Talk #4 Collective Intelligence

What must something be such that it can act on its own behalf?
– Stuart Kauffman

Thea: Your approach seems based on two assumptions, neither easy to accept. First, you insist that perception, consciousness, emotion, memory – all the mental functions – are merely the workings of a nervous system. At the same time, you insist on the Darwinian view that this marvelous physiological machinery is itself a product of mindless evolution. What we're asked to believe then, as you've said yourself, is that sentience and intelligence can arise spontaneously, in a system whose components are not themselves intelligent, with no injection of intelligence from the outside, I find this inconceivable, frankly. Until you can show how such a thing is possible, I will continue to prefer some version of the dualist view that mind and matter are wholly different substances that somehow interact. As will most people, I think.

Guy: John Searle's "Chinese Room" argument, makes the same objection, as did Leibniz, 300 years ago.[1] I agree that the onus is on science to explain how mind can emerge through known processes and functions of organic matter. Today, it's on the verge of providing that explanation. That's what these talks are about.

Thea: You really believe that today's neuroscientists can explain the human mind as the functioning of a human brain?

Guy: Not quite yet – not without some hand waving. But we are coming very close. We now have a pretty good theory of how such a thing is possible – one that seems to agree with what is known about the brain. There are excellent books around now that explain in layman's terms how an intelligent mind might be woven in the firing patterns of ten billion unintelligent neurons.

If you are willing to listen, I can give you the gist of what these books are saying. Whether their ideas will convince you, I don't know; but at least you will see why their authors are persuaded that "mind" (or better, "*minding*") is a word for what our brains do – much as "digestion" is a word for what our stomachs do. In either case, we're talking about a process, not a thing – a process that we're beginning to understand.

Thea: Oh, I'll listen. But expect some stiff resistance. I don't want to believe that a mind is just a mush inside the head.

Guy: You should be careful with your words here. No one is saying that. First, what looks like mush to the naked eye is actually the most complex structure we know of – many orders more complex than our most powerful computers. But second, the mind is no more this complex structure of brain tissue than a Beethoven symphony is just the ink marks in a score, or than the Sistine chapel ceiling is just paint on plaster. The miracle of emergent

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[1] In the Monadology. See *http://plato.stanford.edu/entries/leibniz-mind/*.

form is no less miraculous because we know how it was done, or the medium in which it was done – or because we know that in a sense, it composed itself (that is, *self-organized*), because Beethoven and Michelangelo did their work by responding, as they went along, to suggestions from the work-in-progress more than anything else. The art always creates the artist as much as the other way around. If you want miracles, focus on that!

Thea: Point taken. But I'm still skeptical that anything like a mind can emerge from the electro-chemical interactions of those neurons without some other principle at work. Show me how such a thing is possible, even in principle.

swarm logic and "stigmergy"

Guy: Well, I can begin by pointing out that an ant hill or a termite colony is much more intelligent than any single ant or termite. A single ant is little more than an organic robot, responding to various situations according to its program, with scarcely any adaptive intelligence of its own. The ant hill, by contrast, has remarkable intelligence: Collectively, many thousands of worker ants patrol the area around their nest, dig, clean and defend it as needed, and forage for food – making numerous choices as they do so that depend on the availability of workers and resources, weather, time of day, and other factors. Somehow, the tasks must be allocated to available workers, and must be performed efficiently for the colony to survive. No individual ant could make the necessary judgments, but the ants collectively make them.[2] How is this possible?

Thea: That sounds like a child's riddle: How is an ant hill like a brain?

Guy: Indeed it is a riddle, a very promising one; but it goes better the other way: How is a brain like an ant hill? In fact, the ant hill offers a beautiful clue to the brain's working principle. And it's much easier to study.

Thea: I don't see the connection yet. It's not strikingly obvious.

Guy: It will be if you imagine the brain as a sort of colony of static "ants" (the individual neurons) that form connections with one another and with the body's sensory and motor organs instead of scurrying around as the ants do. While life continues, these cells continually influence one another with electro-chemical suggestions. As primitive suggers, they pass suggestions to one other, responding as their evolutionary history shaped them to respond. In both ant hill and brain, the intelligence of the whole "colony" emerges from the interaction of a great many unintelligent components.

Thea: Surely an ant is more intelligent than a neuron. Though I don't know if "intelligent" is the right word. The ant has more autonomy at any rate – more room to maneuver, more choices to make.

Guy: Indeed it does. But the ant has sufficiently little autonomy for its colony to display certain of the principles on which a brain could work.

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2 The collective intelligence of ant hills is amusingly discussed by Douglas Hofstadter in <u>*Godel, Escher, Bach*</u>.

Thea: Well, I admit you've made me curious. How do those little ants know what to? The queen ant must be controlling them somehow. Or the colony as a whole must do so.

Guy: No! That's the key point, right there. The queen ant is just a kind of breeding robot – specialized for laying eggs. She has no more intelligence than one of your ovaries. And the colony as a whole has no intelligence apart from that woven collectively in the activities of the individual ants. The colony exists as an entity and controls its individual ants only in the sense that all the ants together create a context to which each ant responds in its own very simple way.

Thea: Through self-organization you're going to say.

Guy: Yes, exactly. The ant colonies, or those of termites, bees, and other "social" insects are concrete, vivid examples of what is otherwise a mere abstraction – an hypothesis. By studying these creatures, we learn how one instance of cognitive self-organization actually works. If thousands of dumb ants can collectively comprise an entity as marvelously adaptive as an ant hill, then we begin to see how trillions of individual nerve cells, muscle cells, blood cells, liver cells, and many other kinds[3] might comprise a lobster, a squid, a chimpanzee . . . or a person.

Thea: I don't know if I like to think of myself as a cell colony much more than I like to think of myself as a data processing machine or a chemical mush.

Guy: Dear, let me break this to you gently. How you like to think of yourself doesn't really matter. You are free, like everyone else, to follow one or other of the existing, socially constructed stories or to invent a story of your own. I am offering you a somewhat simplified version of what seems to be the most accurate and rigorous story that has been told to-date. Nothing more, but nothing less.

Thea: Very well. And for the time being, I'm just trying to understand that story without passing judgment. Please go on.

Guy: All right. But note that the question you asked a minute ago – How do all those ants know what to? – must also be asked about the cells of the body. And the answer is about the same as for the ants: As I said, the so-called "queen" is just another ant – specialized for laying eggs. She has no regulatory function at all. Likewise, there is no Master Neuron, or Master Cluster of neurons. We find no structure in the body that could be co-ordinating its separate cells. Somehow, they coordinate themselves. The ant colony shows us something of how this is done – and shows us that it can be done, though the mechanisms in the brain may be entirely different.

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3 The human body has an estimated population of 10^{14} cells, of about 220 different types. A typical mammalian cell may contain up to 10,000 different proteins. See *http://en.wikipedia.org/wiki/Cell_(biology)*.

Thea: All right. For the sake of discussion, suppose I grant that there is no such master controller, and no need for one – though the fact that we have not yet found one does not prove that none exists. What then?

Guy: Then I can introduce you to two powerful ideas, "swarm logic" and "stigmergy," which between them begin to explain how those ants, and the cells of a body, know what do. They even begin to show how human individuals – like you and me – know what to do. But let's stick with the ants for now.

Thea: By all means. But don't forget, it's in the analogy of people with ant colonies that I'm going to have a problem.

Guy: I won't forget, I promise you. The first idea, swarm logic, is a way of thinking about the interaction of neighboring ants. Actually, it can be seen more clearly with flocks of birds, schools of fish, and herds of sheep, but the ants use it too. The principle is just that each ant is influenced only by its immediate neighbors. No awareness of the whole colony's state is required by any ant – not even by the queen, as it turns out. The principle is that each individual is attentive to and influenced only by its immediate environment and the actions of its immediate neighbors. It mimics the actions of these neighbors, or responds to them so as to maintain a certain position or relationship to them.

Thea: The way birds or fish distribute themselves in space to maintain a given distance from their neighbors?

Guy: Or the way that human drivers do, or fighter pilots flying in formation. Yes. But those are simple examples. Swarm logic is now being used extensively to target advertising to specific niches in the market by examining the previous browsing and buying behavior of people whose patterns of interest are similar to yours. It's used on the Internet by search engines like Google to order the web sites selected by your query in order of popularity (on the assumption that the sites visited or referenced most frequently by others are likely to be most useful to you). It figures in various forms of mass behavior, like war fever, lynch mobs, and booms and panics on the stock market. It underlies our need to "keep up with the Jones's," and, (remember "power laws"), the odd phenomena of "celebrity" – people who become famous mostly for being famous – and of the "happenings" that draw vast crowds because word gets around that everybody who is anyone will be attending. Man really is a social animal – sometimes, in perverse, maladaptive ways.

Thea: Why did it evolve in us then? I can see how swarm behavior helps ants and birds and fish, but what does it do for people?

Guy: As with other creatures, it relieves us of the need to pay attention to "the big picture," to our global situation and to the over-all functioning of our social groups. It lets us focus on our little lives, and our immediate relationships. In humans, a swarming instinct also supports our propensity for culture-weaving by influencing us to pattern our behavior on what we see around us; and it influences us to feel shame (a characteristically human affect) when we stand out from our fellows. In this way, it contributes to the solidarity and coherence of human groups, and thus to the configuration of human societies. Instinctively, we "go along to get along" – and we prosper in doing so, more often than not.

Human swarming has its dark side, however. It makes an obstacle to original or creative work, and sometimes causes people in crowds to behave in foolish, evil, or self-destructive ways. One may doubt whether our swarming instincts are still adaptive at this point in our history. Both the best and the very worst of human beings can over-ride them from time to time, but there is no doubt that they remain powerful sources of suggestion to conform, and to enforce the conformity of others.

Thea: But swarm logic can't be enough to guide even an ant or a bird through its daily routine, let alone a human being.

Guy: No it isn't. There's also stigmergy, the second principle I mentioned.

Thea: That's a word I've never heard before. What does it mean?

Guy: It's a very powerful concept formed from two Greek words already available in English: "Stigma" means "sign" and "ergos" (as in "*energy*") means "work," so "stigmergy" means "signs provoking work." It's the name for a method of indirect communication, first studied in connection with ants and termite colonies.[4] Their big trick works like this: Worker ants mill around at random, but when they discover a source of food they lay down a chemical trail of external hormone (called a *pheromone*) on their way back to the colony. The scent of this chemical summons other ants who find the food and do the same thing. The accumulation of pheromone eventually recruits a horde of ants who "mine" the food source until it is exhausted.

Thea: What happens then?

Guy: When no more food can be found, the ants misdirected to this site leave no pheromone trail on their way back to the nest, and the existing trails of scent soon evaporate. After a short time the ants are no longer misled, and their labor is directed elsewhere, by newer chemical trails. A similar scheme coordinates the labor of termites and some other social insects.

Thea: I do see what you mean by "collective intelligence."

Guy: It's marvelous, isn't it? No individual ant or termite has the intelligence needed for such a feat. The intelligence, such as it is, resides with the colony as a whole.

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4 The term *stigmergy* was coined as recently as 1959 by a French biologist, Pierre-Paul Grassé. Earlier work along the same lines had been done by a South African, Eugene Marais, and described by him in a posthumous book called *The Soul of the White Ant*, published in 1937.

Thea: In its stigmergy.

Guy: If you care to put it like that. But remember that stigmergy is only the name for an indirect form of communication. We speak of point-to-point communication in which one sugger passes sugges-tions directly to another. There is broadcast communication in which suggestions are just put out indiscriminately to all suggers in the vicinity. We also recognize a kind of communication between a sugger and its natural environment – that of ordinary perception and interaction. But in stigmergic communication, suggers leave sugges-tive marks on the environment for other suggers to find and respond to.

Thea: So the intelligence of the system resides in the ever-changing fields of suggestion that these simple suggers leave for each other.

Guy: You've got it. Like a broadcast, stigmergic markings are put out on a "to whom it may concern" basis. Unlike a broadcast, those markings linger for an indefinite time (in some cases, a very long time), but gradually lose their influence. And as the markings linger, attenuate and are replaced, they comprise a field of suggestive influence in the terrain the suggers scout, and in which they operate. That field changes with time as the suggers interact with their environment and leave their marks upon it. As it sustains itself in dynamic balance, the field can be considered an ecology unto itself, embedded in the larger ecology of the colony's whole environment. It's this stigmergic field that tracks and adapts to the colony's environment, and is the locus of its adaptive intelligence.

Thea: That is a difficult concept, and I'm not sure I can accept it: One wants to think that intelligence is an attribute of minds. Here it's just the attribute of a communications network.

Guy: But look dear: Blurring, and finally erasing the sharp distinction between mind and matter is just what we are trying to do. The phenomenon of stigmergy shows how very primitive suggers can collectively possess adaptive intelligence of much higher order than they do as individuals.

Thea: But without at least some built-in intelligence, those ants or neurons would not know how to respond to the suggestions they are receiving.

Guy: That depends what you want to mean by intelligence. As you would be the first to point out, those ants and the cells in our bodies don't really have what we ordinarily call "intelligence." They are simple suggers that just respond in stereotyped ways to the suggestions they receive. The suggestions they pass each other and the ways they respond to these suggestions have been prepared for them by evolution. No sentient intelligence is needed, and none exists at that level. The result, however, is that the behavior of the whole is not stereotyped at all, but capable of great flexibility. What we surmise is that as the size and inter-connectedness of such a system increases, its collective flexibility may also increase to a point where it must be judged sentient and intelligent by our human standards.

Thea: You're still ducking the question of consciousness completely – talking about flexibility and "adaptive intelligence" instead.

Guy: I'm not ducking the question, just taking things one step at a time. There's still a fair bit of ground to cover. First, I need to show you how much of what we call mind lies altogether outside the brain and body, comprised by stigmergic structures of re-suggestion like those we've just been discussing. Then I have to tell you a little about the brain, which is not much like an ant hill though it exploits these same principles of stigmergy and swarming, among others. Finally, I have to talk about symbolic processing and language. Only then can we begin to address the nature of consciousness.

Thea: All right, then. What's next?

the tuned network

Guy: The problem of distributed cognition – how intelligence might emerge from a configuration of entities not at all intelligent themselves – can be approached from a completely different direction. Today we build devices called "nerve nets" (also known as "neural nets" or "Boolean nets") modeled on an over-simplified conception of the workings of a real brain. They are used in applications requiring the discovery of patterns in vast amounts of data: face and speech-recognition, economic forecasting, medical diagnoses, fraud detection, weather forecasting, and the like.

Thea: How do they work?

Guy: Think of a great many very simple suggers (called binary decision units) connected in such a way that each can receive suggestions to turn on or off, fire or rest, from predecessors in the network – in effect, passing either a 1 or a 0, (a single bit of information), to suggers downstream of them in the network, likewise to turn on or off. As we'll see later,[5] this is a highly simplified model of what real neurons do.

What's remarkable is that the network as a whole can learn to convert complex input signals into appropriate output signals for some given purpose. The learning happens basically by trial- and-error, in good Darwinian fashion, because the network is so configured that connections of its units are strengthened when they produce appropriate results, and weakened when they do not. In this way, the behavior of the network as a whole evolves toward and stabilizes on output tailored to the input it is receiving. We don't need to go into the details of this technology, which is still in its infancy – and which, in any case, does not do justice to the complexity of real brains. For our purpose, only two things are important: First, these networks provide an idealized model of the workings of a real nervous system, but one which can already do useful cognitive work. A body of theory about them has developed, and is developing further. The theory, in turn, affords some groping insight into the properties and performance characteristics of real brains, and is suggestive for further research in neuroanatomy and physiology.

Second, these nerve nets lend themselves to experiment and further engineering. We can make the individual suggers more sophisticated, and

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[5] In Talk #7.

we can refine their protocols of interconnection – either to improve the network's performance or to approximate more closely to a real brain.

Thea: You promised a discussion of mind this evening, but what you're describing now is a kind of artificial brain. Where is the mind in such system? Does a nerve net have anything you could call one?

Guy: It does – in roughly the sense that a radio has music. In this respect, a neural net, and probably a real brain also, might be compared to a radio or TV set whose circuits resonate in sympathy with the broadcast program it is receiving. The circuits of a radio are continually perturbed by electro-magnetic waves jostling the electrons in its antenna. Those of a neural net or brain, are continually perturbed by signals from its sense organs, which are in turn responding to signals from their world. The difference is that a radio merely amplifies those disturbances and converts them into audible sound. But even a very simple nervous system responds to disturbance by generating activities complementary to what is disturbing it. A human nervous system resonates (if that is the right word) both with the world around it, and with saved fragments of its previous resonance patterns – its "memories," "beliefs," "desires" and "habits." It not only generates "intentions" and activities complementary to its immediate situation, but sometimes very subtle and intricate patterns expressive of its internal state.

Thea: Whoa! Wait a minute here! "Memories," "beliefs," "desires," "intentions"? Where did they come from? Those are attributes of a mind. You were talking about a complex switching circuit resonating with its environment. That's quite a jump you're making.

Guy: Admittedly. Creatures with primitive nervous systems probably don't have memories or beliefs, or even desires and intentions in anything like the human sense. They do have brains – much more complex than those artificial nerve nets – that respond to their environments by resonating with them and controlling the creature's glandular and motor responses in the process. And they have minds, of a sort, as I'll show you tomorrow evening. We're still not able to explain in much detail how a human sugger can mentally "stand back" from its world and represent it – to the point of having what we would call "beliefs." But that is where we are headed. The humble cockroach already appears to have a mind of sorts, constituted by the rhythmic firing patterns of a neural net in its environment. It now seems likely that a sufficiently complex neural net working on roughly the principles I've described could have a mind approaching human sophistication.

Thea: I'd be much happier if you'd put that word "mind" in quotes. I'll freely grant that cockroaches can be thought of as suggestion processors, but I doubt that they have minds in any reasonable sense. If you want to say that they have "mind-like" suggestion-processing capabilities, I have no objection.

Guy: All right. If the quotation marks help you, by all means put them in. For myself, I don't see what they add. I know a mind by the mind-like things it does; and it seems both more natural and more interesting to distinguish minds of different capabilities than to distinguish between real minds and things that are merely "mind-like" in their behavior.

Thea: I think there must be more at stake here than our use of words. Ants and robots do things. Minds have feelings.

Guy: You're right. There is more at stake than the words. But we'd be getting ahead of ourselves to argue about it now. We'll get to mind (at least, what *I* mean by "mind") in our next talk. We still have some ways to go before we get to consciousness, and the feelings you want to talk about. The issue is as central for me as it is for you. I won't forget it, I assure you.

Thea: Fine. But there's a phrase you keep using that I'd like you to explain before we go much further. What exactly is this "adaptive intelligence" that you attribute to ants and cockroaches? Does an amoeba have it? Does a bacterium, a virus, a house-cleaning robot? What are the minimum requirements?

adaptive intelligence

Guy: Stuart Kauffman wonders about design requirements for a system that can act on its own behalf. I think your question – What does it mean to have "adaptive intelligence"? – is another way of asking the same thing. It's a good question, bound up with the definition of life itself.

Even the simplest living thing can thrive in some sense, and can act on its own behalf (to whatever extent it can) because it can be said to have interests: in staying alive, in self-perpetuation, in growth and reproduction, etc. It need not be sentient in any dim sense at all; it may be utterly incapable of "caring" whether it thrives or not. But we can say, watching it, that it acts *as if* it cared, because its activities have been exquisitely tailored by evolution. In that sense, we must say that even a virus "acts on its own behalf."

Then, if a creature's repertoire includes alternative activities for different situations, and if it usually gauges its situation correctly and selects its response accordingly, it may be said to show adaptive intelligence.

Thea: So "adaptive intelligence," for you, needs no subjectivity, or ingenuity or foresight. No sentience even. No awareness of its own existence. The functional competence of a plant in turning toward the light is enough to qualify.

Guy: Yes.

Thea: All right. So long as we're clear that you have a long way to go in getting from the adaptive intelligence of an ant hill to that of a bird, let alone a human infant.

Guy: We're clear. We'll discuss mind and sentience in our next talk, and consciousness a few evenings from now, and you are absolutely correct that what I mean by adaptive intelligence is still nothing more than self-interested functional competence. In regulating temperature, gathering food, avoiding predators, whatever.

Thea: Fine. Then you have yet to show that the adaptive intelligence of a termite colony or ant hill has any bearing on the nature of human consciousness.

Guy: Clearly it has some bearing. If nothing else, it shows how novel capabilities for the uptake and evaluation of complex suggestions can self-organize amongst units whose suggestion-processing capabilities are much more limited. It shows that a whole system can be much more intelligent than any of its parts, with no extra intelligence added from the outside.

I ask you to be patient and to follow the logic of these discoveries one step at a time. And to trust me that the concepts of this evening's talk – swarms, stigmergic traces and neural networks – are central to the emerging story.

Thea: To the story you are telling – whether this turns out to be a true story, or not.

Guy: Again, correct. It's true that our understanding of the emergence of Mind in a mindless physical world is still incomplete – and may be radically mistaken for all we know. It's a magnificent story nonetheless: magnificent in its scope, its intellectual integrity, its ingenuity and its depth. It's a magnificent intellectual achievement – well worth getting your head around, regardless of the outcome.

Thea: Fair enough. I can accept it on that basis. Can we break now? I think I'm about ready for bed.

Guy: Can you hold on just a few more minutes? Before we quit for the night, I'd like to show you that human society as a whole can be thought of in these same terms. Swarm logic, stigmergy, and sugger networks are key concepts for human sociology as well.

Thea: Oh? I can see how our society might be imagined as a self-organizing system, as Adam Smith pointed out about the economy. But our cities really aren't much like ant hills, even if they sometimes make us feel like ants. Cities are run by the humans who live and work in them. They don't run themselves.

society as a distributed intelligence

Guy: Yes and no. Much of our knowledge resides in books and libraries and universities. Human competence resides as much in our tools as in the people who use them. One could argue that the adaptive intelligence of human societies is an emergent of stigmergic communication – as much or more so than we'd say about the ants and termites.

A group of engineers and construction workers stranded on a virgin planet without their books and tools and equipment couldn't build a starship, and it might take many generations before their descendants could do so.

Thea: Probably true, but what does it prove? You need to tools to make tools to make tools. And making those tools would take time. Where's the analogy to the ant's pheromone?

Guy: If you want to tell people not to use a reserved parking space, what do you do?

Thea: I put up a sign. Ahhh! And that sign is a stigmergic message to whom it may concern – like the ant's secreted chemicals.

OK. It's obvious. If a sign is an example of stigmergic communication, then so is a newspaper, or a book, or a whole library. In our own lifetime, the World Wide Web happened upon the scene as a stigmergic trail of information, cutting across political boundaries as a global library and filing system.

Guy: Exactly. Now you are seeing it. Whatever else they do, the material artifacts of a culture work stigmergically as re-suggestive structures. The trails that hunters make by trampling down the scrub on a forest floor are not much different from the pheromone trails of those ants. The use of any such trail marks it more clearly, thereby augmenting its suggestive power and attracting further use. If hunters stop traveling that way, the trail is eventually reclaimed by undergrowth. But if hunters continue to take that path it becomes a dirt road, and then a paved one – maybe, eventually, a superhighway. In any city at rush hour, you can observe the stigmergic influence of the established, slowly evolving, transportation arteries, and the stigmergic "pull" from home to workplace in the morning, and back home at night.

Our homes and work places, our public buildings and our monuments are also stigmergic artifacts; and as such, powerful sources of suggestive influence. Likewise our books and our works of art. Likewise, every tool and weapon that balances in the hand, and teaches its user how to use it – just by feeling good when it is held and wielded in the right way. Likewise every "user-friendly" machine or program, transparent in suggesting the uses it affords.

Thea: Books, roads, tools, buildings, electronic equipment, works of art: We use stigmergy more than the ants! Even if we are sentient and conscious as the ants are not.

Guy: We make more use of stigmergy and much richer use. All the tools we use, all the artifacts we make, have stigmergic value as an adjunct to their instrumental value. A gun can be used to shoot people that we don't like; by this very fact, it suggests we do so, and that others might. Usually, of course, there are powerful suggestions to the contrary, but we should be aware that conflicting suggestions never fully cancel each other.

As suggers we have much more autonomy than the ants – far greater responsive repertoire, and subtler means for evaluating suggestions. But great as this autonomy is, it is not unlimited. We are a social species, specifically adapted in many ways to swarm with our neighbors and respond appropriately to the stigmergic cues they lay down for us.

Thea: How does swarming figure in our social behavior?

Guy: We worry about status and follow leaders. We want what our neighbors want; we copy their habits and mannerisms; we crave their approval and feel shame when we don't have it. We evaluate and respond to suggestions less on their merits than on the social status of those who make them, and on their relationship to us. We are susceptible to various forms of mass emotion and mass behavior – from stock market booms to lynch mobs to waves of panic on a battlefield.[6]

Thea: This is just why your biologically-grounded psychology is scary. I know you do not say human beings are just like ants, mindlessly following each other's trails. But other people will say that. Some already are. And some will use these ideas to tighten the control that elite groups already exercise over the rest of us through advertising and clever marketing.

Guy: I can't disagree with you. Although it may be that people's awareness of the sinister uses of swarm logic and stigmergy will make them more resistant. Probably both effects will happen. It's not easy to see what these new ideas will do with us, in the long run. That's what I'm trying to understand.

Thea: And what conclusions have you come to?

Guy: Stick with me. That's what these talks are about.

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6 See, for example, Charles MacKay's book *Extraordinary Popular Delusions and the Madness of Crowds*, and Elias Canetti's *Crowds and Power*, classics on this subject.