Metaphoric Usage of the Second Law:

*Entropy as time's (double-headed) arrow in Tom Stoppard's "Arcadia"**

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Almost as soon as the concept of entropy and the second law of thermodynamics were introduced, people began exploring their application to matters that, at first glance, appear to be outside their scope. This is perhaps not surprising—if the second law tells us about things as small as the efficiency of a heat engine and as large as the ultimate fate of the universe, it seems logical to conclude that there are *no* matters that fall outside its domain. The implications of the second law are as deep as they are broad, as the following quote insists [1]:

> The law that entropy always increases—the second law of thermodynamics—holds, I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations—then so much the worse for Maxwell's equations. If it is found to be contradicted by observation—well, these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation.

Couple that with the difficulties that existed (and persist!) in defining exactly what entropy is [2], and it is easy to see why it turns up in such a range of intellectual pursuits. Just a quick search of a library's (University of California) holdings for titles with the word "entropy" turned up dozens of books on topics not explicitly concerned with thermodynamics, such as the environment, information theory, traffic patterns, etc. Also included are at least half a dozen works of fiction, as well as a score for a piece entitled "Entropy" for woodwind trio (which, alas, I have not yet heard).

To what extent do these various endeavors represent *rigorous* application of the second law, as opposed to approximate or even metaphoric usage? Nobody questions the rigorous applicability of the second law to heat engines. The inevitable "heat death" of the universe, too, is little questioned [3]. However, there is rather less immediate concern about the conclusion that we're all going to die in some billions of years than about the potential implications for the fate of man and society over a more relevant time scale. Are *those* implications rigorous? If not, are they nonetheless of value in the realms to which they are applied?

The metaphoric exportation of scientific concepts to other fields and the reverse process are well-explored topics. It has been noted that there are risks attendant upon imprecise usages, and the second law is no exception. Indeed, it gives us some prime examples, such as the creationists' entropic argument against evolution or Jeremy Rifkin's appallingly neo-Luddite "new world view" [4], which misapplies the second law in about every way possible. Such distortions are in-

Fig. 3. M.C. Escher, "Waterfall" © 1996 M.C. Escher/Cordon Art–Baarn–Holland.

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deed dangerous, doubly so: not only do they validate dubious agendas by clothing them in (pseudo)scientific garb, but they also tend to discredit others who engage in related but more careful projects [5]. However, they do not (in my opinion) demonstrate that approximate or metaphoric treatments of scientific concepts are *inherently* bad; just that anything can be done badly.

The question of how the second law applies to the world of the human mind, and its interactions with the physical world, has received intense and enduring attention. From the early days of the concept of entropy, following the introduction of statistical treatments (by Maxwell, Boltzmann, and others), it has been suggested that the entropy of a system is in some way connected to how much we know about the system and that there is therefore a "subjective" component to entropy. The idea of subjective entropy reached its peak, perhaps, with the development of information theory around 1950 (Shannon, Brillouin, etc.), in which *mathematical* relationships between entropy and information are proposed. Denbigh and Denbigh have examined this idea and its history in some detail; they conclude that it is in fact *not* rigorous but at best approximate, and only applicable in certain, restricted situations [6]:

> Although information theory is more comprehensive than is statistical mechanics, this very comprehensiveness gives rise to objectionable consequences when it is applied in physics and chemistry....It remains true, nevertheless, that information theory can be of value in an heuristic sense....Notions about "loss of information" can sometimes be intuitively useful. But they can also, like the comparable concept of "disorder," give rise to mistakes....It needs to be kept in mind that *thermodynamic* entropy is fully objective...and the same must apply to any other "entropy" which is used as a surrogate.

A much earlier treatise considered if and when thermodynamics might be applicable to human activity [7]:

> The Second Law in its objective-physical form (freed from all anthropomorphism) refers to certain mean values which are found from a great number of like and "chaotic" elements. . . . this law has no *independent* significance, for its roots go down deep into the Theory of Probabilities. It is therefore conceivable that it is applicable to some purely human and animate events as well as to inanimate, natural events... provided the variable elements present constitute adequate haphazard for the Calculus of Probabilities.

This suggests that a minimum requirement for applicability of the second law is a sufficiently large number of elements—an Avogadro's number of people, perhaps?—as well as hinting at issues such as free will versus random actions. It appears, then, that the connection between thermodynamic entropy and informational "entropy" is at best only approximate, not rigorous [8].

Nonetheless, these analyses do not deny that even such approximate analogies may be of value, even if only to provide mental stimulus. So, with the above as background, let's turn to the explicitly metaphoric use of the second law in fiction. As I indicated earlier, there are hosts of examples, with widely varying purposes and impacts, ranging from the whimsical (pardon the pun) [9]:

> What I like about your evidence, Miss Kohn, is that it adds the final touch of utter and impenetrable obscurity to the problem.....It reduces it to the complete quintessence of incomprehensible nonsense. Therefore, by the second law of thermo-dynamics, which lays down that we are hourly and momently progressing to a state of more and more randomness, we receive positive assurance that we are moving happily and securely in the right direction....I have got to the point now at which the slightest glimmer of commonsense imported into this preposterous case would not merely disconcert me but cut me to the heart. I have seen unpleasant cases, difficult cases, complicated cases and even contradictory cases, but a case founded on stark unreason I have never met before.

to the rather pretentious [10]:

> [He] found in entropy or the measure of disorganization for a closed system an adequate metaphor to apply to certain phenomena in his own world. He saw, for example, the younger generation responding to Madison Avenue with the same spleen his own had once reserved for Wall Street: and in American "consumerism" discovered a similar tendency from the least to the most probable, from differentiation to sameness, from ordered individuality to a kind of chaos. He found himself, in short, restating Gibbs' prediction in social terms, and envisioned a heat-death for his culture in which ideas, like heat-energy, would no longer be transferred, since each point in it would ultimately have the same quantity of energy; and intellectual motion would, accordingly, cease.

Both these extracts suggest how one *might* apply the second law, in metaphoric form, to mental as well as physical processes, although it is far from clear how aware these authors are of the extent of their imprecisions. [Note in the second extract how Pynchon (or his protagonist?) recognizes the importance of a "closed system" in his definition of entropy but then applies the concept to a system that is about as far from closed as possible!]

In the remainder of this article, I will examine Tom Stoppard's treatment of this theme, in his recent play "Arcadia." Stoppard's earlier work evinces his interest in the intersection between art and science, most notably in the play *Hapgood*, which explores ambiguity by interweaving espionage and quantum physics. The main scientific themes in "Arcadia" are of chaos, time, and entropy. To be sure, "Arcadia" is about much more than that; other themes featured prominently include English gardens, Romantic poets, straying wives, outraged husbands, obsessed academics, etc. But a significant part of the mix is a picture of how entropy and time work—at least, in the world of the human mind—that is intriguingly different from more traditional and "purely scientific" views. One aspect that makes it particularly intriguing, as I will try to show, arises from the mode of presentation: not by overt exposition (although there is some explicit discussion of the scientific themes in the text) but, much more subtly, via the overall structure of the play, including staging.

A brief synopsis is in order first. "Arcadia" is set in a single location—an English country estate—but in two time periods, one around 1810 and one around now. The main characters (for our purpose) in the early period are Thomasina Coverly, the teenaged daughter of the manorial family, and her tutor, Septimus Hodge. Other characters include a son, Augustus, and a guest, Chater, with a notably promiscuous wife (never seen). In the contemporary period, the three key characters are all academic types. Hannah Jarvis is a guest, studying the history of the estate (concentrating on a mysterious hermit). Bernard Nightingale drops in, looking for support for his theory (based on some letters and penciled notes in manuscripts) that the poet Byron was a guest at the estate in 1809, had an affair with Mrs. Chater, killed Chater in a subsequent duel, and was forced to flee England (the last being the only established fact in the sequence). Valentine Coverly (the same family still owns the estate) is a mathematician, working on chaos theory—specifically population dynamics as represented by the records of grouse hunting in the estate game books. There are also two younger Coverly children, Chlöe and Gus.

It is clear from very early on that the play has *something* to do with time and entropy. Within the first ten minutes, we get this exchange [11] (pp 4–5):

> THOMASINA: When you stir your rice pudding, Septimus, the spoonful of jam spreads itself round making red trails like the picture of a meteor in my astronomical atlas. But if you stir backward, the jam will not come together again. Indeed, the pudding does not notice and continues to turn pink just as before. Do you think this is odd?
>
> SEPTIMUS: No.
>
> THOMASINA: Well, I do. You cannot stir things apart.
>
> SEPTIMUS: No more you can, time must needs run backward, and since it will not, we must stir our way onward mixing as we go, disorder out of disorder into disorder until pink is complete, unchanging and unchangeable, and we are done with it for ever. This is known as free will or self-determination.

Obviously Septimus is a bit of a cynic; his last sentence can't be meant seriously. [Earlier in the play (p1) he defines carnal embrace for Thomasina as "the practice of throwing one's arms around a side of beef."] Equally obviously, Thomasina is quite a prodigy; she anticipates both Laplace (p 5):

> THOMASINA: If you could stop every atom in its position and direction, and if your mind could comprehend all the actions thus suspended, then if you were really, *really* good at algebra you could write the formula for all the future; and although nobody can be so clever as to do it, the formula must exist just as if one could.

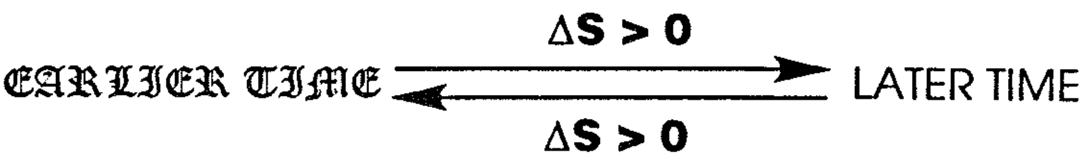
and the second law (pp 87, 93):

> THOMASINA:...Newton's equations go forwards and backwards, they do not care which way. But the heat equation cares very much, it goes only one way...
>
> SEPTIMUS: So, we are all doomed!
>
> THOMASINA: (*Cheerfully*) Yes.
>
> SEPTIMUS: So the Improved Newtonian Universe must cease and grow cold. Dear me.

Stoppard has drawn here the classic contrast between the eternal mechanical clock universe and the universe decaying toward its inevitable heat death—and if we go no deeper than these expository statements, then he seems to be accepting the latter, pessimistic view. Of course, Prigogine and Stengers have explained how this long-term pessimism is *not* the only alternative to the reversible and static Laplacean universe: so-called dissipative systems create order in localized subregions of open systems [12]:

> A new unity is emerging: irreversibility is a source of order at all levels. Irreversibility is the mechanism that brings order out of chaos. How could such a radical transformation of our

Fig. 1. Entropy as time's double-headed arrow



views on nature occur in the relatively short time span of the past few decades? We believe that it shows the important role intellectual construction plays in our concept of reality.

No doubt Stoppard would agree with the last sentence. However, the play seems to present a picture of reversibility at odds with both Laplace and Prigogine and Stengers. The latter argue [13]:

> When time goes forward there is a role for chance, because small or random fluctuations near a bifurcation point can cause a system to take a different path than it otherwise would....But when time runs backward along the same track it took before, every juncture point is already predetermined, and hence chance can play no further part in the system's evolution.

Since "Arcadia" presents us with a single setting at two different times, we can examine how the "system" evolves over time. We may take it for granted that evolution in the forward direction is characterized by chance and disorder, even though Stoppard does not explicitly dwell on this motif in the play. (There are veiled hints about degeneration of the Coverly family: whereas Thomasina is a child genius and Augustus is a budding young aristocrat, Chlöe appears to be pretty much an airhead, while Gus is mysteriously mute.) On the other hand, a *major* focus of the play is on the various attempts—especially Bernard's—to *reconstruct the past,* which, in the informational world, is metaphorically a *backwards* trip in time. And what we see is that these backwards time travelers are subject to exactly the chance events and random fluctuations that Prigogine and Stengers deny! Bernard gets (nearly) everything wrong, because letters are left in the wrong place, misleading inscriptions are misattributed, crucial documents turn up at the wrong time, etc. So if we make the usual commonsense connection (but not the only possible choice; see below) equating randomness, disorder, and loss of information with increasing entropy, we get the result shown in Fig. 1. If entropy is "time's arrow," in this play it points both ways!

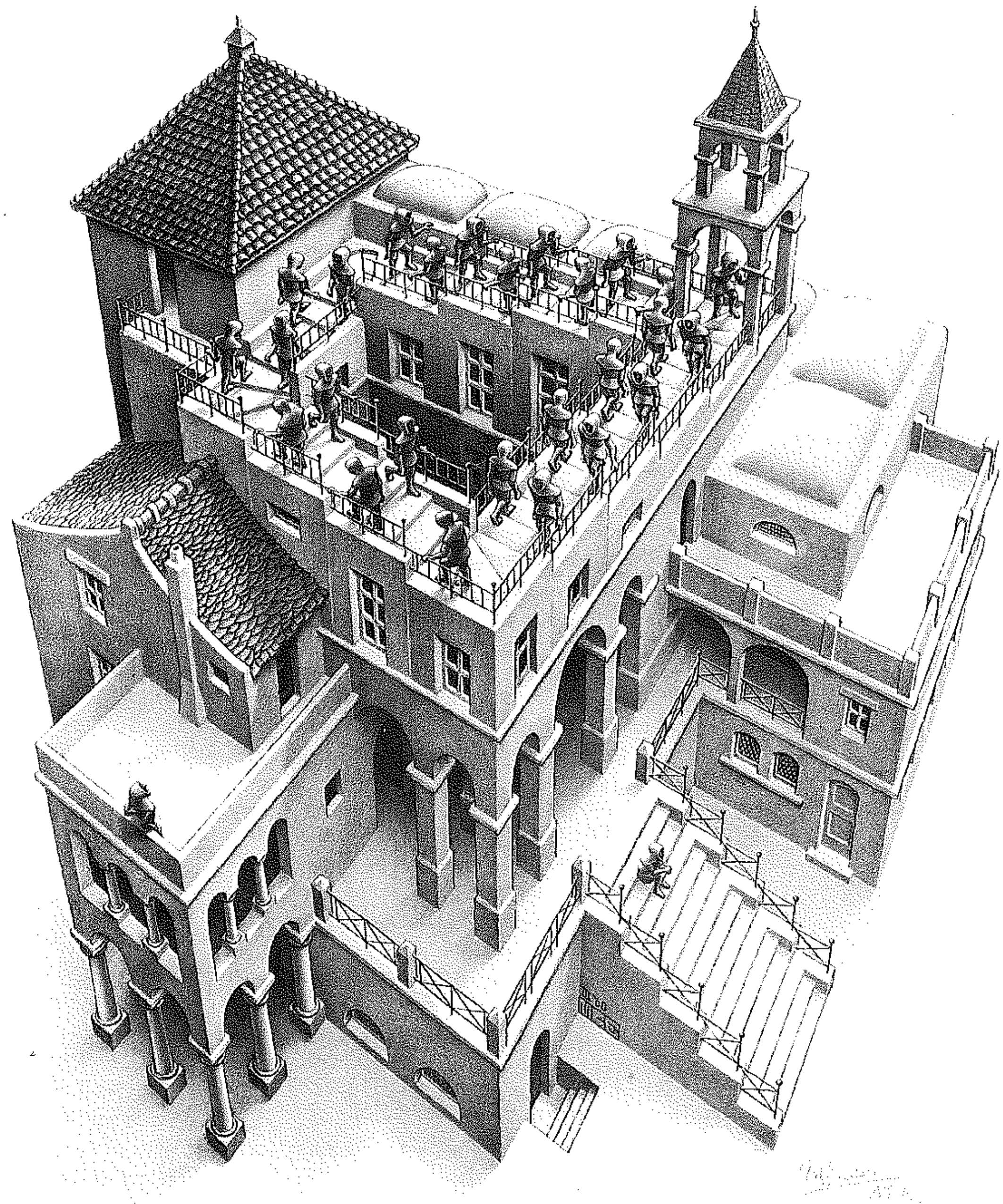
Well, this is just silly, isn't it—how can a quantity increase in both directions? Perhaps in the mental/perceptual world it *can.* A familiar illustration by M. C. Escher is shown in Fig. 2, where one gets from point A to point B by going uphill and from point B to point A by going uphill! Before I try to interpret this paradox, though, let me extend it a bit further. As the Escher print shows, if you can travel uphill in *either* direction, then by continuing to travel in *one* direction, you must return to your starting point [14]. The analogue in "Arcadia" would be a demonstration that the system is in the same state (since thermodynamic entropy is a state function) in the two time periods. That equivalence is suggested by the staging. The directions for the opening of Scene Two, where we shift, for the first time, from 1809 to the present, read (p 15):

> The lights come up on the same room, on the same sort of morning, in the present day, as is instantly clear from the appearance of Hannah Jarvis; and from nothing else.
>
> Something needs to be said about this. The action of the play shuttles back and forth between the early nineteenth century and the present day, always in this same room. Both periods must share the state of the room, without the additions and subtractions which would normally be expected. The general appearance of the room should offend neither period....The landscape outside, we are told, has undergone changes. Again, what we see should neither change nor contradict.

This equilibration of the two time periods intensifies as the play proceeds. Whereas the first six scenes alternate between 1809 and the present, the seventh (last) scene is set in *both* time frames (the earlier one has moved forward to 1812). Eventually, characters from both periods occupy the stage simultaneously, right up to the end. Furthermore, in the final scene the action in the contemporary period includes preparation for a costume ball, so the characters are all wearing Regency dress and are not readily distinguishable from those of the earlier period—especially the 1812 character Augustus and the modern Gus who, the author directs, are to be played by the same actor.

What is Stoppard trying to convey by portraying in "Arcadia" a universe where changes over time are reversible—not in the Laplacean sense, but rather in the paradoxical Escherian mode of continuous change and return? I read it as a message

Fig. 2. M.C. Escher, "Ascending and Descending" © 1996 M. C. Escher/Cordon Art–Baarn–Holland. All rights reserved.



of optimism, to counter the second law's pessimistic prediction of decay; but it does so quite differently from Prigogine and Stengers. Their message comes from superseding Laplace's time-reversible vision of stasis [15]:

> The world of Laplace was eternal, an ideal perpetual-motion machine.

by one centered on the role of irreversibility in creating order. How do these pictures translate into informational entropy terms? If entropy and information are mathematically related, then, in Laplace's universe, entropy is constant, since information is constant—everything we need to predict the future or retrodict the past is always present. As we intuitively took entropy and information to be *inversely* related, the creation of order seems obviously to correspond to a decrease in entropy. But, in fact, Shannon's version of information theory assigned entropy and information as mathematically *identical*, not opposite—entropy increases together with information. Perhaps with that in mind, Stoppard is not much concerned with creating order—which if continued indefinitely, after all, amounts to a one-way trip just as surely as its opposite. The destination of that trip is yet another dismal fate the second law holds out for us: we will be smothered to death by a glut of information [16]:

> The achievement of redundancy—when everything that needs to be said has already been said—is analogous to entropic homo-

geneity when matter–energy settles into terminal equilibrium.

an image that is echoed in "Arcadia" (p 94) [17]:

> VALENTINE: And everything is mixing the same way, all the time, irreversibly . . .
> SEPTIMUS: Oh, we have time, I think.
> VALENTINE:...till there's no time left. That's what time means.
> SEPTIMUS: When we have found all the mysteries and lost all the meaning, we will be alone, on an empty shore.

So this is how the second law works in the Stoppardian–Escherian universe of the mind: entropy and information are always increasing but always stay the same. Perpetual motion *is* possible (see Fig. 5 for a diagram of a perpetual-motion machine)—but not as in Laplace's static universe. We are continuously creating information, but that simultaneously creates the demand for more information—and it is the creation, not the information itself, that is important (p 75):

> HANNAH: It's *all* trivial—your grouse, my hermit, Bernard's Byron. Comparing what we're looking for misses the point. It's wanting to know that makes us matter.

And thus this metaphoric variant of the second law shows us how to escape its pessimistic implications [18]—all we need to do is never run out of questions. Which brings us back to the intersection of art and science—for Victor Hugo said much the same thing, over a hundred years ago [19]: "La science cherche le mouvement perpétuel. Elle l'a trouvé; c'est elle-même."

REFERENCES AND NOTES

1. Eddington, A. S. *The Nature of the Physical World;* Macmillan: New York, 1948; p 74. (Quoted in Ref. 12 below, p 233.)
2. Discussed, for example, in Kragh, H.; Weininger, S. J. "Sooner Silence than Confusion: The Tortuous Entry of Entropy into Chemistry," *Historical Studies in the Physical and Biological Sciences,* submitted for publication.
3. But not unquestioned; for an example, see Layzer, D. *Sci. Am.* **1975,** *233* (December), 56. This subject has of course also been treated in fiction, as in the familiar Asimov short story "The Last Question."
4. Rifkin, J. *Entropy: A New World View;* Viking: New York, 1980.
5. For illustrations of how this "guilt by association" can operate, see Gross, P. R.; Levitt, N. *Higher Superstition: The Academic Left and Its Quarrels with Science;* Johns Hopkins University Press: Baltimore, 1994.
6. Denbigh, K. G.; Denbigh, J. S. *Entropy in Relation to Incomplete Knowledge;* Cambridge University Press: Cambridge, 1985; p 117.
7. Klein, J. F. *Physical Significance of Entropy or of the Second Law;* D. van Nostrand: New York, 1910; pp 89–90.
8. A number of commentators have remarked on how Shannon's connecting the concepts was rather arbitrary, based largely on resemblances between the mathematical forms of equations and von Neumann's recommendation to call an information measure entropy: "It is already in use under that name . . . and besides it will give you a great edge in debates because nobody really knows what entropy is anyway" (quoted in Ref. 6, p 104).
9. Sayers, D. L. *Have His Carcase;* Avon Books: New York, 1932; p 236.
10. Pynchon, T. "Entropy," in *Slow Learner;* Little, Brown: Boston, 1984; pp 88–89. In his introduction to this volume, a collection of early stories, Pynchon rather agrees with my characterization. Since then, many critics have made a small cottage industry out of tracing themes of entropy and chaos through Pynchon's later oeuvre.
11. Stoppard, T. *Arcadia;* Faber and Faber: London, 1993. (Page number references to the text are given in parentheses.)
12. Prigogine, I.; Stengers, I. *Order Out of Chaos: Man's New Dialogue with Nature;* Bantam Books: New York, 1984; p 292.
13. This is a paraphrase of Prigogine and Stengers, rather than a direct quote: Hayles, N. K. *Chaos Bound: Orderly Disorder in Contemporary Literature and Science;* Cornell University Press: Ithaca, 1990; pp 98–99.
14. Here in my presentation I used an audio illustration—a tone that seems to be continuously descending in pitch but always returns to where it began (Pierce, J. R. *The Science of Musical Sound;* Scientific American Books: New York, 1983; pp 193–194)—which is obviously unavailable for this written argument.
15. Prigogine and Stengers, Ref. 12, p 115.
16. Again, a paraphrase, this time of Michel Serres: White, E. C. In *Chaos and Order: Complex Dynamics in Literature and Science;* Hayles, N. K., Ed.; University of Chicago Press: Chicago, 1991; p 268.
17. Note that this "dialogue" involves characters from the two different time periods; they share the stage, but they are not speaking to each other. [This would be a good point to remind ourselves of what Stoppard has frequently stated, that a play is not a text but an event; reading it (or reading about it!) is but a pale substitute for the real thing.]
18. We learn toward the end of the play that Thomasina dies in a fire just after the final (1812) scene—that is, she suffers her own "heat death." During the discussion after the presentation of this paper, a member of the audience reported that he heard Stoppard explain in an interview that he added this touch after his son, a physics student, told him that his take on thermodynamics was rather *too* optimistic.
19. Quoted in Lévy-Leblond, J.-M. *SubStance* **1993,** *71/72,* 7–26.

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