A Course on the Creative Scientific Process

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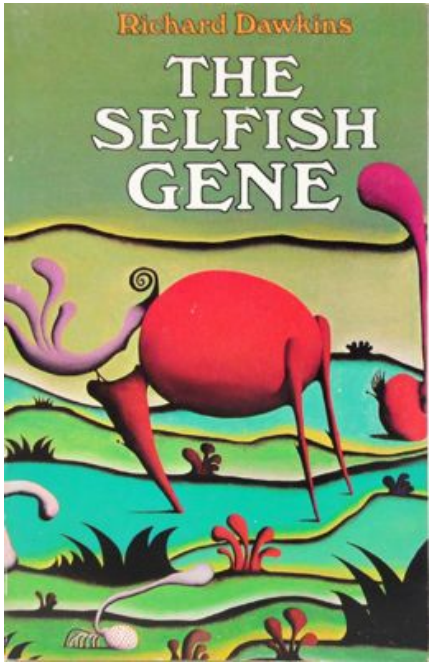
Chapter 3

The two languages of science

“If we allow ourselves the license of talking about genes as if they had conscious aims, always reassuring ourselves that we could translate our sloppy language back into respectable terms if we wanted to, we can ask the question, what is a single selfish gene trying to do?”

Richard Dawkins, The Selfish Gene

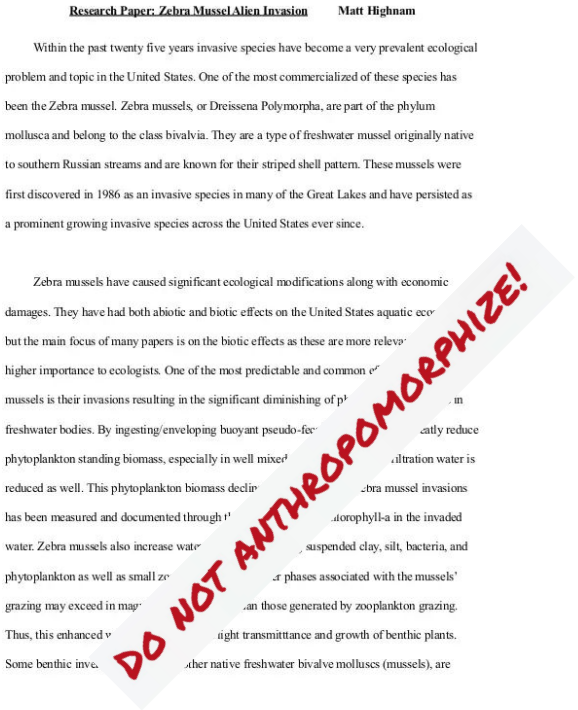
“The Selfish Gene” by Richard Dawkins (1976)



“We are all survival machines – robot vehicles blindly programmed to preserve the selfish molecules known as genes”

Anthropomorphisms are a special type of metaphor

- To ‘anthropomorphize’ is to give human attributes to nonhuman things.
- Anthropomorphisms are a special type of metaphors.
- Some believe that anthropomorphizing can lead to miscommunication and misunderstanding.
    - Clearly genes, proteins, and cells do not “feel” or “want” anything, they are not driven by intentions, but instead move and change based on physical and chemical forces.



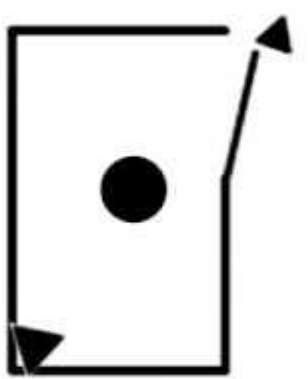
Research Paper: Zebra Mussel Alien Invasion **Matt Highnam**

Within the past twenty five years invasive species have become a very prevalent ecological problem and topic in the United States. One of the most commercialized of these species has been the Zebra mussel. Zebra mussels, or Dreissena Polymorpha, are part of the phylum mollusca and belong to the class bivalvia. They are a type of freshwater mussel originally native to southern Russian streams and are known for their striped shell pattern. These mussels were first discovered in 1986 as an invasive species in many of the Great Lakes and have persisted as a prominent growing invasive species across the United States ever since.

Zebra mussels have caused significant ecological modifications along with economic damages. They have had both abiotic and biotic effects on the United States aquatic ec… but the main focus of many papers is on the biotic effects as these are more relev… higher importance to ecologists. One of the most predictable and common e… mussels is their invasions resulting in the significant diminishing of p… … in freshwater bodies. By ingesting/enveloping buoyant pseudo-fe… …atly reduce phytoplankton standing biomass, especially in well mixed … …iltration water is reduced as well. This phytoplankton biomass declin… …ebra mussel invasions has been measured and documented through t… …torophyll-a in the invaded water. Zebra mussels also increase wate… …, suspended clay, silt, bacteria, and phytoplankton as well as small zo… …r phases associated with the mussels' grazing may exceed in mag… …an those generated by zooplankton grazing. Thus, this enhanced v… …ight transmittance and growth of benthic plants. Some benthic inve… …ther native freshwater bivalve molluscs (mussels), are

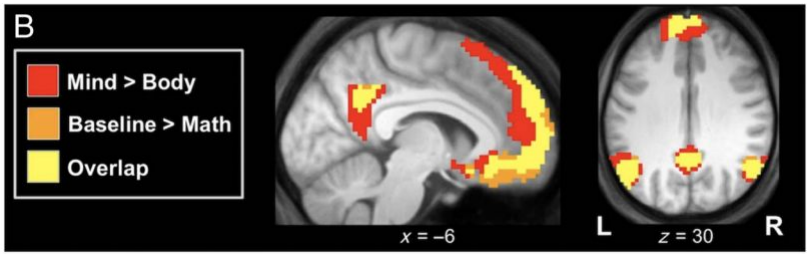
DO NOT ANTHROPOMORPHIZE!

What do you see in this animation?



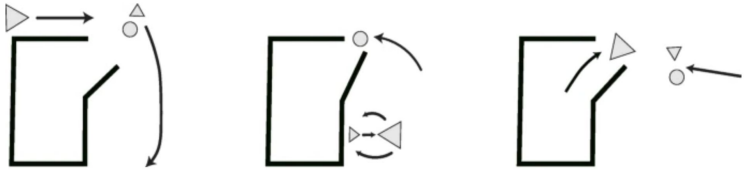
Our brains are wired to adopt the ‘intentional stance’

- Social cognition was crucial in our evolution.
- To interact with other people we try to predict their actions.
- We do this by adopting the intentional stance: we infer beliefs, desires, and intentions
- Neurological research supports this notion.
- This is analogous to GPUs, which are optimized for processing image-based information



Spunt et al. J Cogn Neurosci. (2015)

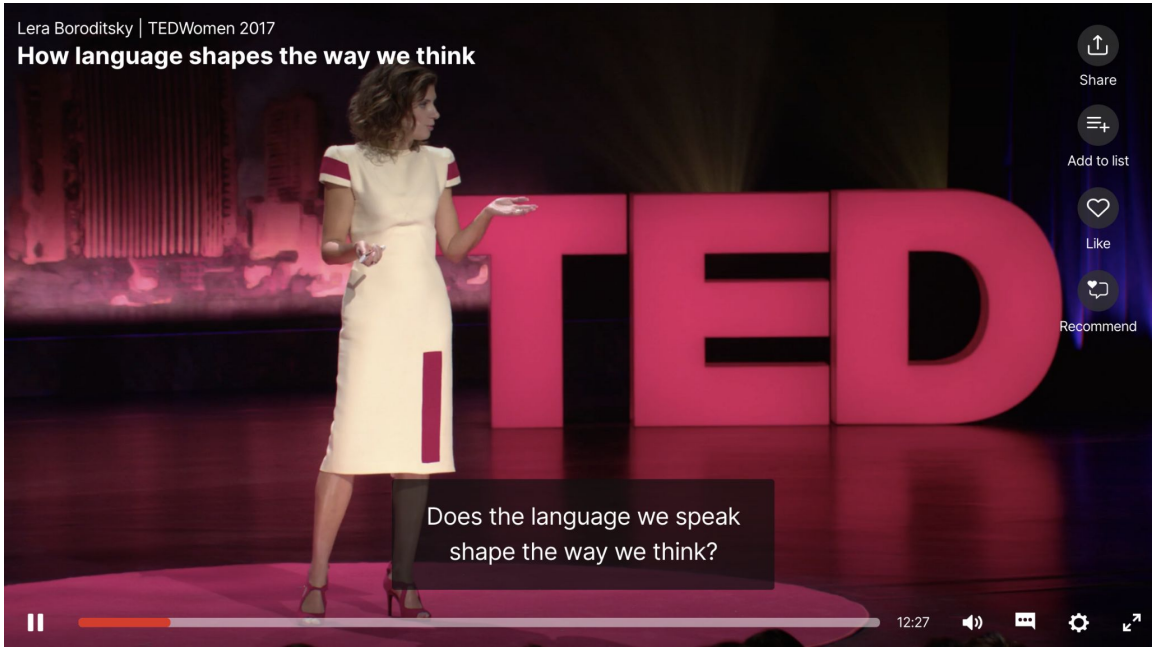
The Heider-Simmel animation demonstrates how we intuitively take an intentional stance



The Heider-Simmel animation. An animated movie involving two triangles and a circle leads us to tell a story filled with motivations and purpose.

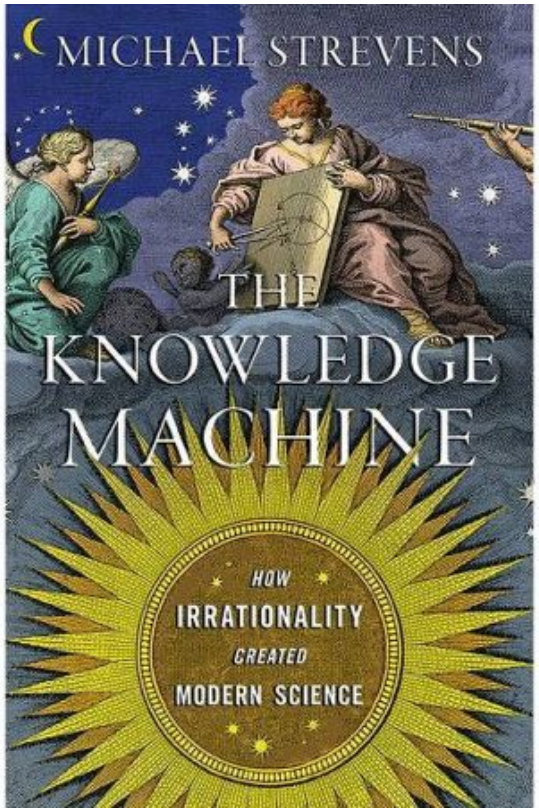
Metaphors We Think With: The Role of Metaphor in Reasoning

“We find that exposure to even a single metaphor can induce substantial differences in opinion about how to solve social problems”



Thibodeau PH, Boroditsky L. PLoS One. (2011)

Science has been successful because it only accepts empirical testing as evidence for an argument



- The “Iron Rule” of science is that all scientific arguments must be settled by empirical testing, and empirical testing alone.

The language of day science

- Day science language is used in:
  - Scientific papers
  - Conference presentations
  - Grant proposals
  - Journal clubs or peer reviews of manuscripts, where we ask if the claims are supported by evidence
- Day science starts with a hypothesis that must be expressed in **precise, metaphor-free language.**
- Day science then sets up conclusive experiments with the appropriate controls, and uses statistical methods to assess our confidence in the results

Day science questions
Is it necessary and sufficient?
What is the significance (*P* value)?
What is the mechanism?
Is there a negative control and a positive control?
Is the proposed experiment sufficiently powered?

The language of night science

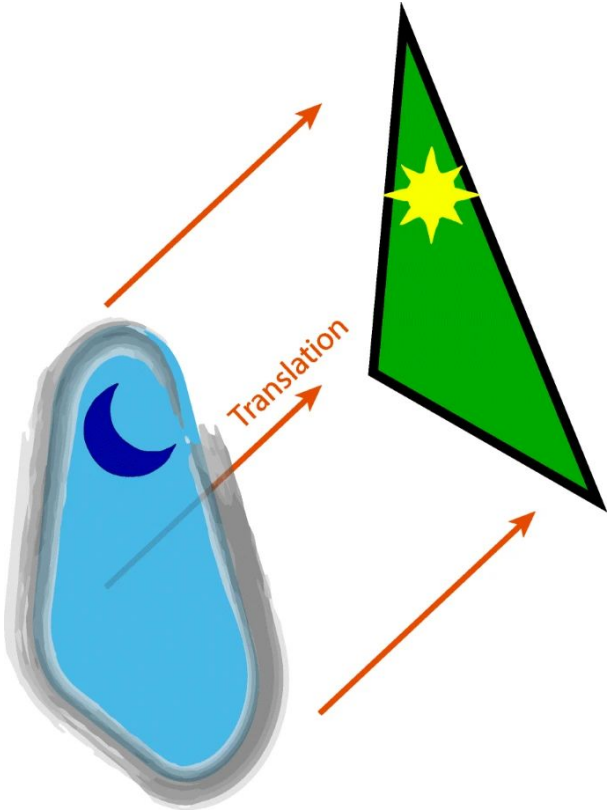
- As humans, we require a language permissible to intuition—one that gives us a “feeling” for the phenomenon.
- In night science language, we are allowed to anthropomorphize freely, helping us to grasp why and how something may be happening.
- Night science language is not precise, but what we lose in rigor, we gain in intuition.
- We ask “what does the organism want?” We put ourselves into the shoes of a gene. We ponder the best strategy for a genome in a given situation.
- We speak in night science language when we are improvising with a colleague.

Night science questions
What does that protein want?
Why would the cell do something that stupid?
How does the cell know what to do?
Why did the cell not know that it has been invaded by the virus?
How do these cells know to stop dividing?

Translating between night science language and day science language

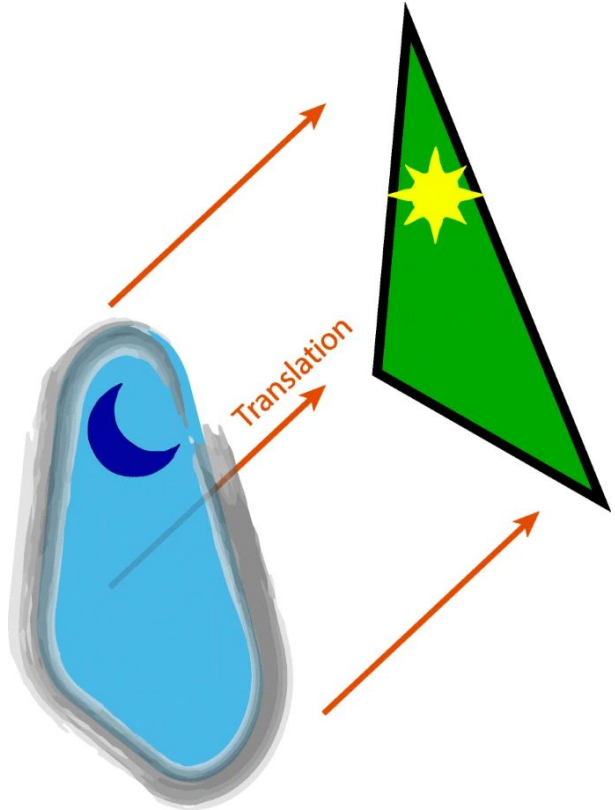
- “If we allow ourselves the license of talking about genes as if they had conscious aims, always reassuring ourselves that we could translate our sloppy language back into respectable terms if we wanted to, we can ask the question, what is a single selfish gene trying to do?”

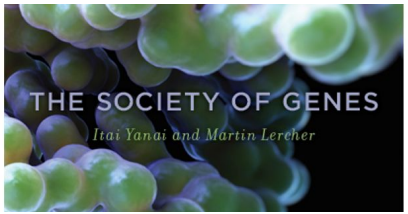
Richard Dawkins, The Selfish Gene



Scientific statements expressed in the anthropomorphizing terms of night science can be rephrased in the language of day science.

- *Night science language:*
  - “a cancer gene aims to secure an unfair advantage”
- **Translated** into respectable *Day science language:*
  - “a mutation to a proto-oncogene that causes an increased growth rate of the cells that carry the mutation will over time lead to an increase in the total fraction of body cells that carry the mutation.”





From our book, “The Society of Genes”

Translating night science language into respectable day science language

Night science	Day science
"Nature *abhors* a vacuum" (attributed to Aristotle)	"Effusion or movement towards lower pressure occurs because unobstructed gas molecules will become more evenly distributed between high- and low-pressure zones, by a flow from the former to the latter." [21]
"A much more demanding *task* for these enzymes is to *discriminate* between similar amino acids ... However, the observed error frequency in vivo is only 1 in 3000, indicating that there must be subsequent *editing* steps to enhance fidelity. In fact the synthetase *corrects* its own errors ... How does the synthetase *avoid* hydrolyzing isoleucine-AMP, the *desired* intermediate?" [22] as cited by [23]	"Each aminoacyl-tRNA synthetase is highly specific for a given amino acid. Indeed, a synthetase will incorporate the incorrect amino acid only once in 10^4 or 10^5 catalytic reactions. How is this level of specificity achieved?" [24], in a later edition of the same textbook.
"A cancer gene *aims* to secure an *unfair* advantage." [25]	"Mutations to a proto-oncogene that cause an increased growth rate of the cells that carry the mutation will over time lead to an increase in the total fraction of body cells that carry the mutation" [25]
"We are *survival machines – robot vehicles blindly programmed* to preserve the *selfish* molecules known as genes." [3]	"Genes are the sole replicators in biological evolution. [...] As fascinating as all the complex adaptations that have arisen through selection may be, the results of this process matter in selection only if they are reflected in the content of their respective replicators." [26].
"The image of a relatively *smooth [fitness] landscape*, where populations adapt by *going up-hill* once they fix an advantageous mutation, are *trapped* in mountain peaks and remain isolated from other possibly higher fitness maxima by deep valleys, often appears as the way in which adaptation proceeds." [27]	Evolutionary adaptations of a population can be quantified by fitness changes due to the fixation of mutations that increase fitness. Such increases may lead to genotypes with locally maximal fitness, i.e., fitness cannot increase further through additional point mutations, as any individual such mutation would first lead to a strong decrease in fitness.
"Non-hazardous bacteria also *help* prevent diseases by occupying places that the pathogenic, or disease-causing, bacteria *want* to attach to. Some bacteria protect us from disease by *attacking* the pathogens." [28]	Commensal bacteria with no direct detrimental effects on human health often benefit humans by occupying ecological niches in the human body that could alternatively be occupied by disease-causing bacteria, thereby reducing their potential fitness. Some bacteria release compounds toxic to pathogens, thereby reducing the probability of disease for their host.

The language of discovery

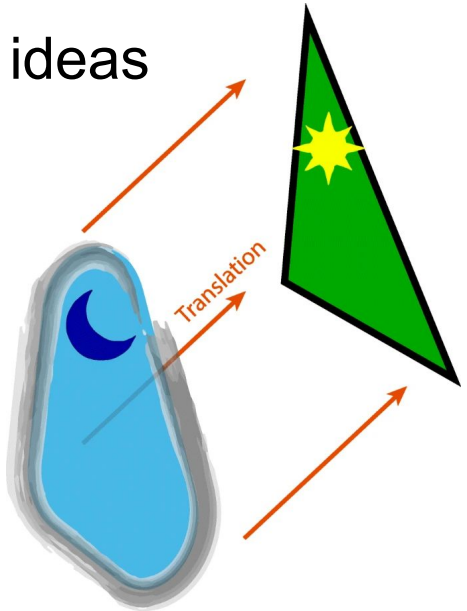
- A truly new idea is born only roughly formed—there may not even be words for it yet.
- To make that idea falsifiable and thus testable by day science, it needs to be reshaped and refined, and an inexact yet intuitive language is all we initially have for that task. Day science starts with a hypothesis that must be expressed in precise terms.
- An example is ultra-selfish elements in the genome.
- Another example: Transcriptional scanning in spermatogenesis.

Lost in translation

- Night science language can lead to misunderstandings if we do not clearly distinguish it from the realm of day science.
- When venturing into night science language in a scientific talk or paper, it should be explicitly noted.
- An insistence on day science language during a night science discussion will bring the flow of thoughts to a halt.

Exercise: Using anthropomorphisms for new ideas

- **Pairs:** Again we will get into pairs.
- **Explain a project** you are working on to your partner **in day science language**.
- Then **translate** your project **into night science language**.
- Together with your partner **ask questions in night science language**.
- Try to **translate** any interesting questions back into day science language.
- **Swap roles** with your partner, and repeat.



Night science questions
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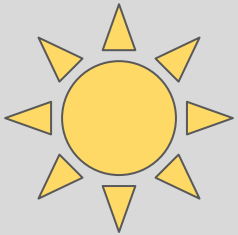
Post-exercise reflection

Did the anthropomorphisms give you ideas?

We would love your feedback!

Summary of Chapter 3



Day Science: *Highly precise and metaphor-free*

Night Science: *Metaphors, analogies, and anthropomorphizing*