Ending well is the best revenge.

Why do we need to get the last word in an argument? Why do Aesop's fables end with a "moral of the story"? Why is the punchline at the end of a joke? The answer to all of these, of course, is because endings are power positions. People remember the last thing you say. The resolution should be your "take-home message," your strongest and most memorable words.

A good resolution shows us how our understanding of nature has advanced, and by offering new insights into the problem identified in the opening, it wraps up the story. This creates the story's spiral, closing back to the original topic, but drawing it out by showing how the starting point has moved. A good resolution achieves this by stepping backward through OCAR: it reiterates the action, answers the questions raised in the challenge, and demonstrates how those answers contribute to the larger problem.

If you put anything but that new insight in the resolution, you undercut it, and with it the entire paper. Because last words are so powerful, people will accept whatever you put there as the take-home message. If you are not careful, some weak or extraneous thought that finds itself in the closing position can come across as your most important.

Don't blow the punchline.
9.1. GOOD RESOLUTIONS

The first example of a good resolution is straightforward, walking backward
through the OCAR steps without distraction or complication. The paper exam-
ined the enzymes that drive mammalian cells through their cell cycle, focusing on
how cyclin–cyclin-dependent kinases become active at specific points in the cycle,
driving further development. It examined inhibitor p27, which regulates a kinase
complex, and asked whether it has a single mechanism—blocking the enzyme’s
active site—or whether it also blocks enzyme activation via phosphorylation. The
resolution paragraph is as follows.

Example 9.1

1 In conclusion, 2 our data suggest that Y-phosphorylated p27 can inhibit
cyclin D-ck4 complexes by two independent mechanisms: blocking access
to the T-loop and disrupting the cdk4 active site directly. 3 Our model sug-
gests that p27 Y phosphorylation is a molecular “switch” that would help
turn cdk4 activity on or off. 4 Modulation of Y kinase activity would permit
activation of preformed, inactive p27-cyclin D-ck4 complexes by cdk7 and
may be used to regulate cdk4 activity throughout the cell cycle.1

This resolution does a number of things well.

1 The statement “In conclusion” is a flag, telling the reader that what
follows is the resolution. Such road signs make it easier to navigate
through a paper.

2 This states that two mechanisms of inhibition are involved. This is the
key result of this work, and it answers the question posed in the
challenge.

3 This statement interprets that result and synthesizes it into the idea that
p27 Y phosphorylation is a “molecular ‘switch.’” That creates a simple
message and an accessible intellectual model for how this compound
works—switches turning on and off the processes that drive the cell
cycle. This starts “widening the hourglass” by moving away from the
specifics of how p27 inhibits, to what that means for cell cycle
regulation.

4 This finishes opening the hourglass by bringing the story back to issue
the paper opened with—what regulates the cell cycle. It even puts the
phrase “the cell cycle” at the end of the concluding sentence, closing the
circle back to the opening sentence of the paper, which was: “Cyclin–
cyclin-dependent kinase (cyclin-ckd) complexes drive progression
through the different phases of the cell cycle by acquiring catalytic
activity only at specific points.”

D-Cyclin-Dependent Kinase 4 by Two Independent Modes,” Molecular and Cellular Biology 29
This paragraph puts the right ideas in the right places, uses appropriate language to guide you through the paragraph, reiterates the key conclusions and their implications, and closes the circle to complete the story. It isn't elegant or literary in its use of language, but it is inordinately effective in doing its job.

A second example is from materials science and is about producing inorganic/organic composite materials, with a specific focus on semiconducting films that would be useful in electronic devices, including photovoltaics and LEDs. This is a more complex resolution but it achieves the same essential goals.

Example 9.2

[1] These templated nanostructured frameworks thus hold several advantages for the design and synthesis of devices. [2] Films can be selectively deposited through solution phase routes using the chalcogenide affinity to bind to gold. [3] Furthermore, the ability to control the elemental compositions of the nanostructured films allows the band structure of the inorganic framework to be tailored for specific applications. [4] Current research is underway to create composite materials using an organic semiconductor as the structure directing agent. Such materials would make good candidates for device applications such as photovoltaics. Moreover, it is likely that these same band energy trends will hold for nontemplated versions of chalcogenide glass semiconductors synthesized using Zintl cluster precursors. [5] As a result, the data presented here provide a basis to predicatively synthesize a broad range of semiconductors with desired band properties using Zintl cluster precursors and simple solution phase methods.2

[1] This is a statement of the overall accomplishment—the authors created a useful material. It gives a clear sense that this is the resolution and that they will flesh out this point in the rest of the paragraph.

[2] In this second sentence, they state the key result from the work: “films could be selectively deposited.”

[3] Here they start expanding back out, with a more general interpretation of that result.

[4] The authors continue the widening process, going beyond their specific research and discussing the implications of the work. They expand it by pointing out that “these same band energy trends will hold for nontemplated versions.”

[5] Here in their final wrap-up statement, the authors give the most general application of their work: “a basis to predicatively synthesize a broad range of semiconductors.”

In contrast to the first example that used the flag words “in conclusion” to tell us we’re at the resolution, this uses a whole sentence to frame the point of the

paragraph and guide you through it. It then, however, carries out the same functions—it identifies the key result, opens up the hourglass, and resolves by tying back to the big picture of the paper’s opening. This paragraph creates a complete story within itself—opening, developing, and resolving, a strong approach for a longer paper and a longer resolution.

9.1.1. Concluding with a Question

In each of the foregoing examples, the authors identified a result and explained its significance. Sometimes, however, the most important thing you discover is that there is a new question, one you hadn’t anticipated, that you want to pose to the community. Fine. Do it, but make the question concrete, and be clear about how it grew from your work—you didn’t fail to fill one knowledge gap but identified a new one. Ending with a concrete new question engages a reader’s curiosity and can be a powerful way to resolve a paper.

The following is an example of how to resolve effectively with a question. It comes from arctic climate science, examining the mechanisms responsible for the enormous loss of sea ice in the Arctic Ocean during 2007. That loss shocked the climate community—such massive ice loss had been predicted to be decades away.

Example 9.3

{1} There was an extraordinarily large amount of ice bottom melting in the Beaufort Sea region in the summer of 2007. Solar radiation absorbed in the upper ocean provided more than adequate heat for this melting. An increase in the open water fraction resulted in a 500% positive anomaly in solar heat input to the upper ocean, triggering an ice–albedo feedback and contributing to the accelerating ice retreat. The melting in the Beaufort Sea has elements of a classic ice–albedo feedback signature: more open water leads to more solar heat absorbed, which results in more melting and more open water. The positive ice–albedo feedback can accelerate the observed reduction in Arctic sea ice. {2} Questions remain regarding how widespread this extreme bottom melting was, what initially triggered the increase in area of open water, and what the summer of 2007 portends for 2008 and beyond.3

{1} The main part of this resolution states both the findings and conclusions using clear strong language: “solar radiation . . . provided more than adequate heat for the melting” and “The positive ice–albedo feedback can accelerate the observed reduction in Arctic sea ice.” There is no hesitation or weakness.

[2] The resolution goes further to frame a series of questions about both the mechanisms involved and the implications for the future. However, rather than undermining the conclusions, these questions actually reinforce and extend them; they point the direction forward. They engage a reader's interest. Even using a word like *portend* emphasizes the new question—it's an ominous word.

Here is a slightly more complex example from astrophysics.

Example 9.4

(1) Finally, while the details of the solutions that we have discussed specifically apply to the case of a rotating NS accreting from a disk fueled by a companion star, the general feature of a multiplicity of states available for a given mass inflow rate of matter can probably be generalized to other accreting systems in which recycling occurs. (2) An example is that of an accretion disk around a rotating black hole. Numerical simulations show that while a fraction of the accreting mass is ejected through a jet, another fraction, of slower velocity and at larger angles from the jet axis, falls back into the disk, getting recycled. (3) It would be interesting to include this mass feedback process into numerical simulations of accretion disks around black holes and to investigate whether the discontinuous states and cyclic behavior might ensue in those cases as well.4

(1) Here, the authors start with the specific results of the work, defining the system it is limited to, but start opening the hourglass back up by suggesting that this multiplicity of states "can be generalized."

(2) They develop that by highlighting a particular system that they think it would generalize to the black hole's accretion disk and how it would fit into their analytical framework.

(3) Finally the authors frame the new question that grows from their work and pose it to the community. It's an interesting question and in no way undermines the accomplishment of what the authors did. Rather, it creates a natural progression. This is nicely done.

9.2. BAD RESOLUTIONS

All of the previous examples illustrate strong resolutions, and, despite the different writing approaches, they all carry out the core functions of identifying the main results and their implications. Now let's consider bad ones—resolutions that fail in those core functions. There are several ways to destroy a good paper with a

bad resolution. You can be weak, distracting, or, at worst, you can actively undermine your conclusions.

9.2.1. Weak

Weak resolutions fail to frame the conclusions. In this type of ending, authors usually synopsize their results and then tell you that they are important, but don’t clarify how—they don’t answer the questions they were asking and don’t synthesize their information into knowledge. Here’s an example.

Example 9.5

A proteomic evaluation of hummingbirds under simulated migratory conditions revealed evidence of several stress-associated processes: protein degradation in wing muscle tissues, depletion of metabolic cofactors, and enhancement of stress-response proteins. These results suggest that changes in the hummingbird proteome may provide new insights into the complex physiology of avian systems biology.

This paragraph does a good job of synopsizing the results, but then it stumbles. Rather than synthesizing new knowledge, it skips that step. Instead, it simply tells us that the research is important and has implications beyond hummingbirds. In doing so, it overreaches and underdelivers, being simultaneously unconvincing and obvious.

These authors were trying to widen the hourglass to reach the largest possible audience, which is commendable, but they did it badly. They tell us that it “may provide new insights . . . into avian systems biology,” but they don’t tell us what those insights are! What did these authors contribute to the wider field of bird physiology and ecology? We’re left to figure it out for ourselves. We might conclude that the authors didn’t fully understand their own data and are tossing them out in the hopes that we’ll figure it out for them. That isn’t the take-home message you want to give readers.

As to the work’s implications to the wider field, it goes without saying. Would a scholar studying migration in geese, albatrosses, or swallows ignore a paper on hummingbirds? No. Saying it is relevant accomplishes nothing without the concrete substance to illustrate that relevance. This is a train wreck of a resolution.

To fix a resolution like this, you need to identify the new insights.

“A proteomic evaluation of hummingbirds under simulated migratory conditions revealed evidence of several stress-associated processes: protein degradation in wing muscle tissues, depletion of metabolic cofactors, and enhancement of stress-response proteins. While hummingbirds migrate long distances over water without feeding or resting, it is physiologically stressful, and the birds’ ability to manage this stress may limit the distance they can migrate.”
Here, rather than trying to make a methodological but largely meaningless suggestion about how to study birds in general, the paper ends with a clear conclusion about what these data mean—migrating is stressful—and a suggestion for what they say about hummingbird biology and behavior, suggestions that clearly relate to other birds. This resolution says something concrete—it resolves.

If the authors wanted to open the hourglass wider to explicitly encompass other migratory birds, they could modify the last sentence to make hummingbirds a member of that larger group:

"While many birds, such as hummingbirds, migrate long distances without feeding or resting, it is physiologically stressful, and birds' ability to manage such stress may limit the distance they can migrate."

This adds "such as hummingbirds" to make it clear that they are an example; it also condenses "and the birds" to "and birds," a subtle change that shifts it from referring to specific birds to birds in general. This does, however, suggest that we know migrating is stressful in other birds and that we had developed that argument in the Introduction. If that isn't the case, this might be an excessive stretch to draw from this study alone.

Here's another example of a weak resolution, this one from the field of medical microbiology.

Example 9.6
In summary, we show that X7 alters the expression pattern of extracellular proteases in the "flesh-eating bacterium" Streptococcus pyogenes, which causes necrotizing fasciitis. If the function of X7 can be fully established, it would likely deepen our understanding of this destructive disease.

In this example, the authors clearly knew they couldn't end with a summary of the data; they needed some kind of wrap-up. But all they could come up with was a throw-away line that included a patently obvious truth and a back-handed slap at their own data. Of course if we understand what controls the expression of protein-destroying enzymes, we would understand the disease better! And they remind us in the last sentence that they haven't fully established the function of X7. There's nothing wrong with not fully establishing its function, but don't end a paper by telling your readers what you didn't achieve.

As in the previous example, the fix is to make a concrete conclusion that synthesizes the results into knowledge and provides a meaningful take-home message.

"In summary, we show that X7 alters the expression pattern of extracellular proteases in the 'flesh-eating bacterium' Streptococcus pyogenes, which causes necrotizing fasciitis. This research may offer a route to developing therapeutic agents that would minimize tissue damage while antibiotic treatments were directly attacking the bacterium itself."
This version identifies the work's real conclusion—it might lead to drugs that would provide a tool for managing the disease. That would close the circle to the paper's opening, which framed a story about necrotizing fasciitis, the bacterium that causes it, and potential therapies for a horrible malady.

Note that this resolution, while ending with a strong message, is carefully constrained. It doesn't say that $X7$ is necessarily going to be that new therapeutic agent, and it only says that this "may" offer a route—it might not work in vivo. You can make a strong statement without overselling.

9.2.2. Distracting

Some papers conclude with material that is distracting—ideas that should be in the Introduction or is already in textbooks and that neither synopsizes nor synthesizes the results. The next example is from a paper about forest tree nutrition, asking how much organic N is taken up by mycorrhizal fungi, which acquire nutrients from the soil and transport them to the root.

Example 9.7

The mycorrhizal fungal hyphae extending out from tree roots can comprise more than 1/3 of the total biomass of microbes in the soil. They greatly extend the absorptive surface area of the root system and enhance total nutrient uptake by the trees. Additional work, however, is required to assess how much mycorrhizal fungi enhance the uptake of organic N forms in forest soils.

These first two sentences are truisms that have been known for decades—textbook material, rather than results of this particular study. The only thing this paragraph says about the study itself is that additional work is required to assess how much organic N mycorrhizae take up. So did we learn anything? In the paper we actually did, but not from this resolution—it resolves nothing and merely distracts from the story.

A second way a resolution can be distracting is by introducing new information at the end. The following might appear to be a strong resolution.

Example 9.8:

In arid environments such as East Africa, termites are critical "ecosystem engineers." They collect resources such as nitrogen and phosphorus from far afield and accumulate it in and near their mounds, creating nutrient hot-spots on the landscape. These hot-spots may be sites for colonization by new seedlings of both the native savanna trees and for novel invasive plant species.

The problem here is that invasive plants were never mentioned in the Introduction. The idea that termite mounds create invasion sites is interesting and important, but it must not be a new idea, first raised in the resolution.
The resolution must close the circle back to the opening. Instead of closing the circle, however, this resolution goes haring off in a new direction.

I would guess that the idea of termite mounds creating invasion sites developed while the authors were writing the paper. That’s great; developing new ideas while you are writing is exactly what Montgomery meant when he said that “clear thinking can emerge from clear writing.” Never close your mind to new insights about your work and its implications. But when you have them, go back and weave them into the opening and Introduction. You are not writing a “whodunit” mystery where shocking plot twists are expected. You are writing science, where such plot twists are forbidden.

From the perspective of getting your message out to the widest possible audience, surprise resolutions are a disaster. The points they make won’t get picked up in a literature search, so potential readers will only find your paper by accident. Plant ecologists should know about work showing that termites facilitate invasion, but they probably wouldn’t learn it from this paper. Everyone loses—plant ecologists miss useful information, and the authors lose citations.

9.2.3. Undermining Your Conclusions

The worst possible way to end a paper is to actively undermine your conclusions, and yet this may be the most common way to end scientific papers. Many end by saying “more research is needed to clarify our findings.” Resolving a paper this way focuses on what you haven’t accomplished. That is worse than throwing away a power position—it uses that power to weaken your conclusions and your science.

I understand the humility involved in “more research is needed”—we know our work isn’t perfect and that there are still questions about both the big issue of our opening and the small issue of our challenge. Uncertainties remain. But the resolution is not the place to discuss them.

A really egregious example of undermining the conclusions is in the next example.

Example 9.9

To conclude, 3-methyl-ambrosia offers a new approach for thyroid carcinoma therapy. Our data provide evidence on safety and in vivo activity of this compound in patients with this condition, although the proof for clinical benefit remains to be established in future clinical trials.

In the first part of this passage, the authors tell us that they have a new therapy that appears safe and effective. Their take-home message, though, is that they don’t know whether it really works! Talk about destroying the story. This would have been much better as:

“While further clinical trials will be necessary to establish the full benefits of 3-methyl-ambrosia as a therapeutic agent, our data provide evidence that it is
safe and shows in vivo activity against thyroid tumors. 3-Methyl-ambrosia therefore may offer a new approach for treating patients with thyroid carcinoma."

This version says the same things as the original, but strongly and positively. It is clear that additional clinical trials are necessary and that the efficacy remains uncertain (it only "may offer" a new approach). But it ends by highlighting the authors' intended message: 3-methyl-ambrosia may be an effective new anticancer drug.

The earlier example about flesh-eating bacteria also undermined itself with a "more research is needed" expression as well: "if the function of X7 can be fully established."

This kind of "more research is needed to clarify our results" statement is fundamentally different from "concluding with a question" that I illustrated in examples 9.3 and 9.4. Those resolved by posing concrete questions that grew from the work. "More research is needed" poses questions about the work and makes it sound like the author didn't complete the research.

There are many ways to undermine your results, including expressions such as "but the importance of this has yet to be assessed," "we hope that this review will simulate further research to answer the many unanswered questions," "this topic deserves more research," and so on. All of these use fuzzy expressions that suggest weaknesses in the existing work, rather than expressing substantive conclusions or pointing out clear new questions.

9.3. HOW TO FIX A BAD RESOLUTION

Although the problems in the bad examples are superficially different, they share the same core problem and solution. In each example, the authors ended with a line that concludes little, weakens the existing conclusions, or fails to complete the circle of the story. Each version misses some component of the SUCCES formula—frequently C, concrete.

The solution is to first pare away the dead tissue—the fluff, the detractions, and the new ideas. When those are important, move them elsewhere. Then, condense your resolution to do three things: (1) synopsize the key results, (2) synthesize those results—show us how they answer your question, and (3) show us what this contributes to solving the larger problem. If you achieve those three objectives, each clearly and concretely, you will have a strong resolution that ends your paper with maximum punch.

9.4. RESOLUTIONS IN PROPOSALS

Most proposal authors recognize that they need to grab a reader's attention quickly—the critical energy is right up front in the initial action or lead. But many
go all the way to a pure LD structure. After describing the proposed experiments, they end, having said everything that seems to need saying. There is no synthesis, no wrap-up, no resolution.

That's a mistake. Make space for a resolution paragraph that encapsulates the proposal, reiterates the big issue and explains how the components work together to address it—make the final pitch for why the proposal should be funded. Some may argue that they have already made those points, so repeating them would waste valuable space.

But reviewers' thoughts may not be fully crystallized. They have just worked through pages of dense, detailed material. They read about multiple hypotheses and lines of experimentation. They are thinking about how the pieces fit together, whether the experiments will work, whether this will really solve the problem, and, importantly, what to write in their review. This is your last opportunity to give them the words. To convince them to check "excellent;" or as the program officer holds your fate in her hand, hovering over the line on the whiteboard, asking "which side does this go on?", to say "must fund."

To illustrate a proposal resolution, here is one from a proposal evaluating why nitrogen availability in arctic tundra soils crashes in the middle of the growing season and how that affects overall ecosystem function and C-cycling.

Example 9.11

The Arctic tundra is one of the world's major stores of C and the possibility that the temperature-decomposition-CO₂ flux positive feedback may accelerate climate warming is a concern in Arctic and global climate studies. The "spin-off" feedbacks via nutrient effects on vegetation change may further accelerate the climate-warming feedback. However, biogeochemical models assume that decomposition is limited by C-availability but regulated by temperature. Thus, the assumption is that if temperatures rise and the snow-free season lengthens, decomposition and CO₂ release will increase dramatically. However, C cycling is N-limited in tundra, at least later in the growing season after the nutrient crash, challenging these ideas. We propose research that will span multiple scales to evaluate the mechanisms causing the "nutrient crash," how they are driven by seasonal weather patterns and plant phenology, and what the effects of the nutrient crash on C-cycling will be. This work will require intense mechanistic work focusing on transitions and transformations that occur over only a few weeks at most, but which have profound impacts on the tundra ecosystem. We will scale this mechanistic work to the intermediate spatial scale by doing transect measurements along the Kuparuk Basin to validate that patterns that occur locally are robust. We will scale to the whole Arctic system by integrating these mechanisms, and importantly the N-effects on decomposition, into the MEL model that is designed to explore multiple limiting resource effects on ecosystem function. As an integrated package, this research will explore how the changing seasonal pattern that drives the crash in nutrient availability in tundra soils will alter overall
tundra C-cycling and its role as a source or sink of C and through this its role in the global climate system.\footnote{From M. Weintraub, lead PI, "The Changing Seasonality of Tundra Nutrient Cycling: Implications for Ecosystem and Arctic System Functioning," funded by the U.S. National Science Foundation's Arctic System Science Program.}

This paragraph reiterates the entire proposal, laying out the problem, challenge, research, and how it will solve the problem. This takes a half-page, which seems like a lot when you're struggling with a page limit. But the feedback from the program officer suggested that this barely squeezed over the line into the "funded" category. We'll never know whether that resolution paragraph was what gave it the million-dollar nudge, but I do know that a reviewer's opinion is sometimes not solidified until the end. So end strong.

EXERCISES

9.1. Analyze published papers

Examine the resolutions of the papers you are evaluating. Do they effectively resolve? Do they briefly sum up the most important results? Do they answer the question? Do they close the circle by returning to the big problem identified in the opening? If not, how would you rewrite the resolution to achieve these goals?

9.2. Write a short article

Do the same exercise for the short articles you and your peers are writing.
Internal Structure

I figured out, over and over, point A, where the chapter began, and point B, where it ended, and what needed to happen to get my people from A to B.

—Anne Lamott, *Bird by Bird*

OCAR defines the overall structure of a story. The opening grabs your attention with characters and a setting that you care about. The challenge creates uncertainty and curiosity: what is going to happen to those characters? Novelists describe that as creating “tension”—the emotional drive to keep reading. The action feeds you information and develops the story. Finally, the resolution rewards your efforts and relieves the tension—our hero and heroine finally get together, our questions are answered! We may not feel the emotional intensity in a science paper that we do in a good novel, but the tension that keeps us reading is fundamentally the same—it’s grounded in curiosity. We don’t bother reading a paper if we already know the story. This flow of opening, development, and resolution—building and then rewarding curiosity—creates a story’s “arc” (figure 10.1). The vision of story as arc also emerges from the idea that a story has a spiral structure, moving forward but coming back, at the end, to where it began.

Scientific writing is successful when it creates that flow and that arc. But papers and proposals are made up of sections, each of which tells its own story and has
its own arc. The Introduction tells us why you did the work—it opens, narrows, and resolves with the paper’s overall challenge. The Materials and Methods starts with the study system, then the measurements, and wraps up with how you analyzed the data. The Discussion, too, should form a story of its own, as I argued in chapter 9. It opens by restating the issue, discusses the evidence, and resolves with the paper’s conclusion.

These major sections, however, are built of discrete modules: subsections that describe a single method, a single data set, or a single argument. Those subsections should be written to package complete ideas—that is, form story arcs of their own. When you describe a method, you should tell us what information you were trying to gain and what you did to get it. In describing a result, give the overview, the specifics, and the significance.

Going further, each subsection is built of units finer still: individual paragraphs, sentences, and clauses within a sentence. Each tells its own story and has its own structure—they should each form an arc. A story, therefore, doesn’t have just a single overall arc, but a hierarchical structure, with small arcs nested within larger ones, ultimately creating the whole (figure 10.2). This hierarchy is analogous to the structure of matter: quarks within protons within atoms within molecules.

A good story works when this hierarchical structure works. Each little arc draws readers forward—it grabs them with a local opening, engages them with a snippet of action, and then rewards them with a resolution. Each forms one turn of the spiral, and step-by-step, carries the reader from the initial issue to the final resolution.
Creating arcs compartmentalizes your thoughts and makes them manageable. It works because we learn by placing information into an established framework. For each new point we build a structure: we give the context and then describe the information, which makes a small story arc. That provides context for the next point, allowing us to construct increasingly complex stories piece at a time. This is like computer programming. Good programs are built from subroutines or objects, each of which is internally complete; they interact with others by passing specific pieces of processed information. Bad programs look like plates of spaghetti. Writing is linear, so we have to lay out these modules in series, each building from the previous.

Effective arcs make it easier for readers to deal with multiple ideas in a single paper. Compare the visual patterns when you link three complete arcs and when you break them up and intersperse them (figure 10.3). The two patterns each contain three arcs and take the same amount of space, but the bottom one is painful to look at (it makes me dizzy). When you write that way, it’s just as painful.

Arc structure is effective as well because beginnings and endings are power positions. They emphasize the information contained there, saying this is an important point. Without such positions, readers have a hard time distinguishing what is more important from what is less. Creating discrete arcs creates and highlights those power positions. In the top panel of figure 10.3, there are four: the beginning, the end, and the two connecting points in the middle. The bottom panel loses those points; even the beginning and ending are muddled.

10.1. EFFECTIVE ARCS

The last six chapters were all about how to build effective story arcs. They focused on the entire paper, with its opening, action, and resolution. The same principles, however, apply at every level of organization. I’ve discussed at length how to create the arc of the Introduction (chapters 5–7) and touched on the Discussion (chapter 8). Here I illustrate how to use the same principles to write effective subsections.
before going on to even finer scales—paragraphs and sentences—in the following chapters.

Let's look at some examples of sections from papers that make effective story arcs. The first is from a paper that evaluated patterns of nitrogen retention in watersheds in the Eastern United States. Nitrogen enters these watersheds from atmospheric deposition, fertilizer, and sewage treatment plants. It runs into rivers as nitrate \(\text{NO}_3^-\) and is ultimately flushed into the ocean. The authors found that in southern watersheds, less of the \(N\) entering them reached the ocean; these watersheds "retained" more \(N\). They analyzed the factors that caused this pattern and developed a hypothesis that the warmer ecosystems in the South allowed more biological denitrification, in which \(\text{NO}_3^-\) is converted to gaseous products: nitrous oxide \(\text{N}_2\text{O}\) and \(\text{N}_2\). The following section develops one piece of that overall story, evaluating the effect of human population on the proportion of \(N\) retained versus exported. I flagged important points with numbers in curly brackets.

Example 10.1

1 Population density

2 Increased \(N\) export has been shown to be related to increased human population density. 3 If northern watersheds had higher population densities than more southern systems, it is possible that the attendant increase in \(N\) input could potentially result in less watershed processing and hence an increase in proportionate riverine export in northern systems.

4 However, the ranges of population densities in northern and southern watersheds overlapped considerably, and, for a given density, the proportion of \(N\) export was always higher in northern systems than in southern ones. When all watersheds were considered together, there was a significant relationship between population density and riverine export due only to the influence of the three most densely populated watersheds (the Charles, Blackstone, and Schuylkill). 5 We conclude that population density cannot explain the difference in \(N\) export between northern and southern watersheds, but it is a factor to consider for explaining high \(N\) export in some watersheds. 1

1 The passage starts with a subhead to identify the issue: human population density.

2 This is the opening (O), which identifies the topic and characters: \(N\) export and human population density.

3 This poses the challenge (C): if northern watersheds have more people they might export more \(N\).

Here, the action (A) starts. The authors briefly analyze the data before coming to the climax: the apparent relationship between export and population density was driven by just three rivers.

The story resolves (R) with the statement "We conclude that population density cannot explain the difference in N export between northern and southern watersheds." The phrase "We conclude" is a flag that this is a resolution point.

This passage contains an entire OCAR story arc that completes the discussion of human population density—this is the last time the paper discusses it. After this, the authors move on to analyze other factors that might explain greater N retention in southern watersheds. This is an effective use of story arc structure.

A second example is from a paper that is also about global N cycling, but which asks the question: "What processes cause N to be in short supply in many terrestrial ecosystems?" When the atmosphere is 78 percent nitrogen (N\textsubscript{2}) and bacteria can convert that N into biologically available forms, why are plants limited by N? The specific section discusses N relative to carbon (C) and how organisms have characteristic ratios of those elements in their tissues.

**Example 10.2**

**Stoichiometry**

Organisms use essential elements at characteristic ratios, and these ratios differ systematically among different groups of organisms. Element ratios are widely used in the analysis of marine ecosystems. Their application is usually less explicit in terrestrial ecology, but they provide the basis for using critical element ratios to predict element mineralization or immobilization during decomposition. One general feature of terrestrial ecosystems is that C:element ratios in plants, especially trees, are much wider than those in other organisms as a consequence of plants' use of C-based compounds (cellulose, lignin) to provide structure. For N in particular, soil bacteria generally have a C:N ratio near 6, while plants often have C:N ratios > 100. Even the leaf litter produced in forests on infertile soils can have C:N ratios in excess of 100.

Consequently, relative to their own requirements, animals and microbes live in a C-rich, N-poor world. Animal nutrition and growth are often constrained by the N content of their food, and protein deficiency is widespread. This difference in stoichiometry can sustain N limitation to animals even where plants are not limited by N supply. Microbes also encounter little N (relative to their requirements) in the plant litter they decompose, and so they retain the N they obtain from their substrate and acquire more directly from inorganic pools in the soil. As a result, N cycling from organic matter back to biologically available forms lags behind the decomposition of plant litter.2

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This example opens by defining the overall issue and characters (organisms, essential elements, and characteristic ratios). The two paragraphs discuss these ratios and how they vary among different groups of organisms. It resolves by telling us about why organisms are N-limited: “As a result, N cycling from organic matter back to biologically available forms lags behind the decomposition of plant litter.” This section tells a discrete story, one that helps build the larger argument.

What sets this passage off from example 10.1 is that these authors split the story into two paragraphs, each of which makes its own arc. The first paragraph develops the idea that all organisms have characteristic element ratios, but it focuses on plants. That focus is established in the first sentence: “One general feature of terrestrial ecosystems is that C:element ratios in plants, especially trees, are much wider than those in other organisms.” Although one sentence starts by mentioning bacteria, it ends by saying “while plants often have C:N ratios > 100,” returning the stress to plants. The last sentence of the paragraph starts with “Even the leaf litter,” making plants the sentence’s subject, and so closes the story arc about plants.

The second paragraph, in contrast, opens with “Consequently, relative to their own requirements, animals and microbes,” which makes animals and microbes, the organisms that consume plants, the prime characters. All the sentences in this paragraph are about plant consumers, rather than about plants. Thus, it makes a story of its own.

Together, these paragraphs explain why organismal stoichiometry regulates N flow through an ecosystem and why N limits plant growth. The authors could have written this as one long paragraph, but it is stronger this way—each paragraph forms an independent arc. They linked them together with the word consequently and in the second paragraph by picking up the idea that the environment is C-rich and N-poor.

Through the devices of subheads, paragraph breaks, and flag words such as however and consequently, successful authors guide the reader through story arcs and arguments. Individual arcs integrate to form the overall paper. Watching your arcs and ensuring they are coherent and connected gives structure and flow to your writing. Making and resolving complete story arcs makes the reader’s job easy.

10.2. ARCLESS WRITING

When writing lacks clear story arcs, it becomes an incoherent mass with no obvious direction, no internal structure, and no points of clear emphasis. The reader may learn little from the work, or worse, they may misinterpret it. Example 10.3 illustrates such arcless, and artless, writing.

Example 10.3
California supports rich fisheries off its coast. The high productivity of fish is supported by high rates of algal production. Algal growth in the ocean is
typically limited by nitrogen supply, but this is high off California because
N-rich deep water wells up to the surface along the coast. This upwelling is
driven by winds that push the south-flowing surface water away from the
shore, allowing deep water to rise to the surface. These off-shore winds are
driven by regional climate patterns, including El Niño, that are being intensi-
ified by the greenhouse effect, which results from increased CO₂ in the atmo-
sphere. Increased CO₂ in the atmosphere also increases the amount of CO₂
dissolved in the ocean, which reacts with water to form carbonic acid
(H₂CO₃), reducing the ocean's pH. This reduced pH makes it hard for shell-
forming organisms to make calcium carbonate shells, and so may reduce the
productivity of important marine species such as abalone, oysters, and even
sea urchins. Thus, increasing atmospheric CO₂ is going to have many impor-
tant effects on marine ecosystems.

I find this paragraph completely incoherent, but I wrote it to be that way.
Importantly, though, it isn't incoherent because the sentences are unclear; they
aren't—each is a simple declarative statement. It also isn't incoherent because the
sentences don't link together. Rather, the opposite is true: each sentence builds
tightly off the idea developed in the previous one. Look at the ideas each sentence
starts and ends with. They tie together seamlessly.

California... fisheries
Fish... algae
Algae... nitrogen... upwelling
Upwelling... winds
Winds... climate
Climate... greenhouse effect... CO₂
CO₂... acid... reduced pH
Reduced pH... damage to shell-forming organisms
Thus... CO₂ will affect marine ecosystems.

The problem is that although the sentences flow, they don't flow anywhere in
particular. This feels like the result of a game where the first person writes a sen-
tence, passes it to the next person, who writes one and passes it on to the next. The
paragraph opens by identifying characters of California and its fisheries, but then
keeps adding new characters and new directions—first nitrogen and upwelling,
wind and climate, CO₂, acidification, shellfish, and finally marine ecosystems. It
then ends with a resolution statement that, although true, has no closure back to
the opening.

This paragraph lacked thematic coherence. As a result, the story was unclear. Is
it about how climate change will affect California fisheries? Or is the fisheries
example intended to illustrate the larger theme of climate effects on oceans?
The paragraph is incoherent because it fails to develop the OCAR functions
into an effective structure. There is no clear point and no arc to the story. It drifts.
This kind of writing can emerge because the authors never knew where they were
going, or because they got distracted in the middle by CO\textsubscript{2} and allowed the story to float off into uncharted and unplanned territory. In revising a paragraph like this one, you need to figure out what the story arcs are and break them into separate units.

Example 10.4
California supports rich fisheries off its coast. The high productivity of fish is supported by high rates of algal production. Algal growth in the ocean is typically limited by nitrogen supply, and is high off the California coast because N-rich deep water wells up to the surface along the coast. This upwelling is driven by winds that push the south-flowing surface water away from the shore, allowing deep water to rise to the surface. These winds are driven by regional climate patterns, including El Niño, that are being intensified by the greenhouse effect. Thus, the productivity of California fisheries will likely change as a result of climate warming, and the changes may result via complex and unexpected mechanisms such as changes in ocean circulation patterns.

In addition, increasing CO\textsubscript{2} is causing the pH of the ocean to decline, and this may have separate but important effects on California fisheries. As CO\textsubscript{2} increases in the atmosphere, more dissolves into the ocean as carbonic acid (H\textsubscript{2}CO\textsubscript{3}) \ldots

Now this passage is structured in coherent arcs—the first, main one, is about how fishery productivity is driven by ocean circulation and thus is sensitive to climate change. Then I pulled the information about acidification into a separate arc that follows but connects to the first one through the climate change-CO\textsubscript{2} link and the language “in addition.” By creating linked arcs, the writing gained coherence and SUCCES-type “simplicity.” Instead of being a complex mass of interwoven information, it now has a series of simple messages that together add up to a larger, equally simple message: increasing atmospheric CO\textsubscript{2} is going to alter California fisheries.

This kind of arcless writing usually results from what I call “stream of consciousness” writing, in which the author puts down each thought as they come to mind, one idea stimulating another and all flowing onto the page. Many inexperienced authors write this way. Undergraduate essays written the night before the deadline are notorious for this, with no visible structure, ideas appearing in multiple places, and incomplete arguments. Even experienced writers find extraneous thoughts inserting themselves—one sentence sparks a thought, and into the paragraph it goes. What distinguishes an experienced writer is that those extraneous thoughts don’t survive to the final draft. If they are interesting and germane, they go into their own arc elsewhere, otherwise they go in the trash.

To ensure that your final pieces have an effective internal structure, go over them paragraph by paragraph and section by section and ask the following questions:

Does each unit make a single, clear point?
When several paragraphs together form a section, are the linkages among them clear?
Internal Structure

Has every extraneous thought that breaks the serial arc structure been removed?
When you introduce a topic, do you resolve that discussion before introducing a new topic?
Is every major unit of the work defined by either a subhead or clear opening text?

If you can't answer "Yes" to each of these questions, then you haven't finished working on the structure.

EXERCISES

10.1. Analyze published papers

Go back, once again, to the papers you've been analyzing. This time look at their internal structure. Can you block out sections that form complete arcs? How do the authors indicate that they are beginning or ending arcs? Identify the theme of each arc and give it a subheader that describes that theme.

10.2. Write a short article

Go back again to your short article. Evaluate your own story arcs. Do you form complete arcs, or do you have ideas that keep cropping up in multiple places? Rewrite to ensure clear, well-defined arcs.