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SPIRALS, SPIDERS AND SPINNERETS

The Developmental Biology Discussion Group of The Rockefeller Institute was founded in 1959 by a group of faculty members and students. At first an intra-Institute undertaking, it soon enlarged its scope to include speakers from other campuses and subjects other than embryology. On March 31, 1964, at the invitation of Dr. Harry Meinardi and Mr. Paul Burgess, chairmen of the Group, Drs. Peter N. Witt and Charles F. Reed of the State University of New York spoke in Abby Aldrich Rockefeller Hall on "Quantitative Evaluation of Behavior Patterns: Computer Analysis of Spider Webs." The following article is based on their presentations that evening.

IF THIS SUMMER'S occupants of beach cottages and other vacation residences eyed the corners of their habitations and the nether surfaces of their furniture with more interest and respect this season, it may be attributable to Drs. Peter N. Witt and Charles F. Reed. These two Upstate Medical Center investigators, one a physician and pharmacologist, the other a psychologist, have made a series of studies and reports, including one in March at The Rockefeller Institute, on the ways in which spiders, particularly *Araneus diadematus*, fashion their webs and the effects of various manipulations on this complex behavior pattern.

As is familiar to all who have probed the subject, even if only with an inquiring broom, there are many different types of spider webs. Most house spiders build mesh webs, irregular, fine-spun three-dimensional structures that tend to collect dust and artifacts as well as anticipated prey. These are usually maintained by colonies of spiders and are under constant repair and enlargement, sometimes attaining an alarming size. Some spiders, usually of the out-door variety, make sheet webs which t sails from the masts of grasses or tall flo spread flat webs, like firemen's nets or to catch crawling insects; and some ma funnels or tubes or pouches, each clever to fit into cracks or to stretch between fa improbable supports. The making of a type of web is an innate function, spec species and among all the webs. The a vorite of spider fanciers, including D Reed, is the beautiful orb web of the cor spider, a group which includes *Araneus*

Araneus, like other orb weavers, mak several different types of thread or silk from about .03 to 0.1 microns in diame cous material for the threads is formed glands located in the ventral portions men and extruded through spinning tub out of the body in the finger-like spinner there are six in number. The spinnerets the caudal end of the abdomen, belo...

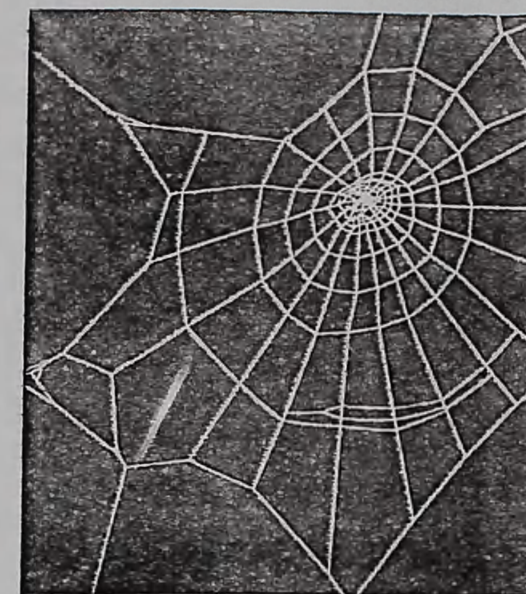
the alimentary canal. om caterpillars which lands, and from ant the Malpighian tubes ligestive tract. Once tein is hardened into ching imposed upon it by the spider.

The heaviest all-purpose thread of the orb-weaver is known as the dragline. It is produced constantly as the spider crawls from place to place and is fastened down at strategic intervals by "attachment discs" which actually are not discs at all but mats of minute looped threads. When a spider wants to undertake space explorations, it simply lowers itself on its dragline, which it can run right back up again if prudence so dictates.

Orb webs, according to Dr. Witt, who has been studying them for more than fifteen years, always start with a horizontal bridge. This can be produced from the dragline which the spider may carry the long way around from one point to another and then pull tight on arrival at its destination. In situations in which this is impossible – as in those puzzling webs that stretch across a brook – the spider raises its abdomen and spins out a line which is carried by the air currents. As soon as this line catches on a twig or leaf, the spider stops spinning, pulls it taut, and fastens it down. This bridge then can be reinforced by more dragline as the spider runs back and forth across it.

Once the spider has laid down the foundation, which is usually irregular in shape since it is dictated by the building site, construction of the orb itself begins. The orb of any species of spider is always essentially the same and is characteristic for the species. The great advantage of working with spider webs, according to Drs. Witt and Reed, apart from their intrinsic biologic interest, is that they provide a permanent record of a complex behavior pattern which is predictable and reproducible and can be measured in entirely objective terms.

Webs chosen for study by the investigators are first sprayed with white paint and then photographed against a black background. With the photograph enlarged to life-size, the various segments and angles of the web are measured and, by a method worked out by Dr. Reed, the figures committed to IBM



Early stage in web construction showing provisional or guy spiral which spider later replaces

punch cards. In this way, it is possible to store and compare data for large numbers of control and experimental webs and so be able to detect and pinpoint even very slight behavior changes.

To start the orb, the spider selects its center and pulls a line through it. Then the radii are fashioned, the arachnid returning each time to the hub to begin a new radius. When these are completed, a total of about 25 radii being average, *Araneus* then weaves a guy spiral, working from the hub out, to hold the radii in place. The turns of this spiral are as far apart as the spider can conveniently reach, holding out the new line at leg's length as it crawls along the one that it has already just laid down.

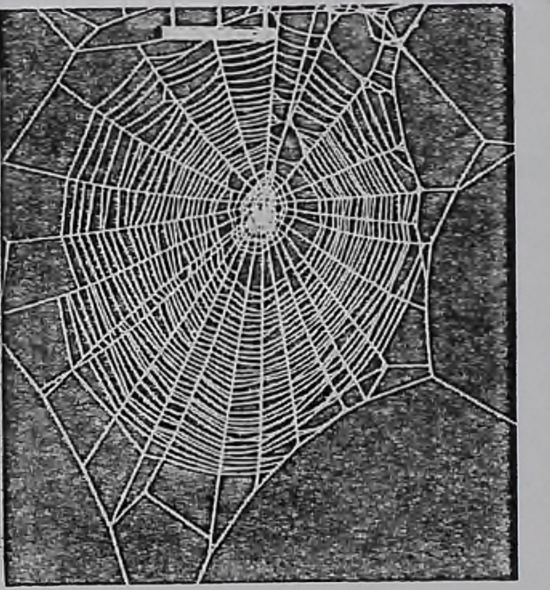
When this guy spiral is completed, the spider switches to a sticky and much more elastic thread, and with this weaves another spiral, this time working from the outside in. Just before attaching the sticky thread on each radius the spider gives it a little jerk with one of its hind legs so the line has a little play in it. This ensures that an insect that gets caught in one thread will bounce around until it becomes entangled in several others.

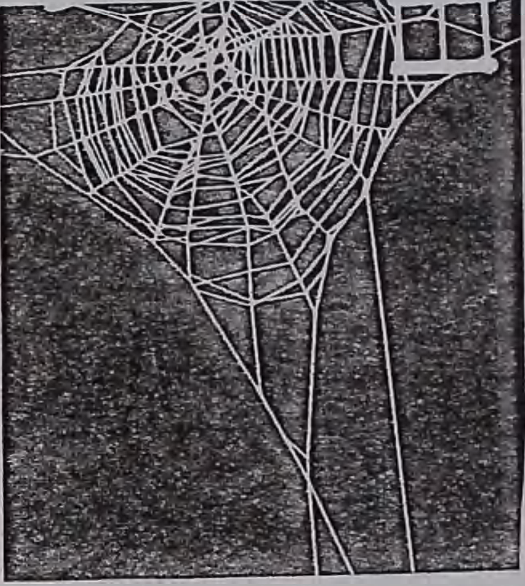
As the spider spins the sticky spiral, it cuts aw the guy lines and then, on finally reaching the center, eats the bundle of threads that have accumulated in the hub. Then, with its web all tidied up and ready for business, one species of spider, *Zilla x-notata*, runs out of the web along one of the radii that it selects as its guideline. This guideline vibrates when anything comes near the web and so keeps the spider in close touch with events throughout the whole structure. When Dr. Witt wants to catch a *Zilla*-spider, he says, he throws a fly into the center of the web and while the spider is enjoying this bounty, he carefully detaches the guide wire and runs it into the bottom of a paper bag. When the spider is finished, it runs back along its line right into the waiting receptacle. Most spiders do not see very well, but electrical responses to flickering light in the eye of the wolf spider were the subject of some interesting studies by Dr. Robert DeVoe while a Fellow at the Institute in 1956-61. Dr. DeVoe is now at the Hopkins.

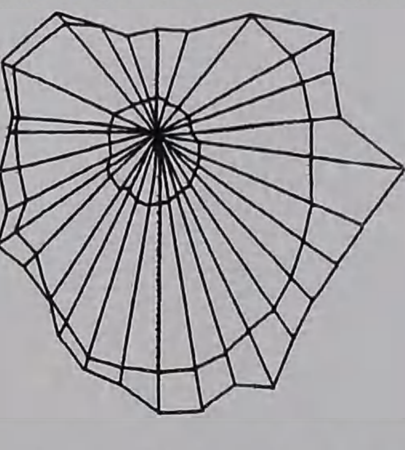
Drs. Witt and Reed are among the few biologists who have studied orb-weavers in the laboratory. They confine them in aluminum frames with glass walls and supply them with houseflies twice a week. Under these conditions, spiders will make a new web almost every day, although a housefly feast may turn off the web-building instinct for a day or two. Webs are built at the coldest point in the diurnal cycle; in Dr. Witt's laboratory this is just before 5:30 a.m. when the lights and heat are turned on. The entire process takes a remarkable twenty to thirty minutes.

No step in web building is learned behavior. Baby spiders make baby webs which were thought at one time to afford them the necessary practice for large ones, but Russian investigators have found that if a spider is kept in solitary confinement from egg to adulthood and never permitted to spin even a line, it can, upon its release, make a perfect adult-sized web on the first attempt. There are a few variables. For example, they have found a spider seems to plan its web on the basis of the amount of silk available for manufacturing purposes. During lean periods, when protein is in short supply, the spider will economize, making the web smaller and the threads finer; after a force-feeding of physostigmine, which increases silk secretion, larger webs are built. Heavier spiders build heavier webs, and if a tiny piece of lead is stuck onto a spider, it will make a web with

Final stage in web construction showing sticky spiral LEFT *and web of same spider* RIGHT *following laser lesion*







Spider web as the computer "sees" it.

Spiders of history and legend have given aid to man, even as *Araneus diadematus* today. Mahomet's life was saved on his flight from Mecca because of an orb woven across the mouth of his cave that led his nonentomological pursuers, the Koreishites, to pass by his hiding place. Robert Bruce, who failed six times to regain the kingdom of Scotland, watched a spider six times fail in attempts to fix its web to the ceiling and vowed to follow its example. The spider of course tried again and this time succeeded whereupon Bruce left the island of Rathlin and took Turnberry Castle in triumph. Frederick the Great, in the first recorded pharmacological use of an arachnid (so named for Arachne of Lydia who made the mistake of beating Athene at a weaving contest and was turned into a spider), observed one fall into his hot chocolate. He called for a fresh cup and the next moment, from the kitchen, heard the report of a pistol. His cook had been bribed to poison him and supposing that his treachery had been discovered, committed suicide forthwith. It is difficult to imagine one of Dr. Witt's spiders failing six times to establish its dragline or lowering itself into a coffee cup, but just as pharmacology has come a long way in the past few decades, perhaps spiders have, too.

a heavier thread and, to compensate, will reduce the number of radii and spiral turns.

Web weaving obviously requires the smooth, coordinated function of a number of different systems. Disturbances in any of these cause distinct, and what is most important, regularly repeated changes in the web pattern of the individual. For example, in one pathfinding experiment, a foreleg was removed from each of a group of sixteen spiders and the webs they produced were subsequently analyzed by computer and compared to control webs. All of the webs made by any one spider following the amputation were the same; no subsequent adjustments were made for the injury. In all the webs built by the seven-legged spiders, the angles between the radii were highly irregular. Some of the webs had irregular spirals, while some did not, and all were the same over-all shape as the control webs. So, the investigators conclude, the front leg is essential for the measurement of radial angles; there are alternate mechanisms for measuring spiral turns, and web shape is determined by a totally independent system.

Recently, the investigators have been using a laser to produce minute lesions, each a fraction of a millimeter in diameter, in the cephalothorax of the spider. Distinct changes have been observed in the web-building patterns of spiders with these small areas of brain damage and it is believed that these changes, recorded and analyzed, will be a useful guide to drawing a functional map of the relatively large and almost uncharted central nervous system of the spider.

Drugs that affect the central nervous system of man also have effects on web construction which, according to Dr. Witt, are far more subtle, sensitive and reproducible than, for example, the alterations in the brain waves of the cat. For instance, mescaline and psilocybin both affect the spider's "judgment" in regard to the weight of threads that should be used for its web construction. Mescaline and pentobarbital seem to interfere with motor behavior; spiders on these drugs make webs that are smaller and less regular in construction. On the other hand, spiders taking chlorpromazine or psilocybin make completely regular webs as long as they make webs at all but, when the dose reaches a certain level, simply lose all interest in the entire activity for a day or two. Drs. Witt and Reed believe that the orb weavers' reactions to various drugs will perhaps some day provide useful criteria for predicting pharmacological effects in man. There is already general agreement that they could not have a more diligent or talented laboratory assistant than *Araneus diadematus*.