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# The Impact of Autonomy and Reasoning on Social Roles for Robotics

**Matthew T. Long** MTLONG@CSE.USF.EDU
**Robin R. Murphy** MURPHY@CSE.USF.EDU
*Institute for Safety, Security and Rescue Technology*
*University of South Florida*
*4202 E Fowler Ave., ENB 118 Room 342*
*Tampa, FL 33620 USA*

## Abstract

In human social systems, roles are a key mechanism for social interaction and integration. In particular, they are instrumental in allowing humans to operate in a variety of different social contexts. This article surveys the sociological understanding of roles, their use by software agents, and the nascent literature of role-based robotics. The survey suggests that robots can use social roles to emulate naturalistic taskability. The article presents a novel mapping of role-based system interaction as a function of system autonomy and reasoning capability.

## 1. Introduction

Multirobot systems are currently used in a wide variety of situations, from search and rescue to military applications to off-world exploration. Unfortunately, these robot systems are rarely shared between domains – existing approaches to multiagent or multirobot system design, such as (Zambonelli, Jennings, & Wooldridge, 2003), incorporate domain knowledge directly in the software and system designs and therefore must be redesigned for a new domain. Efficient operation within a single domain is important, but adaptation to a new context is integral for the rapid deployment of robot systems, particularly since many robot functions (e.g. mobility) may not change. Interoperability could allow robot systems designed for use with United States search and rescue teams (Murphy, 2004; Gage, Murphy, Rasmussen, & Minten, 2004) to be integrated into an agent-based multinational rescue operation of the sort described in (Tate, Dalton, Bradshaw, & Uszok, 2004; Pěchouček, Mařík, & Bárta, 2002).

This paper investigates how humans are able to interact and operate in varied social situations, and discusses how autonomous systems might operate in a similar manner. Human social systems use *roles* as a key mechanism for social interoperability. Roles define the interactions of individuals within a social context, and are inseparable from the context itself. They are also learned; people are not born with the direct knowledge of the roles they will need in life. As roles allow individual human persons to operate in a wide variety of domains on a regular basis, the connection between this concept and artificial social systems may provide useful architectural insights and knowledge structures for robots.

This paper makes three contributions towards understanding the import of social roles in robotics as well as discussing requirements specific to autonomy and reasoning capability for robotic systems. First, robots can use social roles to enable behavior and adapt to new domains. The foundation for this claim is based on roles from the social sciences as well as related work in artificial agent-based systems. Second, this paper provides a survey of the current state of role-based robotics. Finally, it suggests general requirements that robotic systems must support in order to take advantage of social roles and discusses the relationship of social roles to autonomy and reasoning.

## 2. Brief Survey of Roles

In order to facilitate a consistent discussion relating work in artificial roles, this section summarizes terminology related to roles from a sociological standpoint. To solidify the concept, this section will describe a *Search Specialist* role. This role is considered in the context of a disaster scenario and will serve to link role concepts to a practical example. Subsequently, it looks at how roles have been used in artificial systems, particularly software agent (Section 2.2) and robotic (Section 2.3) systems.

### 2.1 Roles

What are roles? And why are they important for robotics? In modern social science, a *role* is "a behavioral repertoire characteristic of a person or a position; a set of standards, descriptions, norms, or concepts held for the behaviors of a person or social position; or (less often) a position itself" (Biddle, 1979, pg. 9).

Biddle also suggested a set of statements that incorporated the early work in roles of Mead (Mead, 1934), Linton (Linton, 1936) and Moreno (Moreno, Jennings, Criswell, Katz, Blake, Mouton, Bonney, Northway, Loomis, Proctor, Tagiuri, & Nehnevajsa, 1960), as well as many others in the field. While these statements did not address specific differences between researchers, the general consensus provides a minimum set of concepts that must be addressed by any technical adaptation of roles to artificial systems. Namely, any treatment of roles must define *roles* relative to a *social position* in a social context. Within that social context, these roles must be associated with some *function* or behavior, and this behavior is subject to a set of *expectations* regarding how the role operates. Finally, there must be a consideration of how the roles change over time as *socialization* into new contexts occurs.

Roles help humans to navigate the myriad social contexts presented in daily life. This abstraction is key for robotics; roles link an agent with action (*what* the agent does) and expectation (constraints on *how* the action is performed) within a particular context.

Jahnke, *et al.* (Jahnke, Ritterskamp, & Herrmann, 2005) examined roles in a socio-technical context and view roles based on both a *static* description (*role dimensions*) and a *functional* description (*role mechanisms*). In this view roles are defined in terms of four static dimensions (position, functions, expectations and interactions) and six dynamic mechanisms (role assignment, role change, role making, role taking, inter-role conflict, and role definition). These ten characterizations form the basis for this discussion of roles. The four role dimensions are described briefly below:

1. *Position*: Roles reflect a static view of an organizational structure. The position of a role in a social structure defines the functions and tasks that are required for the role.

A search specialist fits within the organizational structure of a search team within a task force, and is defined relative to other roles, such as commander or doctor.

2. *Functions and tasks*: Each role is associated with a formal set of permissions, obligations and activities that are defined by the social organization, and associate a role with how it is performed. The functions of a search specialist include looking for signs of trapped victims, bodies and structural or safety conditions. There are often time or safety constraints on these tasks.

3. *Behavioral expectations*: While the functions and tasks of a role are a formal description of the role, the behavioral expectations are informal or formal conventions bound in the social interactions of a role. Violating conventions can earn an agent negative sanctions from other agents in the community. Indeed, in some situations these behavioral conventions are as formal and binding as the functions and tasks. A search specialist, for example, might be expected to terminate a search and get help if a victim is found and must mark structures after they have been cleared.

4. *Social interactions*: Finally, a role player's ability to play the role can feed back and shape the role definition itself, whether through modifying the role's behavioral expectations, core functions, or even position in the social system itself. A search specialist can adapt to new techniques or information from other teams during a debriefing to enhance and modify core skills.

If the four role dimensions are a *structural description* of a role and its relations, the following six dynamic relations, known as role mechanisms, are a *functional description* of how an individual interacts with roles. These mechanisms define a *role lifecycle* which controls the operation and interaction of a role within a social context:

1. *Role assignment*: Role assignment is the process of assigning a role to an agent in a social system. Role assignment is a statement of desire, not a guarantee that the agent will accept or be able to play the role. Note that an agent can assign a role to itself to fulfill internal goals. The search role is assigned by the search team and joining the search team is an implicit acceptance of this role assignment.

2. *Role taking*: Role taking occurs when an agent uses the known role played by another agent to build a model of the other agent's behavior. Coutu (Coutu, 1951) noted that role taking is often erroneously confused with role assignment. Role taking requires a shared understanding of the role dimensions for construction of a meaningful mental model. If one search specialist encounters another coming out of a search area, the first searcher's model of the other would expect the area to be cleared and marked.

3. *Role change*: An agent may play one or more roles simultaneously or in sequence, and role change is the process of relinquishing a role and assuming another. Any individual plays a number of roles in daily life. A search specialist might switch to another role, such as emergency medical technician or paramedic on encountering an injured victim.

4. *Role making*: In a human society, each person that plays a role does so in their own unique manner, and transforms the behavioral expectations into concrete action in different ways. A search specialist might have specific knowledge of certain types of structures, such as those in a commercial business district. This specialist would play his role in a different manner than one with knowledge of single-story dwellings.

5. *Inter-role conflict*: An agent may hold multiple roles, and the goals of each may conflict. A search specialist might note a structural problem with a building making it dangerous to search. This information would conflict with the role's core search function and must be resolved.

6. *Role definition*: Over time the definition of a role may change. This may be due to changing circumstances, where a role may be radically changed or a new role created, or due to a negotiated social change in the behavioral expectations due to the role making of different actors. Introduction of new technologies, such as digital cameras or global positioning, influence how this search role is performed and change how the role interacts with others in the search team.

### 2.2 Agents Using Roles

The bulk of prior work with roles in multi-agent systems has appeared out of the software agent community, which can provide insights for the closely related field of multi-robot systems. Work influencing the static role description in agent systems has included social norms and policies (Boella & van der Torre, 2005; Felicissimo, Lucena, Carvalho, & Paes, 2005) as well as social enforcement (Boella & Lesmo, 2001; Bradshaw, Uszok, Jeffers, Suri, Hayes, Burstein, Acquisti, Benyo, Breedy, Carvalho, Diller, Johnson, Kulkarni, Lott, Sierhuis, & Hoof, 2003). Wooldridge, *et al.* (Wooldridge, Jennings, & Kinny, 2000), in particular, observe that multi-agent system design is more complicated than traditional software engineering, which fails to capture an agent's problem solving behavior and social interactions. They propose the GAIA methodology for agent-oriented design, using roles to model the responsibilities, permissions, activities and protocols of an agent. In a sense, though, this methodology and Zambonelli's (Zambonelli et al., 2003) extension to incorporate organizational structure, only describe the first two static dimensions of role analysis: position and function.

In open multi-agent systems, where agents can enter or leave the system, it is not enough to simply describe the static role dimensions. These agents need to incorporate role dynamics as well. Dastani, *et al.* (Dastani, van Riemsdijk, Hulstijn, Dignum, & Meyer, 2005) have studied dynamic role assignment in such open systems, and Boissier, *et al.* (Boissier, Carabelea, Castelfranchi, Sabater-Mir, & Tummolini, 2005) look at how an individual's cognitive framework and behavior can change when playing a role, and describe how the role can influence the individual's goals, desires and beliefs, as well as cause the individual to dynamically gain or lose influence or power. A reasoning agent may agree to play a role in order to gain access to information that will help with private goals even if it means accepting new restrictions or obligations.

Autonomy is particularly important for fully introducing roles into artificial systems, and Colman and Han (Colman & Han, 2005) have investigated how autonomy relates to roles and agency, particularly with respect to organizational structure (social *position*) and the agent's capability to perform the role *function*. They propose five levels of autonomy: no autonomy, process autonomy, system-state autonomy, intentional autonomy, and autonomy from constraints. Unfortunately, the general level of implementation of the role dimensions and role mechanisms within this framework is unclear.

Other agent systems and architectures do not directly encapsulate the concept of a role, but can often include concepts that are similar or offer similar functionality. The Knowledgeable Agent-oriented System (KAoS) (Bradshaw, Dutfield, Benoit, & Wooley, 1997), for example, "defines basic ontologies for actions, actors, groups, places, various entities related to actions (e.g., computing resources), and policies" (Bradshaw et al., 2003). However, these ontologies do not directly address the role concepts in Section 2.1, but the system's strong policy management capabilities could be used to describe and regulate role expectations.

### 2.3 Robots Using Roles

Multi-robot systems is a less developed field than general multi-agent systems. As a result, research on strong social interactions between robots and well-defined multi-robot domains have been slower to develop. However, there has been some recent work in this area. As field robotics is inherently failure-prone (Carlson & Murphy, 2005), and is thus by definition an open agent environment, it is natural that research will lead in the direction of the dynamic characterization of roles.

Roles appear in previous robotics literature, but they do so primarily as a synonym for *task*, without many of the stronger social aspects; these uses of roles appear to be strictly limited to role-assignment and role-change. Roles have been used in this manner to build formations composed of a set number of specific roles for robot soccer (Stone & Veloso, 1999). As the soccer game progressed, formations (and thus roles) would change dynamically. Roles also appeared as a vehicle to test a Q-learning-based role-assignment mechanism using a foraging task in a hostile environment (Martinson & Arkin, 2003). Finally, roles have been used in a more recursive manner for self-reconfigurable robots; each reconfigurable module could assume a role within the robot such as "leg" or "spine" (Støy, Shen, & Will, 2002). Role selection and assignment provided the required behavior for the module within the social context of the robot, but did not influence how the robot interacted with other agents.

In the robotic context roles are used as a concrete tool to assign and allocate behavior, showing that a role-based system can effectively administer behavior in an artificial system. However, roles have been used in the agent context as both a design tool and as a dynamic regulatory mechanism. Unfortunately, while these artificial uses of roles in agent systems have drawn inspiration from roles in human systems, they have not yet captured the power, flexibility and utility of these natural systems.

## 3. Discussion

This section discusses the relationship of the four role dimensions and six role mechanisms to autonomy and reasoning, plus offers a graphical mapping to relate these concepts. The need for such a mapping stems from differences in natural and artificial systems. Natural

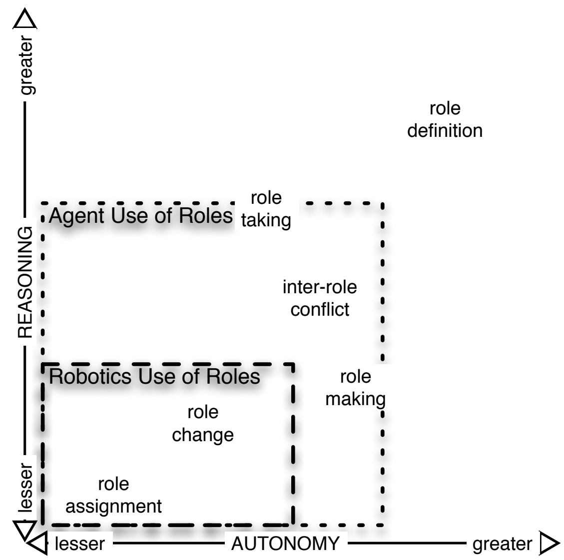


Figure 1: The influence of autonomy and reasoning on role mechanisms

social systems have a particularly large advantage over artificial social systems – all or almost all the members of a natural system are autonomous entities with a high level of reasoning ability. Artificial social systems are typically endowed with much less autonomy and computational power. In systems where none of the artificial agents have the requisite abilities, the role dimensions and mechanisms must be simulated or processed by a human developer or designer and may not operate in real time. Consequently the effect of both autonomy and reasoning ability on these role dimensions, mechanisms, and artificial system design must be considered in order to successfully design these social systems and the agents within them.

Of the four role dimensions, the *position* and formal *functions and tasks* are of primary importance to artificial social systems and the implementation of roles. In particular the *position* is a description of how the different roles relate to each other, essentially defining the social structure of the domain. This has a large impact on the norms of the system, namely the rights, restrictions and permissions one role is granted over another. The functions describe the particular obligations of the role player when the role is assumed. The reasoning ability of a software system is of particular importance in consideration of these two role dimensions; a reasoning system can use a formal definition to infer consequences of the interaction of role obligations, right, permissions and other roles.

The *behavioral expectations* and *social interactions* between roles are of a less direct relevance as they are both informal or an implicit expectation of behavior. However, as Hicinbothom, *et al.* (Hicinbothom, Glenn, Ryder, Zachary, Eilbert, & Bracken, 2002) note, experts often rely on this implicit knowledge to boost performance in human teams. Autonomy has more of an impact on behavioral expectation and social interactions. Both require the ability to vary from a pre-planned behavioral script and the ability to react to other agent's actions that do not conform tightly to a formal specification.

The six role mechanisms are particularly dependent on both autonomy and reasoning. Figure 1 presents a novel characterization of the relative system requirements for each of the role mechanisms as well as the current utilization in both agent (Section 2.2) and robot systems (Section 2.3).

*Role assignment* and *role change* can be handled by a system with limited autonomy and reasoning capabilities through a role or task allocation mechanism such as that described in (Gage, 2004). In this sense role allocation can be viewed as task allocation, although role allocation is constrained not only by the demands of the task and the resources of the robot platform, but also by the behavioral expectations of the social systems in which the robot is embedded.

However, other role mechanisms require increased autonomy and reasoning ability. Anticipating the behavior of other entities in the system (*role taking*) requires a great deal more reasoning ability (to anticipate actions) and autonomy to change behavior based on the predictions. Role taking may not require significantly more autonomy as the responses to these other entities may be dictated by the active roles. A goalie in robot soccer, for example, might take the role of the opposing forward to predict the opponent's actions, but the response might still be constrained by the goalie role itself.

On the other hand, *role making* would require more autonomy to allow variance in individual performance. To some extent, this variance will happen – as hardware fails, batteries run low, or individual robots degrade in some other manner performance of a given role will differ. However, more autonomous systems will begin to have goals that are not entirely constrained by the current role. A robot with individual goals, or one with compatible goals from different contexts, will play a role differently. The role making mechanism provides a framework to capture this difference and update expectations on an individual basis.

The *inter-role conflict* mechanism requires some amount of both autonomy and reasoning to respond correctly. This mechanism is influenced by several factors. On one hand, some portion of conflict can be detected and handled as part of a role assignment or role change mechanism before a role is accepted or played. But what if an error condition is detected at runtime? Failing up to a higher power, a human or other agent in a higher role is always a possibility and certainly a requirement in many social contexts. However, these solutions do not require any additional capability over a minimum level. A more appealing approach does require more autonomy and additional reasoning capability. *Adjustable autonomy* (Bradshaw, Jung, Kulkarni, Johnson, Feltovich, Allen, Bunch, Chambers, Galescu, Jeffers, Suri, Taysom, & Uszok, 2005) allows the robot some freedom to modify, or even temporarily ignore, certain aspects of the role, particularly social expectations of behavior. The robot would require the autonomy to deviate from assigned behavior and the reasoning ability to determine which constraints could or should be changed.

Finally, *role definition*, the creation of new roles, requires the most reasoning ability and autonomy to handle successfully. Here the robot must not only determine that some function is not currently filled by a role in the social system, but the appropriate role dimensions must be generated. On top of this process, there is a social aspect that must be considered – that of sharing knowledge of the new role and the development of appropriate expectations by other agents in the social context. At present, this mechanism is handled by the system designer, but if systems become more autonomous and are able to reason more effectively about the state of their social environment, these tasks could hopefully move to the robots themselves.

## 4. Conclusion and Future Work

This paper has investigated the use of roles in human social systems leading to insights for robotics, and has summarized the literature on roles in the software agent and robotics communities. This work has three main implications for additional research.

First, the preliminary mapping of roles to robotic autonomy in Section 3 should be expanded. A formal understanding of the relationship between roles, agents and domains is needed. While the use of roles to enable behavior can be relatively straightforward, the impact of autonomy and reasoning ability on the role mechanisms is less well understood and is another open area of research.

Second, most previous work on roles in artificial systems has involved agents that have limited autonomy, reasoning ability, or a mixture. A systematic investigation of the effect of both autonomy and reasoning capability on roles and role mechanisms could uncover guiding principles for system design. Mismatches between the role mechanisms expected or required to fully function in a domain and the role capabilities of autonomous platforms could have severe implications for large-scale, flexible robotic systems.

Third, artificial systems may need to model or understand roles to successfully interact with humans for extended periods or within complex tasks because roles are inherent in human social interactions. Research may also find, for social interaction between humans and artificial agents, an analog to the "uncanny valley" of humanoid robotics if the role mechanisms do not work in a fully human-like manner.

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