



Swarm Intelligence

Packaged Topics are designed simply to introduce the topic and provide a quick means to understand the basics. Keywords and content are supplied so that specific investigation can be accomplished without having to search for the foundational understanding and then work for a deeper applied familiarity. Essentially, Packaged Topics are designed to inspire questions.

Topic Scope: Organizational & Behavioral Sciences, Management Theory, Network management, Resource and Path Planning Optimization

Topic Keywords: particle systems; self-organizing distributed systems; subobject system; flock, herd, school, fish, aggregate motion; behavioral simulation; path planning; thought transference; distributed systems in communications; actor systems; collective behavior; self-organization; stigmergy; ant colony optimization

<http://homepages.feis.herts.ac.uk/~nehaniv/al7ev/dautenhahn/node2.html>

Swarm Intelligence: Social Insects Don't have Friends

The term 'societies' is generally applied both to human and other animal societies, including social insects. Social insects (e.g. termites, bees, ants) are very well studied and two important theoretical concepts are used to understand coordination in social insect societies, namely *self-organization* and *stigmergy*. Recently, models of *swarm intelligence* and their applications to problems like combinatorial optimization and routing in communications networks have been studied extensively [BDT99]. The concept *stigmergy* describes a class of mechanisms mediating animal-animal interactions. Generally, the behavior of each insect can be described as a stimulus-response (S-R) sequence (even for solitary species). If animals do not distinguish between products of others' activities and their own activity, then individuals can respond to and interact through stimuli. This does not require direct communication between individuals; individuals 'communicate' indirectly, via the environment. Social insect societies and models thereof are typical examples of collective behavior which does not involve direct communication between individuals.

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Calculating Swarms

Ant teamwork suggests models for computing faster and organizing better

By Ivars Peterson



The frenetic scurrying of ants around a nest may seem like much ado about nothing. There's method in their madness, however. All this activity adds up to ingenious strategies for collectively working out the shortest path to a food source, combining forces to move a large, unwieldy object, and performing other functions crucial to an ant colony's well-being. Certain ant species send out foragers along more or less random paths to explore a nest's surroundings. Each scout lays down a trail of scent molecules, or pheromones. When one of them finds food, it returns to the colony to pass along the news to others, who can then follow the scent trail.



Miniature Khepera robots are programmed to forage like ants. (J.B. Billeter, Geneva)

An ant taking a shorter path to a particular food source returns sooner from its round-trip excursion than a second one following a longer trail. Other ants start on the shorter path, reinforcing its odor cue, before the second ant returns from the lengthier route. The stronger its scent, the more ants choose a given path. So, the longer route gets less traffic, and its scent slowly fades away as the pheromone evaporates.

In effect, astonishing feats of teamwork emerge from a large number of unsupervised individuals following a few simple rules. This sort of self-organizing cooperative behavior among ants, bees, and other social insects has become the envy of engineers and computer scientists as they work to solve tough path-finding, scheduling, and control problems in industrial and other settings.

In recent years, studies of ant behavior have suggested powerful computational methods for finding alternative traffic routes over congested telephone lines and novel algorithms for governing how robots operating independently would work together.

In the July 6 *Nature*, engineer and biologist Eric Bonabeau of EuroBios in Paris and the Santa Fe (N.M.) Institute and his colleagues argued that this new line of research transforms knowledge about social insects' collective behavior into new problem-solving techniques, which the researchers term "swarm intelligence."

"These techniques are being applied successfully to a variety of scientific and engineering problems," the researchers contend.

They're not the only ones who think so. In September, an assortment of biologists, ecologists, computer scientists, and engineers came together in Europe to compare notes on insect behavior and algorithm development at three meetings with intriguing titles: the Sixth International Conference on Parallel Problem Solving from Nature and the Sixth International Conference on the Simulation of Adaptive Behavior, both in Paris, and the Second International Workshop on Ant Algorithms (ANTS 2000) in Brussels.

The classic traveling-salesman problem has long served as a stringent test of methods designed to solve difficult computational puzzles. The task consists of finding the shortest route that takes a traveler just once to each of a given number of cities before returning home.



Obtaining the shortest route requires trying all the possible combinations of city-to-city connections. When the number of cities is large, this would take a prohibitively long time. There are billions of route possibilities among just 15 cities.

In practical situations, however, engineers and others usually settle for a good answer, instead of the best one. Ant foraging behavior suggests a shortcut for getting an acceptable answer.

Computer scientist Marco Dorigo of the Free University of Brussels in Belgium and his coworkers have devised a path-optimization method that mimics in software the pheromone-trail building of an ant swarm.

In this instance of virtual sales trips across a digital landscape, each artificial ant, or agent, hops from point to point on an electronic map, favoring nearby points but otherwise traveling randomly. After it completes its sales tour, the agent goes back to each hop and deposits the digital equivalent of a pheromone on that segment. The amount of pheromone depends on the tour's length—the shorter the total distance, the more pheromone each of the segments receives.

After all the artificial ants have completed their tours and spread their scent, the software pools their results. Point-to-point links that belong to the largest number of short tours become richest in pheromone. The swarm is then released again. This time, however, the agents favor both the nearby links and those with higher faux pheromone concentrations.

Dorigo and his collaborators found that while repeating the routine hundreds of times, artificial ants follow progressively shorter routes.

Permitting artificial pheromone to evaporate at a steady rate proved to be the key to avoiding a mediocre solution. The evaporation kept the colony from getting stuck with a link that happened to be part of many routes but was not a component of a suitably short tour.

Interestingly, the researchers had to adopt a pheromone evaporation rate much higher than that found naturally among ants to obtain an acceptable answer within a reasonable period.

You typically start with models of ants' behavior, then add things that are not present in the real world, Dorigo says.

More sophisticated versions of the method, known as ant-colony optimization, include such refinements as local searches that check several nearby sites to see which one works best. These improved ant algorithms are competitive with other state-of-the-art approaches to the traveling salesman problem, Dorigo says.

Variants of the same technique can also be applied to other optimization problems, such as finding vehicle routes. Just such an algorithm is already in use in Switzerland for routing gasoline trucks, and one company, Unilever, is considering another version of the algorithm to schedule production at a large chemical plant.



Computations based on ant-colony optimization don't always work well, Dorigo admits. For example, when cities in the traveling-salesman problem are truly randomly distributed, the method generally fails to zero in quickly on an acceptably short route. Luckily, many real-world problems possess enough of a pattern for the technique to be efficient, Dorigo says.

A similar approach, called ant-colony routing, can help switching stations pass packets of information efficiently across telecommunications networks (SN: 1/2/99, p. 12). Antlike agents wander a network and report where they experience delays and for how long. With that information, the software then updates switching-station routing tables to improve the network's performance.

Developed by Ruud Schoonderwoerd of the Hewlett-Packard Laboratories in Bristol, England, and his colleagues, the technique enables a network's switching stations to respond quickly to congestion, local breakdowns, and other network problems.

The foraging behavior of ants also provides lessons for robotics engineers who want to create independent, mobile robots that operate effectively in unpredictable environments.

Ecologist Laurent Keller of the University of Lausanne, Switzerland, and his coworkers have applied experimental data on the division of labor among real-life ants to orchestrate the behavior of a swarm of small robots. The researchers describe their approach in the Aug. 31 *Nature*.

In their experiments, the team used up to 12 miniature, mobile Khepera robots, developed at the Swiss Federal Institute of Technology in Lausanne. Just 55 millimeters in diameter, each robot was programmed to roam a 9-square-meter area to search for tokens representing food and bring them back to a base station, the equivalent of a nest.

The researchers tracked the swarm's overall energy level—a numerical measure that reflects the amount of energy expended by robots looking for food versus the amount added to the colony's energy reserves by the food retrieved. Radio messages informed individual robots at the nest of the colony's overall energy status. When energy dropped below a certain threshold, one or more robots would leave the nest to forage.

Keller and his coworkers programmed the robots to avoid colliding with each other. They also introduced individual differences among the robots by varying the energy thresholds that would trigger action.

The investigators found that, in general, groups of robots foraged more efficiently and maintained higher levels of total energy than any single robot did. However, as the groups included more than three or so robots, the benefits of group living decreased, possibly because the robots would slow each other down during foraging.

Other scientists have documented a similar relationship between group size and



A diminutive Khepera robot, developed at EPFL, shows off its gripping and lifting prowess. (Alain Herzog/EPFL)



efficiency in social insects, Keller says. Real-life ants and wasps, for example, tend to have foraging parties that do not exceed a certain size.

In some of the robotic experiments, one robot could enlist another if it happened to identify a resource-rich area. This recruitment made the group's overall foraging effort more efficient.

"Our results show that an ant-inspired system of task allocation...provides a simple, robust, and efficient way to regulate activity within teams of robots," the Swiss team concludes. "This has important implications in robotics, particularly in situations where risk of system failure must be avoided, for example during missions on Mars and other planets."

Ant colonies have stimulated many other researchers whose interests include controlling crowds, designing office buildings, sorting data, and pushing large boxes.

Consider ants' remarkable cooperation in moving large, heavy objects up steep slopes. Whereas human movers tackling a bulky object might talk to each other during the task, ants typically "communicate" with cues delivered through the object itself, says Bonabeau. Each ant senses imbalances in forces directed at the object by other ants and automatically shifts to reinforce the weak side. The same idea could be applied to robots designed to move bulky containers.



A swarm of miniature robots fans out from a "nest" in search of "food." (J.B. Billeter, Geneva)

In the ant species *Leptothorax unifasciatus*, researchers have observed that the eggs and the tiniest larvae are in the center of the brood area and progressively larger larvae are farther out. Worker ants seem to expend considerable effort sorting and consolidating the brood.

Biologists have proposed that an ant picks up and drops an item according to the number of similar items nearby. If an ant is carrying a large larva, it's more likely to drop it off among large larvae. If an unladen ant happens upon a large larva surrounded by eggs, it will zero in on the larva and move it away.

Although this model for ant behavior has yet to be validated, computer scientists already have found it useful for data sorting, where artificial ants perform random walks to pick up or drop off data items according to criteria of similarity.

"We have no doubt that more applications of swarm intelligence will continue to emerge," Bonabeau and his colleagues insist. "In a world where a chip will soon be embedded into every object, from envelopes to trash cans to heads of lettuce, control algorithms will have to be invented to let all these 'dumb' pieces of silicon communicate."

Moreover, as models of swarm intelligence become more commonplace in the world of computation and control engineering, there may be some payback for the biologists who have helped uncover the basic rules. Models from the realms of computation and robotics could provide new insights into the behavior of social insects.



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<http://abcnews.go.com/sections/science/dailynews/ant000706.html>

Swarm Smarts

Engineers Find Solutions in Ant Colonies



By Amanda Onion

abcNEWS.com

July 6 — Anyone who has spent time gazing at a colony of zigzagging ants has probably noticed the insects are all about teamwork.

Ants rely on teamwork to move huge objects and find quick routes. Now engineers are learning from their systems.

(ArtToday)

Working together, a swarm of ants can haul a piece of food 10 times their size up a steep slope. And, somehow, workers streaming to and from the nest always seem to settle on the shortest path to a food source.

Recently engineers have taken notice of the insects' impressive use of collaboration and have started finding ways to apply it to problems in the world of humans.

"Ants have been around for 50-90 million years," says Eric Bonabeau, a telecommunications engineer and biologist who conducted studies on ant colonies at the Sante Fe Institute. "That might be the reason why they've got a good system down that doesn't require complex units."

Collective Intellect

The ant, itself, Bonabeau points out, is not a complex unit. In fact, all of its movements are based on immediate reactions to its surroundings or to its fellow ants. Put those ants together, however, and a sophisticated system emerges. Some scientists call it a collective intelligence.



The Harvard University naturalist Edward O. Wilson estimates between 1 and 10 million billion ants are alive at any given moment. (PhotoDisc)

Take, for example, the ability of ants to find the shortest path to a food source. When an obstacle, such as a stick or even a person's foot, blocks the most direct path, ants very quickly find the next best route.

Translate that ability to glitches on the Internet or roadways or in telephone lines and the ant can offer some solutions. If the nodes on one Internet network are clogged with too much traffic, it's sometimes necessary to reroute new traffic. The same problem occurs with telephone lines that become tied up or trucking routes that become congested by holiday traffic.

Ants get around the problem by laying down a thin layer of signaling chemicals called pheromones wherever they travel. When other ants detect these pheromones, they instinctively follow the path the chemicals mark. The thicker the pheromone trail, the more likely other ants will follow the path.

Because the ants that follow the shortest path are also those first to make a return trip to the food source, their pheromone trail quickly becomes thicker. The heavier pheromone scents attract more ants and the shortest path is even further reinforced.

Meanwhile, there are always some ants that follow their own trail and explore new routes. These individuals also lay pheromone trails as they go. So when, say, a rock tumbles across the main route and traffic is jammed, the ants are ready with a backup path. Rarely used, inefficient routes are eventually abandoned as the pheromone trails marking them evaporate.

"Ants are not adaptive, themselves," explains Marco Dorigo, a computer scientist at the Universite Libre de Bruxelles in Brussels, Belgium, and coauthor with Bonabeau of a study on ant swarming in this week's issue of *Nature*. "It is the ant colony as a whole that adapts to the changing problem."

To build on the technique that they observed in ants, Dorigo and Bonabeau devised a system they call the Traveling Salesman Problem. In this scenario, virtual ants travel to every point on a given electronic map. When they reach a node that is highly useful (by offering say, a traffic-free zone or a powerful connector) they are programmed to release more virtual pheromones. Other virtual ants then follow this preferred route and eventually the best path is mapped out on the network.

Bonabeau says the system is already being used to design clog-free telephone and computer networks and to map efficient trucking routes in Switzerland.

Heavy Lifting

Another ant trick that has inspired Dorigo and Bonabeau is the way the insects team up to carry improbably large objects up steep slopes. Human movers carrying, say, a couch up a stairway might handle such a problem by talking each other through the task. But ants communicate through the object they're carrying.

"They don't exchange information directly," says Bonabeau. "Instead, if the item needs realignment, ants will sense that and reinforce the weak side."

The same idea has now been applied to robots that are designed to move large boxes. The robots are able to manipulate boxes and move them efficiently without



actually communicating with one another.



Ants find the fastest routes between food and home base using chemicals called pheromones. (ArtToday)

Although Bonabeau is a biologist as well as an engineer, he stresses that his main interest lies in finding solutions in nature while not necessarily understanding exactly how nature works. One of his ant swarm models, for example, is based on a system that he isn't sure actually exists in ant colonies. Instead, he drew from what he knows about ant swarms and devised a system that could theoretically work in an ant colony.

"We don't necessarily care about biological accuracy," he says. "What we care about is taking what we know about species like ants and creating efficient systems."

Eamon Mallon, a researcher at the Ant Lab at the University of Bath in England says that Bonabeau's approach is understandable, considering how difficult it is to observe ant swarms carefully.

Paint by Ants

To study even very small colonies of about 200 ants, Mallon and his colleagues first individually mark each ant. To do this painfully minute work, they anesthetize the ants using carbon dioxide. Then they use single hair paintbrush's and model paint to make four distinctive markings on each three-millimeter ant.

"You make sure your hands aren't shaking and you haven't drunk too much coffee and then you paint your ants," Mallon says, adding that "people can't believe I do this for a living."

Once each ant is marked, Mallon and his colleagues can trace what each ant is doing. Right now, Mallon is learning how ant groups settle on the best locations for nests.

While Bonabeau and Dorigo have focused on applying ant colony behavior to automated systems where each unit is simple and predictable, Mallon believes that ant systems can even work for settings that involve one of the most complicated agents — humans. He says that ant colonies offer good models for designing buildings, office work-flow arrangements and crowd control.

"Some are quick to point out that people are much more complicated than ants," he says. "But in a group, people aren't thinking many existential thoughts. They're more like ants. They're just trying to figure out where to go." ■

<http://news6.thdo.bbc.co.uk/hi/english/sci/tech/newsid%5F764000/764085.stm>

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Bees invade the Internet



The net must turn to the natural world for help

By BBC News Online Internet reporter Mark Ward

Soon software that acts like bees or ants could be running the Internet.

Researchers at the University of California are claiming that we need radically new ways to run the net as more and more people and devices go online.

Michael Wang and Tatsuya Suda say that existing methods of keeping the net going will not be able to cope when billions of people, mobile phones, hand-held computers and household appliances are routinely using it to communicate.

What is needed, claim the pair, are self-organizing systems inspired by biology.

The researchers are experimenting with discrete programs called agents that have been modelled on bees and ants.

Individually these insects are very stupid but put enough of them together and they do a very efficient job of running and maintaining huge structures like nests and hives without any central control.

By contrast, current Internet management systems tend to be very centralized and directed by people.

Mr. Wang says that this set-up will be unable to cope when everything from our PCs to refrigerators is online.

No one will have the time or inclination to ensure that all the devices are doing what they should, he says.

"The devices should just self-manage or self-organize and just do the right things," says Mr. Wang.

Many popular web events already struggle to serve all the people that want to see them.

When Sir Paul McCartney did a webcast of a performance at the Cavern in Liverpool, servers were overwhelmed by the numbers wanting to watch the show.

Ants everywhere



Sir Paul: He overwhelmed the internet



Under the scheme proposed by the US researchers, as a website increases in popularity the content on it, be it a video or audio stream, will be copied and ferried to websites closer to the people trying to see or hear it.

Mr. Wang says that the user requests are like food and the small software programs that ferry the content across are like bees blazing a trail to the source. The bees "die" when users stop requesting clips.

Belgian scientist Marco Dorigo is looking at using small, stupid, ant-like programs to improve the running of the Internet. But he is proposing to let the ants run the infrastructure of the net rather than just serve up video clips to people.

The bee-like software entities are programmed with a few simple rules that define what they do.

This rule-based approach is also being used to recreate huge battle scenes for the Lord of the Rings movie currently being filmed in New Zealand.

The troops in the battle scenes are computer-generated orcs, elves, humans and dwarves that have been programmed with a few rules that define their fighting style, who their enemies are and what to do when a foe has been killed.

Battle commences when the troops are unleashed on each other and computer cameras record the flow of action.

<http://www.santafe.edu/sfi/publications/Bookinforev/icsummary.html>

Swarm Intelligence: From Natural to Artificial Systems

Back-of-Book Information

Social insects---ants, bees, termites, and wasps---provide us with a powerful metaphor to create decentralized problem-solving systems composed of simple interacting, and often mobile, agents. The emergent collective intelligence of social insects, swarm intelligence, lies not in complex individual capabilities but rather in networks of interactions that exist among individuals and between individuals and their environment. The daily problems solved by a social insect colony include finding food, building or extending a nest, dividing labor among nestmates, feeding the brood, cleaning the nest, responding to external challenges, spreading alarm, etc. Many of those problems have counterparts in engineering and computer science.

The collective behavior of social insects is not only decentralized, it is also flexible and robust: flexibility allows adaptation to changing environments, while robustness endows the colony with the ability to function even though some individuals may fail to perform their tasks. Swarm-intelligent artificial systems exhibit the same features. At a time when the world is becoming so complex that no single human being can understand it, when information (and not the lack of it) is threatening our lives, when software systems become so intractable that they can no longer be controlled, swarm intelligence offers another way of designing "intelligent" systems where autonomy, emergence, and distributed



functioning replace control, preprogramming, and centralization. This book surveys several examples of swarm intelligence in social insects and describes how to design distributed algorithms, multiagent systems, and groups of robots according to the social insect metaphor.

About the Authors

Eric Bonabeau holds engineering degrees from Ecole Polytechnique and Telecom Paris, France, and a PhD in theoretical physics from the University of Orsay, France. After being a research engineer with France Telecom from 1990 to 1996, he is currently the Interval Research Fellow at the Santa Fe Institute, USA. His research interests are modeling animal behavior and designing adaptive algorithms inspired by social insects.

Marco Dorigo holds a PhD in electronic engineering from Politecnico di Milano, Italy, and the title of Agrege de l'Enseignement Superieur from the Universite Libre de Bruxelles, Belgium. After being a Research Fellow at the International Computer Science Institute of Berkeley (1992-1993), a NATO-CNR Fellow (1993), and a Marie Curie Fellow (1994-1996), he is currently a Research Associate with the Belgian Fonds National pour la Recherche Scientifique (FNRS). His research interests include ant colony optimization, a novel research area that he initiated, evolutionary computation, autonomous robotics, and reinforcement learning. He was awarded the 1996 Italian Prize for Artificial Intelligence.

Guy Theraulaz holds a PhD in neuroscience from the University of Provence, France. He is currently a Research Associate with the French Centre National de la Recherche Scientifique (CNRS). His activities include experimenting with, and modeling, social insects. He was awarded the 1996 CNRS Bronze Medal for his scientific achievements.



About Packaged Topics

Education and research methodology is changing, and there is a need for a compact, fast method of acquiring basic but sophisticated knowledge. While easy to create, Packaged Topics have a few minimum design characteristics worth mentioning.

The first is to assume a relatively low level of familiarity in the audience. The Packaged Topics are intended to share information and get people excited about the knowledge that they comprise. Ideally, the idea of Package Topics will persist and readers will take it upon themselves to create new Packages which inspire new levels of educational excitement around the globe. Philosophically, the Web has to a large degree failed to bring along the masses toward greater knowledge and more enriched lives through a better understanding of our world. Packaged Topics is Kidpacific's small attempt to contribute to a higher purpose for the Net than one-click buying.

The second primary design factor of Packaged Topics is Redundancy. In order to sink in, new topics, and new ideas must be presented multiple times, and in different ways if the audience is to grasp them and count them as their own.

The third design factor is follow-on leads and direction for further study. This information is provided in the Topic Scope and Topic Keywords sections.

The final basic design factor is platform independent and high-quality printable format, so the knowledge can be appreciated online or off regardless of the particular system an end-user has. The Adobe's PDF format allows this.

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