WAYFINDING: AFFORDANCES AND AGENT SIMULATION

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SYNONYMS

Wayfinding behavior;

DEFINITION

Wayfinding behavior is the purposeful, directed, and motivated movement from an origin to a specific distant destination that cannot be directly perceived by the traveler. It involves interaction between the wayfinder and the environment.

Affordances are a concept from ecological psychology based on the paradigm of direct perception. They are specific combinations of the properties of substances and surfaces taken with reference to an observer. These invariant compounds are specified in ambient light—which is the result of illumination—and detected as units. Ambient light has structure and therefore information.

Agent simulation is a technique of imitating the behavior of some situation or process involving one or many agents. An agent is anything that can perceive its environment through sensors and act upon it through effectors. Agents are situated in some environment and capable of autonomous action.

HISTORICAL BACKGROUND

Kevin Lynch's [1] "The Image of the City" is the first documentation of *human wayfinding* research in the literature. His goal was to develop a method for the evaluation of city form based on the concept of *imageability*, and to offer principles for city design. As part of the interviews people had to perform mental trips across their cities, describing the sequence of things and landmarks they would see along the way. Based on his investigations Lynch divided the contents of the city images into five classes: paths, edges, districts, nodes, and landmarks. These elements were described as the building blocks in the process of making firm, differentiated structures at the urban scale and have been the basis for later wayfinding research.

The term *affordance* was originally introduced by James J. Gibson who investigated how people visually perceive their environment [2]. Affordances belong to the ecological approach to psychology, which was developed to solve the major problem of cognitive psychology—the problem of knowledge. It is based on ecological science, a multidisciplinary advance to the study of living systems, their environments, and the reciprocity between the two.

Agent simulation is a part of the larger area of computer simulation, which was developed in parallel with the rapid growth of computers starting with the Manhattan Project in the 1940s. There, the process of nuclear detonation was simulated using a Monte Carlo algorithm. The term *agent* has become popular in the area of Artificial Intelligence.

SCIENTIFIC FUNDAMENTALS

Wayfinding

Research in human wayfinding investigates the processes that take place when people orient themselves and navigate through space. Theories explain how people find their ways in the physical world, what people need to find their ways, how they communicate directions, and how people's verbal and visual abilities influence wayfinding. Wayfinding behavior is described as purposeful, directed, and motivated movement from an origin to a specific distant destination that cannot be directly perceived by the traveler [3, 4]. Such behavior involves interactions between the traveler and the environment, such as moving. Hence, wayfinding takes place in large-scale spaces [5]. Such spaces cannot be perceived from a single viewpoint; therefore, people have to navigate through large-scale spaces to experience them. Examples for large-scale spaces are landscapes, cities, and buildings.

People use various spatial and cognitive abilities to find their ways. These abilities are a necessary prerequisite to use environmental information or representations of spatial knowledge about the environment. The spatial abilities are task-dependent and seem to involve mainly four interactive resources: perceptual capabilities, information-processing capabilities, previously acquired knowledge, and motor capabilities [3]. As for the spatial abilities, the cognitive abilities also depend on the task at hand. Finding one's way in a city uses a different set of cognitive abilities than wayfinding in a building. Three categories of wayfinding tasks can be distinguished [3]: travel with the goal of reaching a familiar destination, exploratory travel with the goal of returning to a familiar point of origin, and travel with the goal of reaching a novel destination. A task within the last category is most often performed through the use of symbolic information.

The literature on human wayfinding performance discusses empirical results of how people find their ways. Investigations are based on collecting individuals' perceptions of distances, angles, or locations. Weisman [6] identified four classes of environmental variables that influence wayfinding performance in built environments: visual access; architectural differentiation; signs and room numbers to provide identification or directional information; and plan configuration. Seidel's [7] study at the Dallas/Fort

Worth Airport showed that the spatial structure of the physical environment has a strong influence on people's wayfinding behavior. People's familiarity with the environment also has a big impact on wayfinding performance.

Research on people's wayfinding performance helped to establish practical guidelines on how to design public buildings to facilitate wayfinding. Arthur and Passini [8] introduced the term *environmental communication*, arguing that the built environment and its parts should function as a communication device. They mention two major aspects regarding the understanding of buildings: a *spatial* aspect that refers to the total dimensions of the building and a *sequential* aspect that considers a building in terms of its destination routes. Destination routes should eventually lead to destination zones. These are groupings of similar destinations within buildings into clearly identifiable zones. In order to facilitate wayfinding to such destination zones the circulation system should be of a form people can easily understand.

Affordances

The theory of affordances [2] is based on ecological psychology, which advocates that knowing is a direct process: The perceptual system extracts invariants embodying the ecologically significant properties of the perceiver's world. Gibson's theory is based on the tenet that animal and environment form an inseparable pair. This complementarity is implied by Gibson's use of ecological physics. Such physics considers functions of the environment at an ecological size level contrary to a description in terms of space, time, matter, etc., within classical physics. Affordances have to be described relative to the person. For example, a chair's affordance "to sit" results from a bundle of attributes, such as "flat and hard surface" and "height", many of which are relative to the size of an individual. Later work with affordances builds on this so-called agent-environment mutuality.

Affordances can be considered as measurable aspects of the environment, but only to be measured in relation to the individual. It is particularly important to understand the action relevant properties of the environment in terms of values intrinsic to the agent. Warren [9] demonstrates that the "climbability" affordance of stairs is more effectively specified as a ratio of riser height to leg length. Experimentally, subjects of different heights perceived stairs as climbable depending on their own leg length, as opposed to some extrinsically quantified value. Additionally, dynamic or task specific conditions must be considered.

Many researchers have believed that Gibson's theory is insufficient to explain perception because it neglects processes of cognition. His account deals only with individual phenomena, but ignores categories of phenomena [10]. Norman [11] investigated affordances of everyday things, such as doors, telephones, and radios, and argued that they provide strong clues to their operation. He recast affordances as the results from the mental interpretation of things, based on people's past knowledge and experiences, which are applied to the perception of these things. Gaver [12] stated that a person's culture, social setting, experience, and intentions also determine her perception of affordances.

Affordances, therefore, play a key role in an experiential view of space, because they offer a user centered perspective. Similarly, Rasmussen and Pejtersen [13] pointed out that modeling the physical aspects of the environment provides only a part of the picture. “The framework must serve to represent both the physical work environment and the ‘situational’ interpretation of this environment by the actors involved, depending on their skills and values.” [13, p. 122] This can be broken into three relevant parts, the mental strategies and capabilities of the agents, the tasks involved, and the material properties of the environment. In order to supplement Gibson’s theory of perception with elements of cognition, situational aspects, and social constraints, Raubal [14] presented an extended theory of affordances suggesting that affordances belong to three different realms: physical, social-institutional, and mental. In a similar effort, the framework of distributed cognition was used to describe and explain the concept of affordance [15].

Agent simulation for wayfinding

Simulation of human behavior in space is a powerful research method to advance our understanding of the interaction between people and their environment. It allows for both the examination and testing of models and their underlying theory as well as the observation of the system’s behavior [16].

According to the heterogeneity of the fields there is no common agreement about a definition of the term agent. An agent can be regarded as anything that perceives its environment through sensors and acts upon that environment through effectors [17]. Agents are situated in some environment and capable of autonomous action. Autonomy and the embedding into the environment are the two key properties of agents. Categories such as intelligent, distributed, and mobile agents exist.

Multi-agent systems (MAS) depict systems as a combination of multiple autonomous and independent agents and are therefore well suited to simulate the wayfinding behavior of different actors. Formally, the term multi-agent system refers to a system consisting of the following parts [18]:

- The *environment E* consisting of:
    - A set of *objects O*. Objects can be perceived, created, destroyed, and modified by agents.
    - A set of *agents A*. Agents are a subset of objects ($A \subseteq O$) capable of performing actions—the active entities of the system.
    - A set of *locations L* determining the possible positions of the objects (from the set *O*) in space.
- An assembly of *relations R* that link objects and agents.
- A set of *operations Op* enabling the possibility for agents to perceive, manipulate, create, and destroy objects of *O*, in particular representing the agents’ actions.
- A set of *operators U* with the task of representing the application of the operations from *Op* and the reactions of the world to this attempt of modification. The operators from *U* are called the *laws of the universe*.

Agents have been mainly dealt with in Artificial Intelligence but have recently also gained popularity in other fields such as geography. MAS are of interest to simulating various human activities in the geo-domain due to their ability to reflect human behavior.

KEY APPLICATIONS

Agent-based simulation for human wayfinding has been used to simulate people's wayfinding behavior in spatial information and design systems. It can help to determine where and why people face wayfinding difficulties and what needs to be done to avoid them. Affordances have been implemented in such agent-based frameworks to model the agent's behavior in a cognitively plausible way [19]. For example, paths, which are clearly discernible—through markings on the ground or guiding structures on the side or above—facilitate visually controlled locomotion, which is directed by visual perception and depends on sequential optical information. In other words, paths afford moving along (doorways afford entering, columns afford obstructing, etc.). It has also been shown that integrating the affordance theory into agent architectures is an elegant solution to the problem of providing both rapid scenario development and the simulation of individual differences in perception, culture, and emotionality [20].

Agent simulation can also be employed for the analysis of geospatial problems related to wayfinding, such as the behavior of customers shopping in a mall [21], spatial communication with maps [22], and wayfinding in virtual spaces [23]. Other application domains for agent simulation of wayfinding include pedestrian traffic flow [24], and crowd and evacuation simulation [25].

FUTURE DIRECTIONS

In the future wayfinding research will focus more deeply on commonalities and differences between wayfinding in the real world compared to wayfinding in electronic and virtual spaces. Finding the particularities with regard to human spatial cognition will help designing more user-friendly wayfinding systems. The concept of affordances needs to be further developed to account for social and cognitive processes, and also with regard to its representation in computer systems. This way the concept will become more useful, both in geospatial system design and with regard to various aspects of Artificial Intelligence and robotics. Agent simulation of wayfinding will be extended to cover more and different application domains and therefore help in testing wayfinding models.

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Spatial Cognition
Simulation and Dynamic Spatial Modeling
Navigation and landmarks

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