occurs on —at least— two particular conditions with respect to the general case presented in this paper:

- Cognitive information processing is a unit process. In other words: the represented referent equals the singularities processed by the perceptor.
- The set of singularities provided by *proximal information processing* are actually meaningful as to what the environment actually affords. This implies that the resources involved are adapted and configured to that purpose: sensory system, etc.

In this light, we may raise the following points:

1. A unit *cognitive information processing* phase implies that the *proximal information processing* phase necessarily has to be adapted to the process *referents*. In other words, the sensory system must be *specific* to the referents: the resources on which it is embodied and the singularities it considers.

   The range of perceivable referents is restricted by the specificity of the sensory systems. If a sensory system would be too specific, new or modified referents could not be perceived.
2. Direct perception is largely based on physical attributes of the environment. Perception of abstract referents based on abstract or conceptual *singularities* is not accounted for.

   The ecological approach would categorize this kind of processing as *second-hand* or conventional (Gibson, 1965). However, it is clear that first-hand and second-hand processing are related and mutually influenced. Also, that second-hand processing has effects in terms of physiological response and activation of brain areas which in many cases are undistinguishable from first-hand processing.[7] The relation between first- and second-hand processing is not accounted for.

[6] Note that: (1) The system perceives the *affordances* of the environment. (2) "[Affordances] have to be measured *relative to the animal*" (Gibson, 1987). In conclusion: the *animal* —i.e.: observer system— is the referent of the perceptive process.

[7] This has actually led to research in active perception, already

3. *Affordances* as defined in the ecological approach (Gibson, 1966, 1987) are referred to aspects such as *support* and *nurishment*, which answer finally to system *survival*. In our vision (López & Sanz, 2006), this would be regarded as a long-term *objective* of the system.

   However: (1) a system, in the general case, may have more long-term objectives apart from survival. (2) *Survival* may not necessarily be an objective in all systems, especially in artificial ones.
4. Long-term objectives are frequently realized by a hierarchy of shorter term ones which might differ significantly from them.[8] This structure is adapted to shorter time-scopes and levels of abstraction, according to the instantaneous requirements imposed by the environment and the capacities of the system. Therefore, the higher the degree of autonomy of the system, the lower the degree of specificity of the system should be, to be able to react to fast-changing, uncertain environments.

The lack of generality of direct perception leaves multiple aspects uncovered, especially regarding complex, abstract *perceived objects*.

The direct character it assumes in perception does not allow explaining coordination and other forms of mutual depencence between perceptive processes in complex systems, where multiple processes might be taking place concurrently.

However, it must be remarked, against purely symbolic notions of perception, that in the general case a phase of *proximal information processing* must be contemplated, although it will, in general, be dependent on the operation of the rest of the system.

3. Gestalt perception. The present framework has relation with Gestalt perception in key aspects:

Singularities stand for relations between the values of sensory system quantities. *Directed processing* stands for establishing a relation between singularities and referents, which in turn represent a relation between referents and the environment. This framework is therefore based in the concept of relation among parts, following the Gestalt inspiration.

- Gestalt assumed that perception was concentrated on the analysis of some relations such as symmetry. However, this work imposes no constraints in the relations that a perceptive process might consider as *singularities*. A review of the literature regarding low-level perception in biological systems shows sufficient evidence as to the heterogeneous nature of singularities, that no restriction can be imposed on the notion.

  Examples of singularities in biological systems are: spatial proximity/continuity/symmetry of values as in object recognition, proximity/continuity of values in time, as in event-following, discontinuity of values in time, as in attention shift, and frequency spectrum patterns as in voice recognition. These examples show intrinsic differences of kind among the particular forms that singularities might adopt.
- This work conceives perception within the broader notion of system function (López & Sanz, 2006), which in turn operates within a larger topology of system functions (*functional structure*). This implies that perception must answer to more criteria than *optimality*[9] in order to be consistent with the functional structure (coordination between processes, system goals, etc.). The existence of these constraints explains why singularities might present such different natures, and why their interpretation is not necessarily optimal in real perceptive systems. Optimality was a unique requirement for Gestalt.

4. Marr Theory of Vision. The ASys Framework has multiple ideas in common with the Marr theory of vision:

- Both are aware of the duality between representation and processing. In ASys this duality resides in the role of the *referents* in perception and in the role of *implicit perception* in the system.

  Referents largely determine the *point of view* of a perceptive process —its objective—, and therefore partially determine all the intermediate phases. Of course, referents also influence the *perceived objects* that perception will produce, and consequently, the derived cognitive processes. Implicit perception stands for the influence of the process of perception over the rest of the system.
- Both distinguish a qualitative difference between the analysis of the *primal sketch* (*proximal stimulation* in ASys) and the rest of perceptive processes. However, in our view, there is no qualitative, fundamental difference between Marr's $2\frac{1}{2}$ and 3-D models.

  The $2\frac{1}{2}$ and 3-D models differ in their point of view. The first is centered in the system and the second is neutral. This work assumes that each perceptive process has its own *point of view*. The main aspect that defines the point of view is the *referent* of the process. Therefore, system-centered perception or neutrally-objected perception answer mainly to different referents, but there is no qualitative or fundamental difference at this level of analysis.

Conclusions

A general understanding of the concept of system, in particular of its organizational and operational principles, is essential

mentioned. It has also inspired aspects of other approaches (Barsalou, 1999; Marr, 1982).

[8] An example of this in an artificial cognitive architecture is the hierarchy of goals and subgoals in the SOAR architecture (Newell, 1990; Rosenbloom, Laird, & Newell, 1993; Laird, Bates Congdon, & Coulter, 1999).

[9] The Gestalt movement conceived perception as an inferential process to find the *best* interpretation of the proximal stimulation. *best* was understood as regularity: symmetry, analogy, temporal regularity, etc.

in order to explain any aspect of cognition. Systems science, knowledge on parallel distributed systems, theories on cognition, artificial intelligence and perception must be merged into a unique and consistent framework in order to design better artificial systems and analyze natural ones. This is the approach taken in the ASys Framework for the analysis of extant cognitive systems and the construction of artificial ones.

A process of perception is necessarily related to the system in which it takes place. The relation derives from its referents and the interaction with the rest of the system (coordination, resource-sharing, constraints) during the whole process. There exist both sensory and directed processes in perception which interact between themselves and with the rest of the system.

None of these interactions may be neglected if we want a systematic account of perceptual behavior and strive to have a universal theory of cognitive autonomy of applicability both to the natural and the artificial.

References

Barsalou, L. W. (1999). Perceptual Symbol Systems. *Behavioral and Brain Sciences*, *22*, 577-660.

Barth, H., La Mont, K., Lipton, J., & Spelke, E. (2005). Abstract number and arithmetic in preschool children. In 102 (Ed.), *Proceedings of the national academy of sciences* (Vol. 39, p. 14117-14121).

Bengtsson, S. L., & Ullén, F. (2006). Dissociation between melodic and rhythmic processing during piano performance from musical scores. *NeuroImage*, *30*, 272-284.

Bodner, G. E., & Lindsay, D. S. (2003). Remembering and knowing in context. *Journal of Memory and Language*, *48*, 563-580.

Cañamero, L., & et al. (2004, May). *Preliminary plans for exemplars: Cognition & action* (Tech. Rep. No. D7b). HUMAINE IST 507422.

Damasio, A. (2000). *The feeling of what happens: Body, emotion and the making of consciousness*. Vintage.

Duda, R. O., Hart, P. E., & Stork, D. G. (2001). *Pattern classification*. Wiley Interscience.

Farah, M. J. (2000). *The cognitive neuroscience of vision*. Blackwell.

Gibson, J. J. (1965). *The comparison of mediated perception with direct perception.* (Purple Perils, Unpuplished manuscripts, web edition)

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Houghton Mifflin.

Gibson, J. J. (1987). *The ecological approach to visual perception*. Lawrence Erlbaum Associates.

H. Van Dyke Parunak, Bisson, R., Brueckner, S., Matthews, R., & Sauter, J. (2006). A model of emotions for situated agents. In *Proceedings of the fifth international joint conference on autonomous agents and multiagent systems.* (p. 993-995). Hakodate, Japan.

Helmholtz, H. von. (2005). *Treatise on physiological optics* (1962 ed., Vol. III). Dover Phoenix.

Hurley, S. (2001). Perception and action: Alternative views. *Synthese*, *129*, 3-40.

Kensinger, E. A., Garoff-Eaton, R. J., & Schacter, D. L. (2007). Effects of emotion on memory specificity: Memory trade-offs elicited by negative visually arousing stimuli. *Journal of Memory and Language*, *56*, 575-591.

Klir, G. J. (1969). *An approach to general systems theory*. Van Nostrand Reinhold.

Koelsch, S., & Siebel, W. A. (2005, December). Towards a neural basis of music perception. *Trends in Cognitive Sciences*, *9*(12), 578-584.

Laird, J. E., Bates Congdon, C., & Coulter, K. J. (1999). *The Soar User's Manual Version 8.2.*

Levine, M. W. (2000). *Fundamentals of sensation and perception* (3rd ed.). Oxford University Press.

López, I., & Sanz, R. (2006). *A vision of autonomous systems* (Tech. Rep. No. R-2006-08). Autonomous Systems Laboratory ASLab. Universidad Politécnica de Madrid, UPM.

Mandler, J. M. (2004). *The foundations of mind: Origins of conceptual thought*. Oxford University Press.

Marr, D. (1982). *Vision*. W. H. Freeman and Company.

Newell, A. (1990). *Unified theories of cognition*. Harvard University Press.

Noë, A. (2004). *action in perception*. MIT Press.

Picard, R. (1998). *Affective computing*. MIT Press.

Pylyshyn, Z. (1999). Is vision continuous with cognition? the case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, *22*, 341-364.

Radvansky, G. A., & Copeland, D. E. (2006). Memory retrieval and interference: Working memory issues. *Journal of Memory and Language*, *55*, 33-46.

Rock, I. (1985). *Perception* (Reprint edition (August 1995) ed.). W. H. Freeman and Company.

Rock, I. (1997). *Indirect perception*. MIT Press.

Rosenbloom, P. S., Laird, J. E., & Newell, A. (Eds.). (1993). *The soar papers* (Vol. 2). MIT Press.

Schifmann, H. R. (2001). *Sensation and perception*. John Wiley & Sons.

Selfridge, O. G. (1959). The mechanization of thought processes. In (p. 511-529). London: H. M. Stationary Office.

Shanahan, M. (2005). Perception as abduction: turning, sensor data into meaningful representation. *Cognitive Science*, *29*, 103-134.

Smith, W. C., Johnson, S. P., & Spelke, E. (2003). Motion and edge sensitivity in perception of object unity. *Cognitive Psychology*, *46*, 31-64.

Spinola de Freitas, J., Gudwin, R. R., & Queiroz, J. (2005). Emotion in artificial intelligence and artificial life research: Facing problems. In *Intelligent virtual agents: 5th international working conference, iva 2005.* Springer.

Ullman, S. (1996). *High-level vision*. MIT Press.