Swarm Intelligence: A Whole New Way to Think About Business

by Eric Bonabeau and Christopher Meyer

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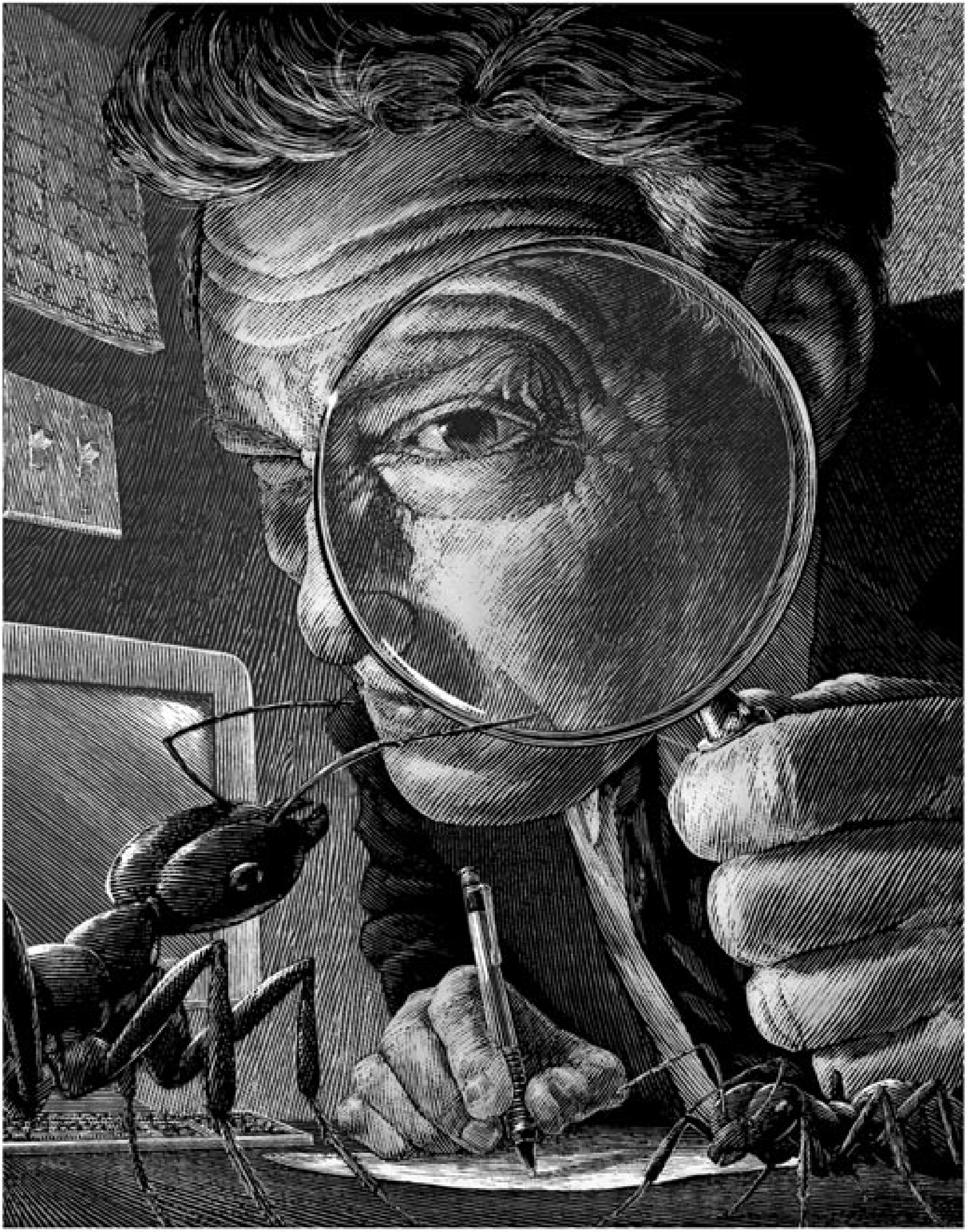
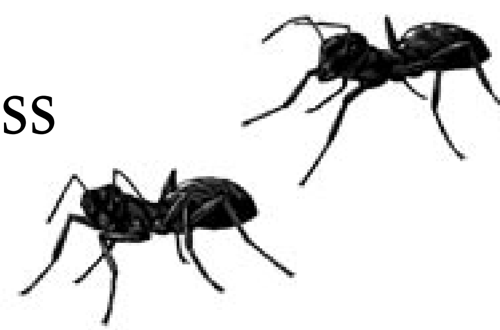


ILLUSTRATION BY GREG DEARTH

For years, scientists have been studying ants, bees, and wasps because of the amazing efficiency of social insects. Now companies like Southwest Airlines and Unilever are actually putting that research to work, with impressive paybacks.

Swarm Intelligence

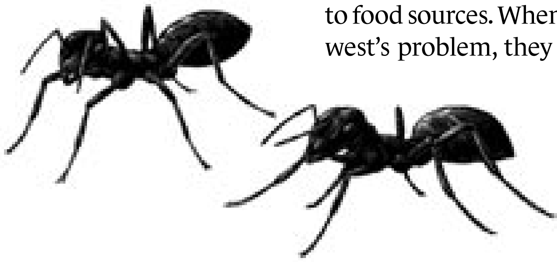
A Whole New Way to Think About Business



by Eric Bonabeau and Christopher Meyer

A LITTLE MORE than a year ago, Southwest Airlines was having trouble with its cargo operations. Even though the average plane was using only 7% of its cargo space, at some airports there wasn't enough capacity to accommodate scheduled loads of freight, leading to bottlenecks throughout Southwest's cargo routing and handling system. At the time, employees were trying to load freight onto the first plane going in the right direction – a seemingly reasonable strategy. But because of it, workers were spending an unnecessary amount of time moving cargo around and sometimes filling aircraft needlessly.

To solve its problem, Southwest turned to an unlikely source: ants. Specifically, researchers looked at the way ants forage, using simple rules, always finding efficient routes to food sources. When they applied this research to Southwest's problem, they discovered something surprising: it



can be better to leave cargo on a plane headed initially in the wrong direction. If, for example, they wanted to send a package from Chicago to Boston, it might actually be more efficient to leave it on a plane heading for Atlanta and then Boston than to take it off and put it on the next flight to Boston.

Applying this insight has slashed freight transfer rates by as much as 80% at the busiest cargo stations, decreased the workload for the people who move cargo by as much as 20%, and dramatically reduced the number of overnight transfers. That's allowed Southwest to cut back on its cargo storage facilities and minimize wage costs. In addition, fewer planes are now flying full, which opens up significant opportunities for the company to generate new business. Thanks to the improvements, Southwest estimates an annual gain of more than $10 million.

Similar research into the behavior of social insects has helped several companies, including Unilever, McGraw-Hill, and Capital One, to develop more efficient ways to schedule factory equipment, divide tasks among workers, organize people, and even plot strategy.

Just what valuable insights do ants, bees, and other social insects hold? Consider termites. Individually, they have meager intelligence. And they work with no supervision. Yet collectively they build mounds that are engineering marvels, able to maintain ambient temperature and comfortable levels of oxygen and carbon dioxide even as the nest grows. Indeed, for social insects teamwork is largely self-organized, coordinated primarily through the interactions of individual colony members. Together they can solve difficult problems (like choosing the shortest route to a food source from myriad possible pathways) even though each interaction might be very simple (one ant merely following the trail left by another). The collective behavior that emerges from a group of social insects has been dubbed "swarm intelligence."

To be sure, many business gurus have overused biological metaphors, spinning clever stories to explain the past woes or successes of companies by using analogies from the life sciences. But the emerging field of swarm intelligence goes far deeper. Over the past 20 years, we and other researchers have developed rigorous mathematical models to describe the behavior of social insects, and we are now applying those techniques to business issues. As evidenced by Southwest and other early adopters, the preliminary results have been promising.

> The ultimate application of ant-based routing methods might be on the Internet, where traffic is painfully unpredictable.

In essence, we believe that social insects have been so successful – they are almost everywhere in the ecosphere – because of three characteristics:
- flexibility (the colony can adapt to a changing environment);
- robustness (even when one or more individuals fail, the group can still perform its tasks); and
- self-organization (activities are neither centrally controlled nor locally supervised).

Business executives relate readily to the first two attributes, but they often balk at the third, which is perhaps the most intriguing. Through self-organization, the behavior of the group emerges from the collective interactions of all the individuals. In fact, a major recurring theme in swarm intelligence (and of complexity science in general) is that even if individuals follow simple rules, the resulting group behavior can be surprisingly complex – and remarkably effective. And, to a large extent, flexibility and robustness *result* from self-organization.

Foraging for Solutions

To understand the power of self-organization, consider how certain species of ants are able to find the shortest path to a food source merely by laying and following chemical trails. Individual ants emit a chemical substance – a pheromone – which then attracts other ants. In a simple case, two ants leave the nest at the same time and take different paths to a food source, marking their trails with pheromone. The ant that took the shorter path will return first, and this trail will now be marked with twice as much pheromone (from the nest to the food and back) as the path taken by the second ant, which has yet to return. Their nest mates will be attracted to the shorter path because of its higher concentration of pheromone. As more and more ants take that route, they too lay pheromone, further amplifying the attractiveness of the shorter trail. The colony's efficient behavior emerges from the collective activity of individuals following two very basic rules: lay pheromone and follow the trails of others.

Variations of this simple yet powerful approach can help solve a number of business problems. Consider the unpredictable environment of a telecommunications network, in which a phone call from one place to another (Paris to Honolulu, for example) generally has to go through several intermediate nodes (perhaps New York and San Francisco). Such a system requires a routing mechanism to tell each call where it should hop next to establish the connection, and a good routing method avoids congestions to minimize delays. Backup routes are especially valuable when traffic conditions change dramatically – for example, when stormy weather at an airport or a phone-in competition on television leads to localized surges of phone traffic, which require that messages be rerouted on the fly to less-congested parts of the network.

Researchers from Hewlett-Packard's laboratories in Bristol, England, have developed a computer program based on ant-foraging principles that routes such calls efficiently. In the program, hordes of software agents roam through the telecom network and leave bits of information (think of them as "digital pheromone") to reinforce paths through uncongested areas. Phone calls then follow the trails left by the antlike agents. To fine-tune the software, the researchers have added a mechanism that continually evaporates the digital pheromone, enabling the program to adjust quickly to changes in traffic conditions. When a previously swift route becomes congested, agents that follow it are delayed, and the evaporation mechanism overcomes the reinforcement process. Soon that route is abandoned, and the agents discover (or rediscover) alternatives and exploit them. The benefits are twofold: when phone calls are rerouted through the better parts of a network, the process not only allows those calls to get through quickly but also enables the congested areas to recover from the overload. Thus the ant-based solution has the inherent advantages of swarm-intelligent systems: flexibility, robustness, and self-organization.

France Télécom, British Telecom, and MCI WorldCom have taken an early lead in designing such ant-based routing methods. But the ultimate application might be on the Internet, where traffic is painfully unpredictable. Marco Dorigo of the Université Libre de Bruxelles and his colleagues have adapted ant-based routing to handle Internet traffic. Simulation results indicate that their technique outperforms all existing routing methods, including the protocol that the Internet currently uses, in both maximizing throughput and minimizing delays.

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Ant-foraging models can also help efficiently route cargo (as at Southwest Airlines) and vehicles. In an example of the latter application, Luca Gambardella and his colleagues at the Istituto Dalle Molle di Studi sull'Intelligenza Artificiale (IDSIA) have developed an ant-based program that Pina Petroli uses to direct its fleet of trucks in distributing heating oil to its residential customers in Switzerland. Various factors complicate the scheduling task. First, the trucks Pina Petroli uses differ in size, hose lengths, street accessibility, and so on. Second, customers' orders are unpredictable and complex. For example, some customers might require emergency service; others have specific delivery windows ("I will be home only on Wednesday after 11:00 in the morning or on Friday from 2:00 to 5:00 in the afternoon"). Third, other factors, such as weather and traffic conditions, vary unexpectedly. Gambardella's truck-dispatching solution handles those factors automatically (for instance, an "ant" representing a large truck is not allowed to visit certain locations where the roads are too narrow), while minimizing the number of vehicles needed and reducing their overall travel time.

Variations on the ant-foraging algorithm can also be used to improve the efficiency of factories. For years, Unilever, the consumer goods multinational, was having trouble developing a fast, automatic, and efficient way to deploy equipment in one of its production facilities. The company's researchers had found that traditional optimization methods could not handle the intricacies of a complex-liquid manufacturing plant. In such a facility, the chemical mixers, storage tanks, and packaging lines each have different constraints, including their rates of operation, ability to be connected to other equipment, capacities, changeover times for switching from one product to another, and required maintenance. Other factors complicate the scheduling as well; some of the ingredients for certain products have to be premixed, for instance. Furthermore, the factory has to adapt to a dynamic environment in which machinery may break down without warning, and customer

What Is Swarm Intelligence?

Social insects work without supervision. In fact, their teamwork is largely self-organized, and coordination arises from the different interactions among individuals in the colony. Although these interactions might be primitive (one ant merely following the trail left by another, for instance), taken together they result in efficient solutions to difficult problems (such as finding the shortest route to a food source among myriad possible paths). The collective behavior that emerges from a group of social insects has been dubbed "swarm intelligence."

demand has become increasingly volatile as lead times have plummeted from several weeks to just days.

To enhance its initial work developing a program in which each piece of equipment submits bids for work, Unilever turned to the Bios Group, the Santa Fe, New Mexico–based consulting firm that helped Southwest Airlines with its cargo operations. We and our colleagues at Bios realized that the solution required a twist on the standard foraging algorithm: instead of minimizing the time to get something from one location to another, the program must determine the shortest time to perform a set of jobs given various constraints. For example, if the changeover time for a piece of equipment might be close to an hour, the software avoids using that machinery for numerous, short tasks. Again through the use of digital pheromone, the software ants find the fastest "legal" schedule, one that allocates jobs to resources while satisfying all the constraints and making sure that every job is performed. As with other swarm intelligence applications, the Unilever program copes easily with changing conditions. When a piece of machinery breaks or demand for a particular product changes abruptly, for example, the software adjusts the schedules quickly and automatically.

Perhaps the most powerful insight from swarm intelligence is that complex collective behavior can emerge from individuals following simple rules.

The Task of Dividing Tasks

Foraging is not the only social-insect behavior rich with applications to business. The way insects allocate labor also holds valuable insights. In a honeybee colony, for instance, individuals specialize in certain tasks, and yet the allocation of work is very flexible. When food is scarce, for instance, nurse bees will help by foraging.

Using honeybees as a model, we have worked with Michael Campos of Northwestern University to devise a system for scheduling paint booths in a truck factory. In the facility, the booths must paint trucks coming off an assembly line. When necessary, a booth can change the color it's using, but doing so is time-consuming and costly. So the booths can be thought of as honeybees governed by the following rule: an individual performs the tasks for which it is specialized unless it perceives an important need to perform another function. Thus, a booth with red paint will continue to handle orders of that color unless a job marked "urgent" requires a white truck and the queues at the other booths, particularly those specializing in white, are much longer.

Although this rule sounds simplistic, in practice it is surprisingly effective. It has enabled the paint booths to determine their own workloads more efficiently (that is, with fewer color changes) than if a centralized computer had devised the schedules. And this self-organizing system has the benefits of other swarm-intelligent approaches: flexibility and robustness. When the number of trucks that need to be painted blue surges unexpectedly, for example, other booths quickly forgo their specialty colors to accommodate the unassigned vehicles. Or when a paint booth breaks down, the remaining stations compensate by immediately divvying up the additional load.

Another useful model of work allocation comes from seed-harvester ants carrying food back to their nest. Like runners transferring a baton in a relay race, the ants pass food down a chain. But the ants are not stationary, and their transfer points are not fixed: an ant carries the food down the chain until it reaches the next ant, and after transferring the food, it turns back until it meets the previous ant in the chain to receive its next load. The only fixed locations in this operation are the start (the food source) and the end (the nest).

This simple approach, known as the "bucket brigade," can dramatically increase the efficiency of operations in which work is passed from one person to another. John Bartholdi of Georgia Tech and Donald Eisenstein of the University of Chicago have applied it to order pickers at a large distribution center of a major retail chain.

Initially, the warehouse used a zone approach, in which each worker was responsible for a particular part of the order, and the next person couldn't begin until the first person completed that task. (Say, for example, in filling an order for books, one person might be responsible for putting in the biology books first, and then another would put in the business books.) One problem with zone approaches is the wide variation in the rates at which different employees work – the quickest person could be four times as fast as the slowest. So zone approaches tend to underuse the faster people and aggravate the slower ones, who are constantly under pressure to keep up. And even if everyone worked at the same speed, fluctuations in customer demand would still make it difficult to demarcate the different zones of responsibility to balance the amount of work. At the distribution center studied, a supervisor had to monitor each aisle to correct for the congestions that inevitably occurred.

Bartholdi and Eisenstein implemented the following rule for each worker: "Continue picking out products to fill the order until the person downstream from you takes over your work; then head upstream to take over the next person's work." The researchers also looked at other ways to maximize productivity. Specifically, they asked, should the fastest workers be stationed at the start of the line, at the end, or somewhere in between? Or should they be located both at the start and the finish? Using computer simulations, Bartholdi and Eisenstein have proven that the optimum sequence of workers is from slowest to fastest. By implementing that setup, workers at the warehouse they studied became 30% more productive than they had been using the zone approach.

Once again, the bucket brigade approach displays all three advantages of swarm intelligence. It allows a work line to balance itself – that is, the optimum solution emerges without any intervention by managers – and the system is also flexible and robust, easily adapting to any unexpected surges in demand for particular products. Variations of the bucket brigade approach are being used in distribution centers at McGraw-Hill; Little, Brown; Bantam-Doubleday-Dell Distribution; and Blockbuster Music, among others.

Simple Rules Rule

Perhaps the most powerful – and fascinating – insight from swarm intelligence is that complex collective behavior can emerge from individuals following simple rules. For social insects, millions of years of evolution have fine-tuned those rules for great efficiency, flexibility, and robustness. Can managers develop similar rules to shape the behavior of their organizations and replace rigid command-and-control structures?

Jim Donehey, when he was CIO of Capital One, tried it. The company, best known for its credit card business, started out as a spin-off from a local bank, and when Donehey joined it in 1994, its IT group had just 150 people. But thanks to its rapid expansion into different markets, Capital One grew at a breakneck pace. Donehey was soon struggling to assimilate new employees into his organization, which in five years grew to 1,800 people spread across ten cities, three of which were abroad. Donehey realized that command-and-control management, which had seemed efficient when Capital One was small, was becoming untenable.

Around that time, Donehey had a discussion with us about swarm intelligence, and he became intrigued with the way social insects can perform tasks efficiently by using just a few fundamental rules. Inspired by that model, Donehey came up with four basic guidelines to ensure that everyone in his organization was working toward the same goals:

1. Always align IT activities with the business (that is, keep the company's overall goals in mind).
2. Use good economic judgment (spend the money like it's your own).
3. Be flexible (don't box yourself into one thought pattern).
4. Have empathy for others in the organization (when people ask you to do something you don't agree with, put yourself in their shoes).

To reinforce the rules, Donehey distributed about 10,000 gaming chips in four different colors, representing the quartet of rules, to all the business managers throughout Capital One's various departments. Each of them was instructed to give chips to people in the IT group whenever they followed any of the four guidelines. If an IT staffer did something that embodied all four, a manager could nominate that person for a special chip, which Donehey himself would present. After a year, Donehey says, the rules became so ingrained that they formed the mantra for the IT organization. In addition to unifying his group, Donehey claims the rules empowered his staff to make decisions on their own and work with little top-down management. The result: the attrition rate is below 4%, compared with 20% for the IT industry as a whole.

Donehey's success notwithstanding, the task of crafting the right fundamental rules to shape an organization is not often easy. Indeed, predicting the behavior that will emerge from even a couple of simple instructions can be surprisingly difficult. Imagine, for instance, that you are at a cocktail party, mingling among a hundred people or so. At random, you silently pick two other people (call them A and B) and then follow this simple rule: always position yourself so that A is between B and you. If everyone else were to do the same, what would happen? Now, change the rule slightly: always position yourself so that you are between A and B. Again, if everyone else were to do likewise, what kind of group behavior would emerge?

When they follow the first rule, people will move around for hours, as they continuously try to keep themselves in the right position. But when they follow the second rule, the result will be markedly different: within seconds, everybody will find themselves clumped into a single, almost stationary cluster.

This trivial game holds two important lessons. First, unpredictable – and often counter-intuitive – behavior can arise from very simple rules. Second, a seemingly minor change in the rules can radically alter group behavior.

The Advantages of Swarm Intelligence

Flexibility:
the group can quickly adapt to a changing environment.

Robustness:
even when one or more individuals fail, the group can still perform its tasks.

Self-organization:
the group needs relatively little supervision or top-down control.

There is a third important lesson: although predicting the group's collective behavior is a task beyond human grasp, it can often be done using simulation modeling. We have built a computer model (available at www.icosystem.net/game) that enables users to test the two rules and observe the resulting crowd behavior. Such simulations can be valuable tools in predicting what behavior will emerge from a group of people under certain constraints. In fact, organizational simulation is currently a booming area of research in both academia and consulting firms. For instance, we and our colleagues at the Cap Gemini Ernst & Young Center for Business Innovation have created a simulation to explore how certain rules affect employee turnover, loyalty, productivity, and knowledge at Hewlett-Packard.

Such research is still in its infancy, and of course any manager should be wary of implementing rules that might lead to unforeseen and undesirable behavior. That said, several Internet companies are already pushing ahead, using self-organization rules as a foundation for their businesses. Epinions, iExchange (formerly MutualMinds), and Plastic.com, among others, have tapped into the collective wisdom of their users, essentially turning them into a self-organized workforce. Indeed, as the trend toward free-agent workers continues, the very notion of what constitutes a company may become blurred beyond recognition. If teams of free agents form on a project-by-project basis, what kinds of rules are best to organize their work?

CompanyWay thinks it has the answer. The Bellevue, Washington-based start-up is working with the Bios Group to develop a Web service that would allow employees to organize and work like swarms of free agents inside their own companies. This on-line community can identify strategic opportunities for the company either by working speculatively or by responding to specific requests from senior management ("How can we make our product environmentally friendly?" for example). Through CompanyWay's service, workers post their solutions, which others then develop and fine-tune. The service is set up to be self-selecting: a promising idea tends to attract the attention of many people, who reinforce it by revising and advancing it – laying a trail – and all this activity then lures still others to contribute. The resulting work can be integrated with executive decision-making tools to give managers control over the product-development process.

At Capital One, employees are primarily responsible to the ideas they have, not to their managers.

For reward, workers earn merit points based on the value of their contributions, and these points are later redeemable for cash or other forms of compensation. Even allocation of the points is largely self-managed, done primarily through voting and other peer feedback mechanisms. Companies in the consumer goods and pharmaceutical industries are currently running pilot deployments of the CompanyWay service.

Raiding New Markets

Swarm intelligence may also hold important lessons for businesses seeking to find and exploit new markets. Consider how different species of ants attract their nest mates to new food sources. There are three basic ways in which ants lead their fellows to new food sources. Laying pheromone is a form of "mass recruitment": a large mass of ants is attracted down the path where the pheromone is strongest. In some species, though, an ant that finds a food source returns to the nest and vibrates its antennae to convince one other nest mate to return to the site. That's called "tandem recruitment." In other cases, an ant vibrates its antennae to get a number of nest mates to follow. That's "group recruitment." In all three cases, individual ants can convey information about the quality of a food source, either by laying more pheromone or by increasing the frequency of their antenna vibrations.

But it turns out that one method is much more effective under certain circumstances, as Jean-Louis Deneubourg and his colleagues at the Université Libre de Bruxelles discovered in a series of intriguing experiments. They placed a food source at a certain distance from a nest of ants and watched as the colony began to raid the food. Then they placed a source of richer food at a different location an equal distance from the nest. The colony using the mass recruitment approach was unable to shift to the better food because the trail to the first source was already reinforced too heavily. The colony using tandem recruitment diverted several individuals quickly, but the number was too small to take full advantage of the richer food source. The colony practicing group recruitment was both flexible and efficient; many nest mates were quickly enlisted to raid the superior food source.

Interestingly, mass recruitment is most often associated with large colonies, tandem recruitment with small colonies, and group recruitment with medium-sized ones. This correlation is not accidental; millions of years of evolution have shaped it. We have developed mathematical models of the different recruitment mechanisms to explain this observation. For a large colony that can defend its food sources, a strong pheromone trail makes strategic sense, particularly when a huge food source, such as an animal corpse, is discovered. Small colonies are less able to defend themselves from predators and competitors, so a flexible foraging strategy is advantageous because it enables the ants to quickly move on to other food sources when they are threatened. Group recruitment appears ideal for medium-sized colonies in fast-changing, unpredictable environments: it allows the ants to exploit a food source efficiently while remaining flexible and capable of exploring their surroundings for additional sources.

We believe these findings have implications for companies because the size of an organization, the characteristics of a marketplace, and the competitive environment are similarly intertwined in the business world. When markets are volatile and short-lived but sufficiently large, and when competition can emerge from anywhere, the ideal enterprise, we suggest, would be of medium size (perhaps a business unit within a larger conglomerate). More important, we believe, the organization would do well to possess strong internal mechanisms that enable – if not encourage – group recruitment.

The classic example here is Enron. In April 1999, Louise Kitchen, then head of the company's gas-trading activities in Europe, started recruiting people for an idea she thought was going to change Enron's business: on-line energy trading. Soon that group of people was enlisting others, and within months a team of 300 people was working on developing the system – all unbeknownst to the company's top brass. Although the recruitees had been working in Enron's core business – interstate gas transmission – each of them was free to join the underground project or choose not to. Thus the fact that such a large team assembled in such a short time was a strong indication that Kitchen's idea had merit. Today, thanks to this successful group recruiting, that new "food source" handles approximately $1 billion of transactions daily and has added a few billion dollars to Enron's market capitalization.

Some companies have encouraged similar group-recruitment efforts at their organizations. Take Capital One, which has repeatedly been able to find and exploit new opportunities. When it identified a potential new market – consumers who run up high debts but eventually pay them off – it invented the concept of balance transfer with low teaser rates to attract those people. Soon, though, deep-pocketed competitors began to invade this market by copying Capital One's approach. So, like a medium-sized ant colony that gets usurped by a larger competitor, the company moved on and started targeting other opportunities. In 1998, for instance, Capital One became the number-one direct marketer of cellular telephone services in the United States. One sentence from the company's 1996 annual report summarizes Capital One's overall strategy: "Many of our business opportunities are short-lived. We have to move fast to exploit them and move on when they fade."

According to George Overholser, Capital One's vice president of growth opportunities, the philosophy at the company is that employees are primarily responsible to the ideas they have, not to their managers. So, people who have ideas should find the best sponsors (who might not necessarily be their bosses) and recruit the people they need. This system, designed to foster group recruitment, is largely self-organized: the best ideas will eventually tend to attract the greatest number of people, and those ideas will be developed, tested, and (if all goes well) actually rolled out as new businesses. To encourage workers to look for market opportunities outside their immediate departments, Capital One's employee evaluation system considers the extent to which people actively search for such "food sources."

Possible applications of swarm intelligence may be limited only by the imagination.

Conversely, the classic example of an organization with a faulty recruitment mechanism is Xerox. Its research facility, Xerox PARC, is the fabled birthplace of amazing technologies, including the graphical user interface, that the company has repeatedly failed to exploit in the marketplace. In a sense, Xerox has been like a huge colony of ants that relies on mass recruitment, which impedes the company's efforts to divert the necessary resources away from its main food source – photocopier products.

For group recruitment to succeed, companies must provide the right nurturing environment. Specifically, we believe they should:

- maintain their ability to explore new opportunities while exploiting existing ones;
- enable a person with an idea to recruit others;
- allow, but not force, people to be recruited, even when they are working in a core business;
- let the system self-select the best ideas; and
- support the winning ideas with sufficient resources.

At Cap Gemini Ernst & Young, researchers are working to create an "idea market," open to the entire organization, that would match these conditions.

A Swarm of Possibilities

The possible applications of swarm intelligence may be limited only by the imagination. The way insects cluster their colony's dead and sort their larvae, for instance, has led to a novel approach for banks to use to analyze their data for interesting commonalities among customers. We and our colleagues are developing reconfigurable robot swarms that can assemble themselves into vacuum cleaners and other home appliances. And future studies of social insects will likely yield additional provocative insights. For instance, when a honeybee colony becomes too large – that is, when it reaches a point of diminishing returns – the nest splits into two; exactly what rules bees follow to do this remains a mystery. Such knowledge could help large corporations determine when to spin off some of their operations. (Interestingly, there is no social-insect equivalent to mergers, only spin-offs.) Another intriguing phenomenon occurs when a queen wasp, fearing that the departure of some of her subordinates could cripple the colony, induces them to stay by granting them the right to lay eggs. The amount of this "staying incentive" depends on ecological conditions. If, say, the weather is mild and food abundant, the queen must offer greater inducements. The parallel with managers trying to retain top talent in a booming economy is striking.

Such fascinating comparisons aside, the field of swarm intelligence faces several obstacles. Many people have great difficulty understanding how swarm intelligence can work, mainly because they are unfamiliar with self-organizing systems. Furthermore, group behavior that emerges – as if by magic – from the collective interactions of individuals can be a frightening concept for those unaccustomed to it. Indeed, we have often found it difficult to convince managers to deploy swarm-intelligent solutions even after much education and hard data that quantify the benefits. Lastly, critics often object that insects and people cannot – and should not – be described with the same mathematical frameworks. But we would argue that in certain environments (a factory, for instance), humans are constrained in similar ways – although perhaps to a different degree – as insects are in a colony. And the parallels between social insects and people are more than just conceptual: they can have practical and useful significance, as recent research has shown.

Indeed, swarm intelligence is becoming a valuable tool for optimizing the operations of various businesses. Whether similar gains will be made in helping companies better organize themselves and develop more effective strategies remains to be seen. At the very least, though, the field provides a fresh new framework for solving such problems, and it questions the wisdom of certain assumptions regarding the need for employee supervision through command-and-control management. In the future, some companies could build their entire businesses from the ground up using the principles of swarm intelligence, integrating the approach throughout their operations, organization, and strategy. The result: the ultimate self-organizing enterprise that could adapt quickly – and instinctively – to fast-changing markets.

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