Collaborative design is a complex group activity involving participants with heterogeneous skills. Any useful support system must take that heterogeneity into account. This article demonstrates that group support agents are viable for design tasks. It explores the problem of supporting emergence, a significant feature of the creative design process. Agents that support emergence cannot simply manipulate predefined objects. They must be involved in the deconstruction and reconstruction of those objects. We will describe how group support agents can assist design teams and illustrate how the outstanding problem of support for shape emergence in design communication is being addressed by the construction of agents that apply pattern recognition methods to object representations.

**Multiagent Support Systems**
Intelligent support to design is a significant topic—see, for example, Gero and Sudweeks [9]. Multiagent systems that support design are being developed, for example, the ACDS project [6]. The goal is to deploy agents to support a range of functions relevant to the design process when considered from a range of perspectives [3]. In this context it is important to note that although agents may be computer programs they may also be humans. A multiagent system can be very complex.

Bird [2] has proposed a taxonomy of multiagent systems. One of the dimensions that he identifies is the heterogeneity of the agents. A collection of agents might be collaborating on a task in a homogeneous way, in which case we are able to assume a certain common base of understanding between them. On the other hand, they may be heterogeneous for a number of possible reasons. Bird classifies the reasons as **syntactic**, **control** and **semantic**.

Syntactic differences can occur because of the use of different knowledge representation formalisms. Given the computational equivalence of the formalisms, translation agents can be provided. This is important, even for a single designer, because alternative views of the same knowledge are often helpful when contemplating difficult problems.

Control differences occur when different inferencing strategies are used to process the same knowledge. This does not represent a fundamental computational problem but is a source of major potential confusion. The difficulty is in identifying clearly which inferencing method is in use.

The third of Bird’s classifications is semantic and, here, the problem is that the same knowledge, as expressed, may have different meanings to different agents. For example, the same symbol may have different meanings in different domains. This issue is particularly significant in the more creative aspects of design where new meanings emerge from old representations.

It follows that the heterogeneity of the agents involved in design has implications for the deepest level of knowledge representation that might be used to share information among
them. We will come back to this issue after discussing the general value of group support agents for design. First, we will describe an approach to heterogeneous multiagent group support that has been applied to design. The specific topic was the design of road systems, although the work was, in practice, more general.

**Multiagent Group Support**

In developing a geographic information application to support design conferences, knowledge-based techniques were applied to group support in order to:

- provide context-sensitive dialogue, that is, dialogue that is responsive to the current state of interaction.
- provide conference management functions, such as enabling users to join and leave the group.
- enable group interaction with a remote geographic information system, that is, enable users to invoke an application's functionality and view one anothers' results.
- provide awareness of other members of the group.
- enable individual preferences.
- provide advice on group administration.

Five types of group agent provide the group support in the Geographic Decision System (GDS) as shown in Figure 1 [10].

A **conference agent** controls the initialization of the system. It interacts with the conference initiator, the person who starts the conference, to specify the other users, their locations and the applications to be shared. The conference agent creates a presentation layer and dialogue controller for each user, it invokes the other agents and it initiates the appropriate application interface module and applications. The conference agent retains the knowledge about the users in the conference and their locations. It enables the configuration of the system to be dynamically changed by the group to allow newcomers to join, members to leave and different applications to be shared.

If there are a large number of people in a group, it becomes difficult for members to keep track of user input. One solution to this problem is to introduce “floor control” whereby only one user can enter data at a time. There are many types of “floor policy” such as moderated, first-come or round-robin. The **floor agent** offers a selection of floor policies and the ability to change the floor policy. It interacts with the user agent, discussed later, to enforce only single-user access.

The **application agent** provides services to the group from existing, possibly remote, software systems. The example from GDS was a geographic information system. The application agent intercepts messages between the dialogue controllers and the application interface module in order to modify their content appropriately. Although this agent is not directly concerned with heterogeneity, it is important that it delivers its information in a form that supports the user agent's concern for heterogeneity.

The **group agent** supports the tailoring of the group options. For example, it might be inappropriate that every user has the option to end the conference. The configuration can be changed dynamically within the conference and is controlled by the configuration agent.

The **user agent** intercepts all messages passing between the presentation layers and the other group agents or dialogue controllers. This enables it to have master control of the interaction with the users. The user agent controls shared views and individual views, and as a result, shared working and individual working. Thus it is specifically responsible for handling syntactic heterogeneity. The user agent enables different members of the group to view the data from different points of view and to interact with it, and with one another, in different styles.

When the system is supporting shared working, the user agent broadcasts user input to all dialogue controllers. Thus, a dialogue controller might receive multiple responses to one interaction object. The dialogue controller handles each response in turn and, being written in a declarative manner, encounters no problem with sequencing. Hence, the GDS system supports preemptive scheduling whereby users are able to enter input whenever they want.

When we later consider semantic heterogeneity, or the identification of different meanings in the same interpretation, it will be clear that the user

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*Figure 1. The GDS architecture*
agent could be extended by the provision of what we will term emergence agents.

There has been a clear emphasis on the separation of function by having distinct components. Certain components are ready-built, such as the presentation layer, the communications bus, the conference agent, user agent, floor agent and the configuration agent. Others must be built for each new application, such as the dialogue controller, parts of the application interface module and the application agent.

How emergence agents for design are to be constructed is not a resolved question. In order to address the problem, we must first look at the nature of innovation and emergent thinking in the design process. We will do this by considering a specific example of innovative design.

**Innovation in Design**

Mitchell [12] points out that . . . design is not description of what is, it is exploration of what might be.

Drawings are valuable precisely because they are rich in suggestions of what might be . . . . Thus the meaning of a drawing is not adequately captured by imposing one structure on it.

He argues that designers frequently see shapes that had not been consciously constructed:

Designers . . . frequently recognize emergent subshapes, and subsequently structure their understanding of the design and their reasoning about it in terms of emergent entities and relationships [11].

The design process has, among its important characteristics, exploration, analysis and evaluation. However, emergence is particularly significant in relation to creativity [4]. A review of a particular design development will help to clarify the importance of emergence and the challenge it represents for design support systems.

A study of the design of the LotusSport bicycle (Figure 2) has provided valuable insight into design reformulation in both form and structure during the design process [5]. This reformulation illustrates how an emergent form arises during the design activity. The process whereby the designer, Mike Burrows, arrived at a radical transformation of the concept of the bicycle frame was the subject of study.

In the development of the design of the “monocoque” frame, the designer moved from adapting existing models toward a complete reformulation of the guiding principle of the design of the bicycle, that is, maximize the aerodynamics. This process began as the work of a single individual who carried out all the sketching, construction, and testing himself. As the transformation from steel-tube diamond frame to single-unit carbon-

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Figure 2. The LotusSport bicycle in action

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1Lotus Engineering defines a monocoque as “a completely closed, thin wall, unitary load-bearing shell construction.”
fiber monocoque took place, so did the nature of the design and development process. The scope of the activities was extended and necessitated a collaborative team effort. This was a result of introducing radically different methods, especially composite materials processing, into the scope of the activities. This emergent design required team effort in order to ensure that all the skills were in place. No individual could cover all that was needed.

The “Funny” bike shown in Figure 3 was based on a conventional diamond frame structure but, at the time of its conception and realization, it was considered to be an unconventional interpretation. By taking one element, the top tube, and sloping it forward as far as was thought practical, the effect was to push to extremes (distort) the existing angles of the frame such as the head tube angle and seat tube angle. This was an open-ended exploratory design that involved breaking conventional rules. The fact that the resulting bicycle proved to be effective in performance was a surprise to its designer.

The sketch in Figure 4 shows a further progression in the design where the “Funny” bike frame is adapted to become the Universal frame shown in Figure 5. This adaptation was a transition stage between the exploratory design of the “Funny” bike and the innovative monocoque frame that eventually became the LotusSport bicycle (Figure 7). The transition was done in such a way as to reduce the size of the frame from 23 inches to 16 inches with a flat top tube and an extended seatpost to accommodate rider size. The result is a new design that has been evolved from the previous one but retains the basic form and structure of the original.

In Figure 6 the diamond frame is overlaid in such a way as to begin to alter the form itself. The steel tubes are hidden and the shape is completely changed beyond the then-current normal expectations of a racing bicycle frame. In construction, using carbon fiber composite material, the underlying structure was transformed: there were no steel tubes and the frame was a single piece, or monocoque.

An emergent form displays characteristics not present in its source. As the final result illustrates, this frame is a true emergent form. Not only is the diamond frame dispensed with, but the underlying structure of the frame has been totally transformed: it is a one-piece carbon-fiber unit. Thus any support system used in such innovative design must take account of emergence of semantic heterogeneity.

**Emergence in Innovation**

If adequate computer support is to be provided to innovative design it must enable designers to readily communicate with and through the computer about emergent shapes. This has certain intrinsic difficulties because of the very fact that an emergent shape in a particular image is not directly implied by the existing components of that image and, therefore, may not be computationally easy to recognize.

It can be suggested that the act of drawing achieves the externalization of knowledge that exists in the designer’s mind. The fact that the drawing is constructed as an arrangement of preconceived objects in a particular relationship is a reflection of the meaning of these objects to the agent concerned. Therefore, the computational modeling of emergence achieves the important function of supporting the semantic dimension of heterogeneous group dynamics, according to Bird’s classification. This is because emergence results in the perception of new shapes that were not intended to be represented in the drawing. In other words, emergence is associated with different interpretations of the knowledge that is expressed in the form of a given drawing.

The key psychological concept fundamental to the notion of emergent shapes is that of structural descriptions associated with a drawing. The entity of a drawing might be thought of as a visual image together with an associated verbal description that imposes structure on it [8]. Thus a drawing may be thought of as a structured entity. From this perspective, an emergent shape occurs when a revised description, or structure, is discovered.

Reed [13] conducted two experiments based on what he termed “ambiguous patterns,” such as Figure 8. This figure can be seen as two overlapping triangles, for example, or two overlapping parallelograms. His results showed that theformer structure was significantly more often perceived than the latter. However, the central diamond, to take another example, was fairly readily seen as a structural element of the whole. In terms of emergent shapes, we might then, say that Figure 8, drawn as two triangles, may readily deliver the emergent shape of the diamond but might not generate a perceived parallelogram so easily. Hence the perception process that leads to emergent shapes is itself structured in some way and favors particular outcomes. Our study of the bicycle showed that this aspect of design is the center of innovation and, therefore, cannot be overlooked.

In simple terms, if the picture is created by one designer using an object-oriented drawing system by placing one triangle on another and a second designer sees the diamond and wishes to select it, conventional systems offer little support. Agents that can understand, even predict, the emergent shape and so facilitate the required interactions are needed.

**Agent Support for Emergence**

A computational approach to modeling emergence, and hence to constructing agents that can, at the least, respond readily to emergent understandings of designers, must handle the deconstruction and reconstruction of objects. What is required is that the user agent discussed previously have access to emergence agents that can track, predict or, at least, rapidly follow a member of the design team as they perceive emergent forms in the design representations. The construction of such agents depends on the determination of appropriate deconstruction and reconstruction methods.

Tan [17] addresses this problem, in the context of the use of line drawings in design, by formulating higher-
Figure 8. Reed’s “ambiguous pattern”

Figure 9. The emergence agent at work

level line descriptors, in terms of construction lines. Thus a representation of a drawing is employed that enables new shapes to be discovered in it. Four functions are described that can produce emergent shapes rather in the manner of a generative grammar (see, for example, Stiny [16]). The basic strategy is, then, to take a drawing as described in its construction process, for example, two triangles, and to transform that description into an intermediate representation that enables the generation of emergent shapes. The same strategy is proposed here, although the intermediate representation is different to Tan’s. It is suggested that our method is more amenable to the taking into account of knowledge about perception. If we are to track and support human users this must be an important consideration.

This approach to constructing emergence agents concentrates on modeling the action and perception elements in the process, in which creative leaps often occur. We illustrate our case by considering drawings of the kind shown in Figure 8. Given that the drawing is an intentional act, it may be considered in terms of the employment of an object-oriented drawing system, such as MacDraw [1]. Thus, we assume that the originator constructs the drawing by combining a number of preconceived objects in particular relationships.

As mentioned by Scrivener et al. [14], a key step is to consider the resulting image, not as a collection of objects, but as a pixel array. We are then able to apply certain image processing methods to it, via a quite separate software system, to search for subshapes. In our exploration of this approach [7], we have applied a computational system based on perceptual psychology, described by Soufi and Scrivener [15]. Thus, to be precise, drawings were created using MacDraw and then presented to the image analysis code in pixel array format, rather than in their structured form. In this way, independent drawing and looking processes were modeled.

The exploration consisted of the construction of a number of images in MacDraw followed by various analyses of them by Soufi and Scrivener’s system. Interesting results are found from slightly varied images and from the application of different grouping hierarchies. We thus model the drawing process in the object-oriented drawing package and the perception
process in the analysis system. An image analysis system can therefore be used to generate an interpretation of an image that was not originally intended.

To take the example of Reed’s ambiguous pattern, we constructed it in MacDraw by combining two triangle objects in the obvious way. The resulting bitmap was then presented to the computational system of Soufi and Scrivener, which produced a description of the image in terms of the single diamond, a group of four triangles and the background (Figure 9). The clear identification of the diamond object is consistent with Reed’s findings. It is not claimed that accurate modeling of the human perception process has been demonstrated from this tiny example. It is claimed, however, that the approach provides a direction in which emergence agents can be developed.

Conclusion
The article has described, through an example system, how group support agents can assist design teams and how the outstanding problem of support for emergence in design communication is being addressed by the construction of agents that apply pattern recognition methods to object representations. This is a key challenge for current computer science research beyond the design domain. The need is to discover the principles underlying the emergence of new objects from collections of existing ones.

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References

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