A bit of advice is offered to *Science* for constructing timelines: "[T]he openness to multiple cultural origins of technological inventions and scientific discoveries...shows that people in many cultures and histories can construct technologies with ingenuity and discover scientific insights." The tendency of bacteria to lose their resistance to a toxin when selection pressure is eliminated is the basis of an idea to rotate the use of medicinal antibiotics on an international scale. Herbicide use data are discussed for a line of herbicide-resistant soybeans. And perspectives on the evolution of animal aggregations are presented.

Timeline Travails

The announcement concerning the yearlong "Pathways of Discovery" series (Editorial, Floyd E. Bloom, 14 Jan., p. 229) and the first essay in the series, "Deconstructing the 'science wars' by reconstructing an old mold" by Stephen Jay Gould (p. 253), proved equally satisfying. However, when turning to the timeline (p. 230), I encountered the traditional and parochial display of Eurocentrism regarding the history of science and technology.

Granted, India gets credit for "zero," only to be followed by the progression of technological innovations and scientific discoveries from Europe. Yes, the proliferation of mechanical clocks in the 13th century is important, but as Daniel Boorstin points out in *The Discoverers* (*1*), Su Sung's heavenly clockwork, a mechanical clock, was operating in China by 1090. Similarly, Gutenberg's moveable type is cited for 1454, yet metal (copper) moveable type was invented in Korea two centuries earlier (*1, 2*). This invention also stimulated a movement away from the thousands of characters of Chinese ideography toward phoneticized and, later, syllabacized writing. Had I the time to make lists of similar inventions and discoveries from *Encylopedia of the History of Science, Technology and Medicine in Non-Western Cultures* by Helaine Selin (*3*), the examples would no doubt proliferate. Rather, my point is that linear, Eurocentric histories are somewhat analogous to having a physics that stops with Isaac Newton instead of including relativity and quantum physics. Nor is the openness to multiple cultural origins of technological inventions and scientific discoveries necessarily an opening to relativism, although it should be a closure to Eurocentric parochialism. To the contrary, it shows that people in many cultures and histories can construct technologies with ingenuity and discover scientific insights.

dEbates!
Respond online.
www.sciencemag.org/cgi/eletters/287/5454/803

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References

1. D. J. Boorstin, *The Discoverers* (Vintage Books, New York, 1985), pp. 60–61 and 506–507.
2. Han Woo-Keun, *The History of Korea* (Eulyoo, Republic of Korea, 1970), pp. 196–197.
3. H. Selin, *Encylopedia of the History of Science, Technology, and Medicine in Non-Western Cultures* (Kluwer Academic, Dordrecht, Netherlands, 1997).

Response

To this letter writer and all others who may find shortfalls within our timeline—we are guilty as charged. By their very natures, timelines are incomplete, bare-bones portraits of their subject matter. Ours is, in fact, Eurocentric, male-centric, physical sciences–centric, and biased in many other ways that we and others will recognize. We continue to ponder how it might be possible to tell the nuanced global story of science on a two-page spread. We knew we couldn't do that. So we included some items at the bottom of the timeline to warn readers of the many sides of the history of science that our timeline bypasses.

In addition to the above apologia, we would like to thank Don Ihde and the many others who are writing to us about the timeline for enriching the portrait of science with their letters and the points made therein. As other comments come in, they will collectively remind readers of just how multifarious the science adventure is. (Comments and suggestions for timeline elements are also appearing as dEbates associated with the Editorial of 14 January.)

Ivan Amato
Editor for "Pathways of Discovery"

Antibiotic Rotation

The possibility of nisin and related compounds becoming a new generation of antibiotics is discussed by Martin Enserink in the News of the Week article "Promising antibiotic candidate identified" (17 Dec., p. 2245). He says, "researchers hope that nisin and related compounds might trump the problem of bacterial resistance [to antibiotics]." But the answer to trumping this problem lying in the hope of finding such compounds violates the principles of natural selection. I suggest another solution: international cooperation to rotate antibiotic use for treatment of disease.

Microorganisms develop resistance to toxins in their environment, but when the toxin is removed, the selection pressure for maintaining such resistance is removed. After generations without selection for toxin resistance, the trait can de-evolve from the population.

If an antibiotic is used to treat a disease and then is removed from the treatment protocol for that particular disease, after a time without selection pressure the antibiotic could effectively again be used for treatment. Such continual rotation of antibiotics used to combat a disease organism could guarantee that the arsenal of treatment would always be effective.

If an international agreement sponsored by the World Health Organization or the United Nations were reached regarding which antibiotics would be used throughout the world to treat each disease during specific time periods, the rotation could trump the development of bacterial resistance to medicinal antibiotics.

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Herbicide Use on Roundup Ready Crops

In his News Focus article "GM crops in the cross hairs" (26 Nov., p. 1662), Dan Ferber refers to the assessment by Charles Benbrook of the effect that the introduction of Roundup Ready crops has had on herbicide use, concluding that the benefits are not clear-cut. We disagree with this conclusion. Changes in herbicide use are largely meaningless unless relative environmental and health risks are taken into consideration, and Benbrook notes the more benign nature of Roundup compared with other herbicides. According to Ferber's article, Benbrook found that farmers apply two to five times more herbicide to Roundup Ready acreage than to conventional soybeans. However, an examination of herbicide use data does not seem to support this finding.

We have compared U.S. Department of Agriculture data on pesticide use in eight major soybean-producing states for 1995, the year before Roundup Ready varieties were introduced, and for 1998, the last year for which pesticide use data are available and a year in which nearly 40% of soybean acres were planted with Roundup Ready varieties (in 1999, more than 40 million acres were planted with Roundup Ready soybeans in the United States). The data show a 16% increase in pounds of herbicides used and a 12% increase in total acreage. This modest increase in herbicide use is not what one would expect on the basis of Benbrook's findings.

Although the total amount of herbicides used with soybeans has changed little with the introduction of Roundup Ready varieties, the data show a substantial reduction in the number of applications made to soybean acreage. From 1995 to 1998, the total number of applications decreased by 8%, even with the increase in total acreage. This demonstrates growers using fewer active ingredients and making fewer trips over the field, which translates into ease of management.

The primary reason growers have adopted Roundup Ready weed control programs is the simplicity of a weed control program that relies on one herbicide to control a broad spectrum of weeds without crop injury or crop rotation restrictions. Before the introduction of Roundup Ready soybean varieties, growers would choose between many herbicides, often applying three or more active ingredients, some of which would cause damage to the growing soybean plants, or cause harm to corn crops that commonly follow soybeans. As for economic benefits, the introduction of Roundup Ready varieties has provided an overall savings in herbicide costs for both adopters and nonadopters of the technology. Competition in the soybean herbicide market resulted in the manufacturers of other products dropping their prices, in some cases by 40%. This resulted in an estimated $278 million cost savings for soybean growers, or 28% of total herbicide expenditures.

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Benefits of Membership

Explaining the multitudinous forms of social aggregation across animal taxa is a major challenge in evolutionary biology. In their Viewpoint "Complexity, pattern, and evolutionary trade-offs in animal aggregation" in the "Complex Systems" special issue (2 April 1999, p. 99), Julia K. Parrish and Leah Edelstein-Keshet contribute to an emerging new framework that considers the evolution of animal aggregations as by-products or "emergent properties" of other natural processes. For instance, J. R. Pawlik (*1*) explained the huge aggregations of marine invertebrates that form some of the world's largest living aggregations (for example, coral reefs) as the by-product of settlement based on attraction between individuals of a species. Relying on conspecific cues for habitat selection is likely to naturally lead animals to aggregate, as illustrated by colonial and noncolonial bird species (*2, 3*). Mate choice is another set of processes that have long been understood to explain another kind of aggregation, that of display territories in promiscuous species [for example, leks (*4*)] and more recently breeding territories of monogamous species (*5, 6*). Accordingly, we have proposed that colonial breeding may be the by-product of the two interacting processes of breeding habitat selection and mate choice (*2, 3*).

The new framework for understanding the evolution of animal aggregations has important implications that require emphasis. For example, individual animals do not necessarily benefit from aggregation, suggesting that attempts to identify benefits of aggregation may be a fruitless approach because aggregation is, at least in the first step, not a target of selection. Instead, it would be more fruitful to identify the mechanisms that generate aggregation. We agree with Parrish and Edelstein-Keshet that it is difficult to argue that all animal aggregations have a functional purpose and stress that aggregations may form without the operation of any Darwinian natural selection. However, in the case of assemblages of living units, as an emergent property of other behaviors, aggregation may become the object of selection. An example is the case of the origin of metazoa, which has involved spatial patterns of kinship in the ancestral cell organisms (*7, 8*). The individual that emerged from such aggregates of single-cell organisms then became the object of selection, and evolutionary ecologists now, 800 million years later, consider it as the unit of selection. Nevertheless, it would not be correct to consider that such aggregations first evolved because of all the properties that are now linked to the individual metazoa. This example illustrates the difficulty of distinguishing between the ultimate causes of a trait and its emergent properties.

Finally, the new framework implies that aggregated distributions may be the natural state of most animals (*2, 3*). If so, we should contemplate the constraints that prevent solitary species from aggregating rather than exclusively searching for the reasons that cause social animals to aggregate. In studying the evolution of colonial breeding, such a reformulation has led to unexpected results (*9*), and we anticipate that more counterintuitive findings will emerge when the new thinking about animal aggregation is applied.

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References

1. J. R. Pawlik, *Nature* **370**, 511 (1994).
2. E. Danchin and R. H. Wagner, *Trends Ecol. Evol.* **12**, 342 (1997)
3. R. H. Wagner, I. Danchin, T. Boulinier, F. Helfenstein, *Behav. Ecol.*, in press.
4. J. Hoglund and R. V. Alatalo, *Leks* (Princeton Univ. Press, Princeton, NJ, 1995).
5. R. H. Wagner, *J. Theor. Biol.* **163**, 333. (1993).
6. H. Hoi and M. Hoi-Leitner, *Behav. Ecol.* **8**, 113 (1997).
7. J. M. Smith and E. Szathmary, *The Major Transitions in Evolution* (Freeman, San Francisco, 1995).
8. R. E. Michod, *Am. Nat.* **149**, 607 (1997).
9. C. Rolland, E. Danchin, M. de Fraipont, *Am. Nat.* **151**, 514 (1998).

Response

We would not characterize animal aggregations as "emergent properties," or by-products, of other natural forces, as Danchin and Wagner describe. Rather, we submit that *aspects* of persistent aggregations, such as edges, uniform density profiles, and shape, are the emergent properties. And although we support the supposition that evolution may explain why animals aggregate, we do not believe that it can necessarily describe how they do it.

The emerging view that complexity and evolution are alternate, antagonistic theories describing patterns in nature (*1*) is simplistic and obfuscational. It is obvious from the inanimate world that self-organization is a prevalent schema (*2–4*). To assume that life is not governed, at least in part, by the same constraints is difficult to imagine (*5*). At the same time, we recognize evolution at the level of the individual by means of natural selection as the major structural framework shaping life, from cell structure to ecosystems. Can these theories be linked using animal aggregation as a model?

The process of animal aggregation is a continuum, from territorial individuals that gather briefly to mate, through vast single-species aggregations, to the more socially gregarious groupings in which individuals may be related to each other and/or come into frequent contact with other known group members. Our Viewpoint article, and this reply, concentrate on the middle of this spectrum—large, persistent groups where individuals (i) are not related, do not know each other, and may be unlikely to interact repeatedly in the sense of reciprocal altruism; (ii) have no sense of the whole; and (iii) can move throughout the physical group including freedom to come and go (that is, membership is fluid).