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The cognitive science of COVID-19: Acceptance, denial, and belief change

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ABSTRACT

Because the spread of pandemics depends heavily on human choices and behaviors, dealing with COVID-19 requires insights from cognitive science which integrates psychology, neuroscience, computer modeling, philosophy, anthropology, and linguistics. Cognitive models can explain why scientists adopt hypotheses about the causes and treatments of disease based on explanatory coherence. Irrational deviations from good reasoning are explained by motivated inference in which conclusions are influenced by personal goals that contribute to emotional coherence. Decisions about COVID-19 can also be distorted by well-known psychological and neural mechanisms. Cognitive science provides advice about how to improve human behavior in pandemics by changing beliefs and by improving behaviors that result from intention-action gaps.

1. Introduction

In July 2020, a motorcycle rally brought hundreds of thousands of bikers to Sturgis, South Dakota. Officials such as the state governor made no attempt to discourage attendance despite the fact that COVID-19 was a serious problem in other states. By October, South Dakota and North Dakota had the highest rates of cases per population in the whole country [1].

Such events raise questions about the thinking of the people who spread the deadly coronavirus and the thinking of leaders who make policy about how to control that spread. Why did the bikers ignore the risks of catching COVID-19? Why did officials not take action to stop people from putting themselves at risk? Because the spread of the disease depends heavily on the behaviors and choices of individual people, psychology is an important contributor to the understanding and treatment of pandemics. The scientific study of pandemics requires the cooperation of many medical fields including virology, epidemiology, and pulmonology. The impact of behavior on disease spread shows that psychology belongs in the collaboration.

However, psychology alone does not have the intellectual resources to explain why people engage in harmful behaviors and why leaders fail to implement effective policies. The interdisciplinary field of cognitive science enhances psychology by integrating insights from five additional fields: neuroscience, philosophy, computer modeling, linguistics, and anthropology [2]. These fields have collaborated to provide compelling explanations of many kinds of human thinking including problem solving, learning, emotion, creativity, and even consciousness [3].

This paper shows the relevance of cognitive science to COVID-19 by outlining answers to the following questions.

Why do scientists believe hypotheses such as that COVID-19 is caused by the novel coronavirus and that wearing masks is a helpful measure for controlling it?

Why do some ordinary people and leaders deny COVID-19 risks and reject effective measures?

Why do some individuals and leaders make bad decisions about COVID-19 and how could their decision making be improved?

How can doubtful people be convinced that COVID-19 is a serious problem that needs to be handled with strong measures such as lockdowns and wearing masks?

Why do some people who believe that COVID-19 is a serious problem nevertheless take dangerous risks?

My answers to these questions will be interdisciplinary, combining psychology, neuroscience, computer modeling, and philosophy.

2. Scientific reasoning

The new disease was only recognized in January 2020 but in less than a year scientific researchers and public health specialist had reached consensus on claims such as the following:

There is a new pandemic disease, COVID-19, that is caused by a novel coronavirus, SARS-CoV-2.

Some treatments are effective at reducing deaths from COVID-19 such as delivering high-dose oxygen and prescribing dexamethasone, but other treatments are ineffective such as hydroxychloroquine.

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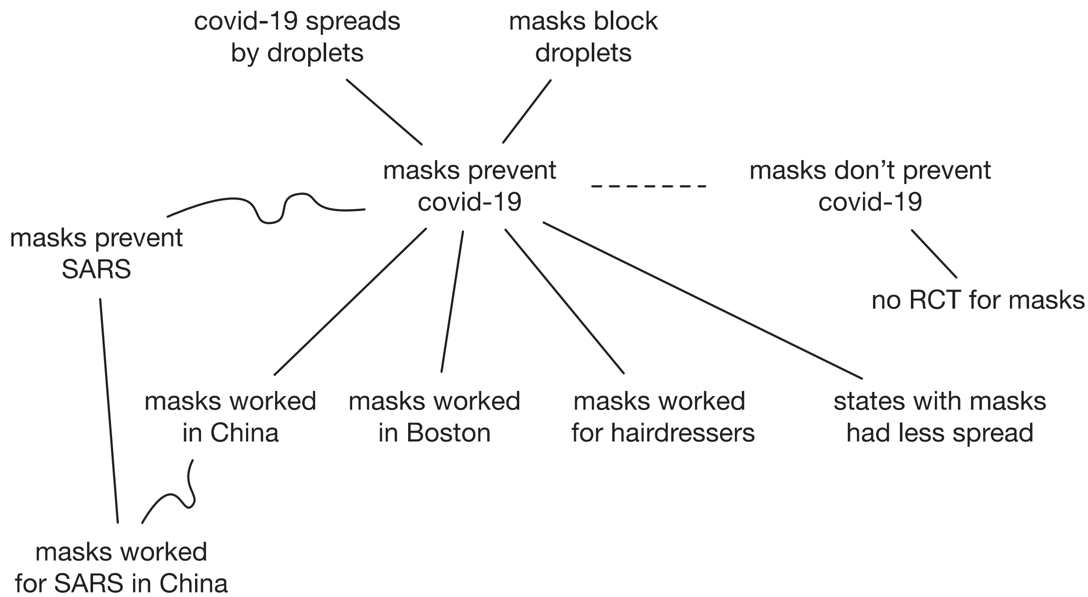

Fig. 1. Explanatory coherence of the hypothesis that masks prevent COVID-19. Straight lines indicate positive constraints based on explanation. The dotted line indicates a negative constraint based on contradiction. The curved lines indicate analogous explanations.

Some social behaviors are effective at slowing the spread of the disease, such as wearing masks, keeping at least 2 m apart, and avoiding indoor social gatherings.

Research and government activities to end the pandemic should be directed at plausible techniques such as vaccines rather than dangerous ones such as aiming for herd immunity by allowing infection to spread.

These claims about the origins, prevention, treatment, and eradication of diseases are all causal, so it is crucial to ask how scientists reach causal conclusions. This question is psychological because it concerns the mental processes of scientists who make causal inferences. But it is also philosophical because it raises the normative question of how scientists *ough*t to reach causal conclusions in order to accomplish inferential goals such as achieving truths, avoiding falsehoods, generating plausible explanations, and improving human lives [4].

2.1. Bayesian inference

In current cognitive science, there are two main approaches to the evaluation of causal claims. The most prominent assumes that such reasoning is probabilistic based on Bayes' theorem, which in its simplest form says that the probability of hypothesis given the evidence depends on the prior probability of the hypothesis times the probability of the evidence given the hypothesis, all divided by the probability of the evidence. In symbols, $P(H \mid E) = P(H) * P(E \mid H) / P(E)$. Powerful computational techniques have been developed for calculating the relevant conditional probabilities [5–7].

However, the Bayesian approach is of limited use in accounting for scientific reasoning about COVID-19. Unlike in some medical domains where there is a wealth of data that can be turned into probabilities understood as frequencies, few probabilities are available for reliably assessing causal claims such as that wearing masks helps to prevent disease. We do not know, for example, what is the prior probability of this claim about mask wearing, what is the probability of relevant pieces of evidence such as that hair stylists who wear masks do not transmit the disease, and what is the conditional probability of this evidence given the claim that wearing masks prevents disease.

Bayesians respond that these are just subjective probabilities - degrees of belief in the claims and evidence; but this response is open to psychological and philosophical challenges. The psychological challenge is that probabilistic thinking, which originated with the invention of probability in the 17th century, is not a natural part of human cognitive architecture [8]. The philosophical challenge is that subjective degrees of belief do not serve to justify scientists' causal claims as objectively true about the world. Another problem with applying Bayesian methods to human thinking is that computations with probabilistic networks become intractable with very large numbers of beliefs such as those operating in the brains of humans thinking about medical problems.

2.2. Explanatory coherence

The alternative account of inference to causal hypotheses is the theory of explanatory coherence that has been applied to many cases of medical and scientific reasoning such as the claim that the Zika virus causes birth defects [9–14]. This theory is based on the philosophical idea that causal reasoning is inference to the best explanation of the available evidence, but fleshes it out into a computational model using neural networks that do not require probabilities. Instead, causal reasoning is understood as a process of simultaneously satisfying multiple constraints.

The main positive constraints for explanatory coherence are that causal hypotheses explain the evidence for them and that these hypotheses can in turn be explained by deeper hypotheses concerning the relevant mechanisms. For example, the hypothesis that wearing masks prevents disease explains various pieces of evidence such as that there is less spread of disease in mask-wearing countries such as China. Moreover, scientists can explain the effectiveness of wearing masks by identifying the underlying mechanism: the virus spreads on droplets through the air and masks block the droplets. Hence the claim that wearing masks prevents disease spread gets coherence both from what it explains and from what explains it.

The main negative constraints operating in explanatory coherence concern the alternative causal hypotheses that compete with each other. For example, the hypothesis that wearing masks prevents disease has to compete with the hypothesis that masks do not prevent disease which purports to explain other pieces of evidence such as that medical personnel get sick despite wearing masks. A hypothesis is accepted or rejected based on its overall coherence with all of the evidence and all other hypothesis, where coherence is a matter of satisfying as many constraints as possible.

Fig. 1 shows the structure of the explanatory coherence assessment of the mask hypothesis. The hypothesis that wearing masks causes a reduction of spread of COVID-19 gets its explanatory coherence from 4 directions: what it explains, what explains it, analogy with SARS and other infectious diseases, and competition with the claim that masks do not prevent COVID-19 [15–27]. Causal explanations are identified by linguistic cues such as “prevent” and “reduce”.

The most important pieces of evidence explained by the hypothesis that masks reduces COVID-19 are that masks have been used successfully in China, hairdressers wearing masks did not infect their customers, mask wearing at Massachusetts General hospital reduced spread, and US states that required masks had less COVID-19 than ones that did not. Additional pieces of evidence for the effectiveness of mask wearing cited by the CDC that could be added to the simulation shown in Fig. 1 include observations of reduced disease incidence in Thailand, a US Navy ship, and passenger flights [28].

In addition to what mask wearing explains, there is a plausible explanation of why mask wearing works because masks block the droplets that spread the virus. Especially in the early days of the pandemic, health officials drew heavily on analogies with other infections such as SARS and MERS: just as masks explained reduction in cases of SARS, so masks explain reduction in cases of COVID-19. Finally, the hypothesis that masks prevent COVID-19 outcompetes the alternative claim that masks do not cause prevention which is only supported by the lack of a randomized clinical trial in the general population that would show that masks prevent the disease. The Appendix specifies a computer simulation of why scientists generally believe that wearing masks reduces the spread of COVID-19.

The explanatory coherence account of causal reasoning combines philosophy, psychology, computer modeling, and neuroscience. Philosophy contributes ideas about inference to the best explanation, coherence, and objectivity. Psychology contributes empirical studies that provide evidence that people do think in accord with standards of coherence [29–31]. Computer modeling is essential for determining that the proposed mechanism of satisfying multiple constraints is feasible and generates results that correspond to human behavior, in this case how many scientists concluded that the claim that wearing masks prevents disease is acceptable. The computer program that computes explanatory coherence uses a simple neural network that translates positive constraints into excitatory links between neurons that represent hypotheses and evidence, and translates negative constraints into inhibitory links. Translation into more biologically realistic groups of neurons is also feasible [32].

Thus the theory of explanatory coherence integrates several fields of cognitive science to provide an explanation of how scientists reach legitimate causal conclusions about the causes, prevention, treatment, and eradication of disease. But it does not explain the widespread resistance to these conclusions among ordinary people and political leaders.

3. COVID-19 denial

Scientists often use explanatory coherence to reach the same causal conclusions based on the available evidence; but how can we explain the scientists, leaders, and ordinary people who reach opposing conclusions? The simplest explanation would be that the dissidents simply lack some of the information: if they are not aware of the relevant evidence, then they can easily reach a different conclusion about what is the most plausible hypothesis. Another explanation is that people who reject the scientific conclusion are lying and that they know the right answer but refuse to say it because of personal or political goals [33]. But the most psychologically interesting case involves people who are familiar with much of the relevant evidence and the alternative hypotheses but sincerely believe conclusions that are contrary to evidence and explanatory coherence.

Psychologists and philosophers have identified more than 50 kinds of thinking patterns that can lead people into erroneous judgments [34,35]. Philosophers call these patterns fallacies while cognitive psychologists discuss biases and heuristics. Even experts can fall into error tendencies such as the fallacy of post hoc ergo propter hoc (after this therefore because of this) which has operated powerfully in anti-vaccination debates. When parents have their child vaccinated and the child is diagnosed with autism, the parents are prone to assume a causal link.

3.1. Motivated inference

While many error tendencies contribute to denial of evidence-supported causal claims about COVID-19, I think that the most important factor is what psychologists call *motivated inference* or *motivated reasoning*. In 1990, the social psychologist Ziva Kunda published “The Case for Motivated Reasoning“ which has been hugely influential, gaining more than 7000 citations [36–39]. Kunda reviewed studies including her own experiments which show that people tend to evaluate causal theories based not just on the evidence but also on their own personal goals. For example, coffee drinkers are less inclined to believe that caffeine causes cancer compared to non-drinkers. In Kunda’s account, motivated inference is more than wishful thinking because people do not just believe whatever they want to believe but rather seek out evidence and arguments that support what they want to believe. I prefer the term ”motivated inference“ to ”motivated reasoning“ because the underlying mental processes are often unconscious and nonverbal in contrast to the conscious and verbal nature of reasoning.

Everyone has succumbed to motivated inference on some occasions. People in new romances tend to believe that their lovers are wonderful despite warning signals. Most parents estimate that their children are above average. People are inclined to downplay medical threats such as lumps or chest pain. New political leaders can be evaluated highly despite the track record of previous politicians. In economics, investors want to believe that the current stock market boom can go on forever. In religion, many people believe that God will take care of them for eternity despite lack of evidence. These are all cases where people’s inferences line up more with their motivations than with the full evidence.

Motivated inference has plausibly contributed to mistakes about COVID-19. In going to the motorcycle rally in Sturgis, the bikers wanted to believe that they could have their annual party without taking any risks. Political leaders such as the local governors and even the president of the United States had strong motivations not to intervene. These motivations included allowing personal freedom, keeping the economy flourishing, and maintaining their own popularity. Such personal and social goals swamped the increasingly available information that COVID-19 dangerously combines a high degree of contagion from both symptomatic and asymptomatic carriers with a high risk of death, especially for victims who are older or have other conditions such as obesity.

Psychological experiments show that people are prone to motivated inference but do not provide detailed mechanisms for how it works in human minds. The most plausible mechanism is emotional coherence in which people’s evaluation of causal hypotheses depends on their passionate goals as well as on the evidence.

3.2. Emotional coherence

Disagreement about science does not always indicate motivated inference because scientists can legitimately dispute the quality of experimental findings and their interpretation. The theory of explanatory coherence shows how scientists and ordinary people can reach rational conclusions about COVID-19 by evaluating causal hypotheses with respect to evidence, underlying mechanisms, and alternative hypotheses. Emotional coherence distorts this process by allowing personal goals to enter into the evaluation of hypotheses and evidence [40,41]. Goals have an emotional valence which is a positive or negative attitude concerning their satisfaction. For example, the goals of having fun and maintaining freedom have a positive (desirable) valence because they

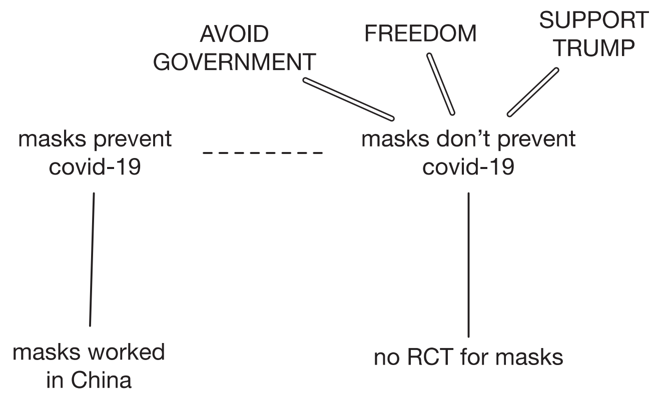

Fig. 2. The emotional coherence of rejecting mask wearing. Despite limited evidence, the hypothesis that masks are ineffective is preferred because it fits with goals shown in capital letters. The double lines indicate emotional associations, while the solid lines indicate explanatory links and the dotted line indicates contradiction.

are associated with emotions such as happiness and joy. In contrast, the prospects of staying home and getting sick have a negative (undesirable) valence because they are associated with emotions such as sadness and fear. These goals are relevant to making decisions but they are not supposed to influence judgments about what is true. In terms of standard decision theory, your utilities should not affect your probabilities.

But human brains do not make decisions based on maximizing expected utility, an idea first sketched in the 18th century and only developed in the 20th. Current understanding of brain mechanisms reveals numerous interconnections among areas responsible for cognition such as the prefrontal cortex and areas responsible for emotions such as the amygdala and nucleus accumbens. In line with these findings, the theory of emotional coherence allows constraints concerning goal satisfaction to distort judgments about the acceptability of causal hypotheses. In the Sturgis case, personal and political goals lead people to discount evidence about the seriousness of COVID-19, which conflicts with such strong goals as allowing freedom, avoiding government interference, stimulating the economy, and supporting President Trump. Fig. 2 diagrams the emotional coherence of rejecting the claim that wearing masks reduces COVID-19 based on the values of freedom, avoiding government, and supporting Trump. These goals ought to be irrelevant to assessing the evidence that masks are effective, but motivated inference provides illegitimate support for a causal hypothesis that should be evaluated solely on explanatory coherence. Emotional coherence adds to the constraints used in explanatory coherence a set of positive constraints that come from satisfying goals and negative constraints that come from actions that go against goal satisfaction.

As with explanatory coherence, emotional constraint satisfaction can be computed by a program that uses neural networks to implement hypotheses, evidence, and goals by artificial neurons, implement positive constraints by excitatory links, and implement negative constraints by inhibitory links. The result is a psychological, neural, and computational explanation of why some politicians and ordinary people have been inclined to make irrational causal judgments about COVID-19.

3.3. Cognitive-affective mapping

The comparative emotional coherence of conflicting sets of values can be vividly depicted by a technique called cognitive-affective maps (also called CAMs or value maps). Concept maps have been used in many fields since the 1970 s to display the conceptual structure of different points of view but they neglect the emotional significance of different values. Since 2010, cognitive-affective maps have been used to illustrate the configuration of conflicting attitudes and values in many social disputes such as climate change [42]. (For a complete bibliography, see

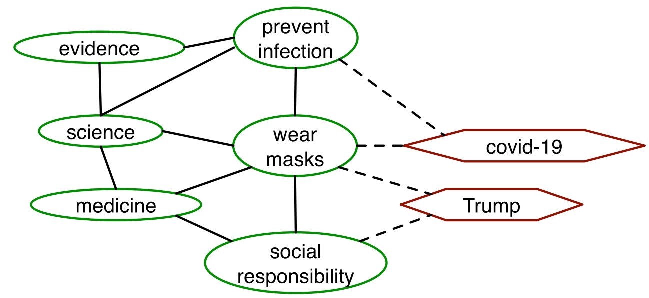

Fig. 3. Cognitive-affective map of values supporting wearing masks. Green ovals are emotionally positive and red hexagons are negative. Solid lines indicate mutual support and dotted lines indicate incompatibility. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

https://paulthagard.com/links/cognitive-affective-maps/.) They also serve to highlight the differences in attitudes about COVID-19.

Cognitive-affective maps use ovals to represent positive values such as freedom; when color is available, these ovals are green like a go traffic light. They use hexagons that can be colored red like a stop light to represent negative values such as disease. Values that fit together are connected by solid lines like the positive constraints in diagrams of explanatory and emotional coherence. Conflicting values are connected by dotted lines like the negative constraints. The resulting maps are a convenient way to illustrate how attitudes are based on a whole configuration of values.

Figs. 3 and 4 are simplified maps of the values underlying disputes concerning wearing of masks. Some countries such as China are committed to mask wearing as a technique for slowing the spread of disease, but masks remain controversial in the United States. Fig. 3 shows the configuration of values that supports mass wearing as recommended by most public health officials. The concept of wearing masks gets strong positive emotional value because it fit well with other values such as keeping people healthy in the face of disease. Some of the these links are based on causal connections, for example that wearing masks prevents infection, but others are based on looser emotional associations, for example that Donald Trump made fun of masks.

In contrast, Fig. 4 shows a configuration of values of people who view public orders to wear masks as an infringement on their personal freedom. In the US, these values are strongly associated with Donald Trump. The map makes it easy to see how someone with this set of values could be so opposed to masks.

Cognitive-affective maps such as Figs. 3 and 4 are not a substitute for the full explanation of attitudes provided by motivated inference and emotional coherence. But they provide a useful approximation for grasping the powerful role of positive and negative values in shaping how people think about situations such as COVID-19. Changing minds in ways that alter people's beliefs and decisions depends on appreciating the role of values and emotional coherence in how people think about matters important to them.

Explaining irrational beliefs about COVID-19 through motivated inference and emotional coherence draws on the interdisciplinary resources of cognitive science. Psychology provides experimental evidence for the prevalence of motivated distortions of human thinking. Computer modeling details the mechanisms required for explaining how people think and provides a methodology for determining whether the proposed mechanisms behave like people. Neuroscience provides insights concerning the relevant mechanisms operating in human brains and ways of understanding why standard models of rationality that sharply distinguish probabilities from utilities fail to explain human behavior. Philosophy provides background ideas about normativity and useful concepts such as coherence.

What about the other two fields that are usually considered to be part

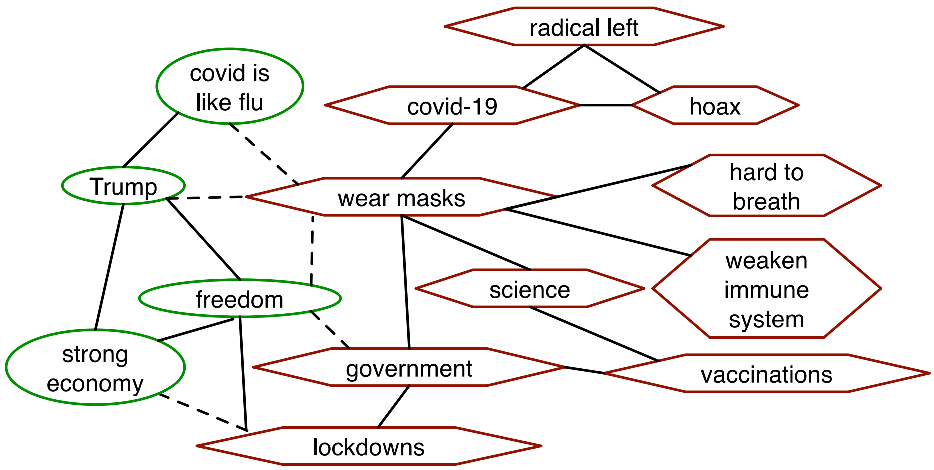

Fig. 4. Cognitive-affective map of values opposing wearing masks.

of cognitive science, linguistics and anthropology? Both are highly relevant to the social processes that my account has neglected in its concern for explaining the operations of individual minds. A full story needs to consider also the social mechanisms by which concepts and values spread from person to person [41]. Language is an important part of such communication which requires attention to how people use syntax, semantics, and pragmatics to exchange information.

Anthropology is also an important part of understanding systems of beliefs and values because it highlights the cultural differences among different groups of people. These differences are important for dealing with pandemics such as COVID-19 that are affected by the varying values and practices in different cultures. For example, the adoption of mask wearing has been much more easily implemented in East Asian cultures where there are greater traditions of social solidarity and mask usage compared to Western countries that are more individualistic and unfamiliar with mask practices.

4. Decision making

Thinking about COVID-19 is not just acquiring and revising beliefs because it requires deciding what to do. Pandemics generate difficult decisions to be made by ordinary people, medical professionals, and political leaders. After reviewing the most important decisions that the pandemic forces upon us, this section describes cognitive models for the making of good, bad, and ethical decisions. This understanding of how minds make decisions should help to improve future decision making.

4.1. Important decisions

Because COVID-19 is so far outside normal experience, it forces people to make important decisions that cannot rely on previous practices. Here are some of the difficult decisions that people have been facing.

4.1.1. Ordinary people

How can I obtain food?
How can I work?
What friends and family can I socialize with?
Should my children go to school?
How can I exercise?
When should I wear a mask?
Should I get vaccinated?
Should my children get vaccinated?
Medical professionals
Which patients should be admitted to hospital?
What drugs and other treatments should patients be given?
Which patients should be admitted to intensive care units?
Which patients should be put on ventilators?
How can I best protect myself from infection?
How can I best protect my family from infection?
Political and health leaders
What economic activities should be restricted?
What social activities should be restricted?
What educational activities should be restricted?
What international travel should be restricted?
When should restrictions be lifted?
What payments can be made to individuals and businesses to overcome economic effects of the pandemic?
When should vaccines be approved?
How should vaccines be distributed?

Answering these questions requires people to choose from conflicting options based on incompatible goals concerning multiple people.

4.2. How to make decisions

According to mainstream economics, the rational way to make decisions is to consider various actions and choose the one which maximizes expected utility. The expected utility of an action is computed by combining the probabilities of various outcomes with utilities of those outcomes, where utility is a measure of the desirability of the outcome. The problem with applying this method to real-life decision making is that people usually do not know the relevant probabilities and utilities so that multiplying them into a neat calculation of expected utility is not feasible.

For example, consider the problem of obtaining groceries in a pandemic. People can choose among various actions such as going to the grocery stores as usual, ordering online and picking up the groceries, or having them delivered. In order to maximize expected utility, one would need to know, for example, the probability of becoming infected with COVID-19 as a result of going to the grocery store and the disutility of getting sick from the infection. Unfortunately, with a novel disease with unpredictable effects, these probabilities and utilities are unavailable. So by what thinking can people decide how to get their groceries, let alone how to manage work or teach their children?

Another popular decision making method requires a more qualitative but still algebraic calculation. Multi-attribute decision making proceeds by listing a number of different attributes (goals) and assigning a degree of priority to them. For example, the goals of decision making about groceries include getting food, avoiding spending too much money, using time efficiently, and avoiding illness. Weighting each of these goals and figuring out the extent to which each action accomplish those goals allows a calculation of the amount of goal satisfaction for each of the actions and picking the one that does best. This calculation is less arithmetically demanding than maximizing expected utility but still suffers from lack of relevant information concerning how to balance goals against each other and how to calculate the extent to which the different actions accomplish the different goals.

Faced with mathematical impotence, people naturally fall back on intuition and come up with a gut feeling about what they should do. Thinking this way is consistent with the theory of emotional coherence described in the last section. You consider various options and your gut tells you which one to go with. But it is not actually the gut doing the thinking but your brain assigning priorities to different goals based on feelings such as fear and pleasure, then reaching a coherent conclusion through parallel constraint satisfaction accomplished by neural networks that integrate cognition and emotion.

Here is a procedure for good decision making by informed intuition based on emotional coherence [40] p. 22.

1. Set up the decision problem carefully. This requires identifying the goals to be accomplished by your decision and specifying the broad range of possible actions that might accomplish those goals.

2. Reflect on the importance of the different goals. Such reflection will be more emotional and intuitive than just putting a numerical weight on them, but should help you to be more aware of what you care about in the current decision situation. Identify goals whose importance may be exaggerated because of emotional distortions.

3. Examine beliefs about the extent to which various actions would facilitate the different goals. Are these beliefs based on good evidence? If not, revise them.

4. Make your intuitive judgment about the best action to perform, monitoring your emotional reaction to different options. Run your decision past other people to see if it seems reasonable to them.

Unfortunately, there is no algorithmic way to find the different goals that have to go into this kind of intuitive decision making. Here balancing is a metaphor for describing the problem of coming up with a coherent set of goals and actions. Sometimes for the sake of transparency it is useful to apply improper linear models that oversimplify the situation but fuel intersubjective discussions [43].

Ordinary people face many such balancing acts in trying to weigh health and safety against the desire to conduct normal activities for work, relationships, and leisure. Similarly, medical professionals require unconscious inferences that balance multiple goals including the well-being of their patients, their own health, and the effective use of scarce resources in hospitals. Sometimes it is possible to state relatively clear rules about such issues as admission to hospital and transfer to intensive care, but patients vary so much in their degrees of infection and underlying conditions that simple rules often do not apply.

The most momentous decisions made in a pandemic are those required of political leaders working in collaboration with medical officials such as directors of public health. When the seriousness of the pandemic threat became evident in March 2020, political leaders in Europe and North America made difficult decisions to drastically shut down economic, social, and educational activities. In most countries, this led to dramatic drops in infection rates of COVID-19 but also to drastic decreases in economic activity. Since then, leaders in many countries have had to balance goals such as personal freedom and economic activities against waves of infection and death. As with individual and medical decisions, the resulting choices have sometimes been made badly.

4.3. How not to make decisions

The cognitive complexity of decision making generates many opportunities for the makings of bad decisions. Here are some of the vulnerabilities.

People often make decisions based on faulty information which consists of the false beliefs discussed in section 3. Beliefs that have fed into bad decisions include conspiracy theories that COVID-19 is just a hoax and that reports of cases and deaths have been exaggerated. With the new disease, evidence is constantly being acquired so there is ongoing need to update previous beliefs, for example concerning the efficacy of masks and the use of ventilators. Failure to update beliefs based on the incessant stream of new evidence can lead to decisions based on ignorance rather than facts. Resistance to vaccines for COVID-19 has resulted from misinformation that they damage DNA, lead to infertility, or disrupt the "natural balance" of the body.

Faulty use of goals can also lead to inappropriate decision making. Because short-term memory is limited, people's conscious thinking tends to focus on just a few goals rather than taking all the relevant goals into account. For example, if someone is feeling lonely then the goal of making social connections can obliterate other goals such as remaining healthy.

A well-known problem with decision making is that brains process short-term goals differently from how they process long-term goals [44,45]. Immediate goals such as food and sex are processed in emotionally intense areas of the brain such as the nucleus accumbens. In contrast, for long-term planning, the brain tends to engage more cognitive, verbal areas such as the prefrontal cortex. Pandemic restrictions are challenged by immediate goals for food, socialization, and recreation which may lead people to discount long-term goals such as remaining healthy and helping society to recover from the pandemic.

Political leaders can be particularly prone to dominance of immediate over long-term goals when they focus on economic recovery and getting reelected over the unavoidably longer-term problem of stopping the pandemic through adjustments over multiple years. Another problem arises with leaders who are autocratic, narcissistic, and psychopathic, making them only concerned with their own goals rather than the goals of all members of the society.

People often make decisions based on analogies with familiar cases [46]. Analogies can be valuable when the new problem situation has the same causal structure as previous ones, but a dramatically novel disease seriously hinders logical problem solving when it produces illegitimate transfers from cases that are familiar but insufficiently similar. COVID-19 turned out to be much more contagious than the previous coronavirus diseases, SARS and MERS, so analogical inferences about how to protect against it were misleading. Similarly, COVID-19 also turned out to be more lethal than influenza so decisions about how to treat it like flu were based on defective analogies. Experts on infectious diseases can use analogies more effectively because they understand the underlying causal relations between infections and diseases.

4.4. Ethical decision making

Decision making is usually prudential, figuring out how to accomplish goals, but sometimes it needs also to be ethical. Prudential errors are ones where people fail to follow standards of good decision making such as considering all relevant goals and using reliable information to predict outcomes. Ethical errors are ones that violate fundamental moral principles. The cognitive science of morality involves both descriptive matters of how people make ethical judgments and also normative, philosophical matters of how they ought to make ethical judgments.

There is intense dispute in philosophy concerning what ethical framework provides the best account of how people ought to make ethical decisions. Alternatives include religious prescriptions such as the Ten Commandments, theories about rights and duties, the utilitarian recommendation to calculate the greatest good for the greatest number, and virtue ethics which recommends acting like a person of good character. Each of these can be applied to difficult questions about dealing with COVID-19.

One convenient framework often applied in medical ethics employs four principles that incorporate the insights of other frameworks [47]:

1. Autonomy: respect people's freedom.
2. Beneficence: provide benefits to people.
3. Nonmaleficence: avoid harm to people.

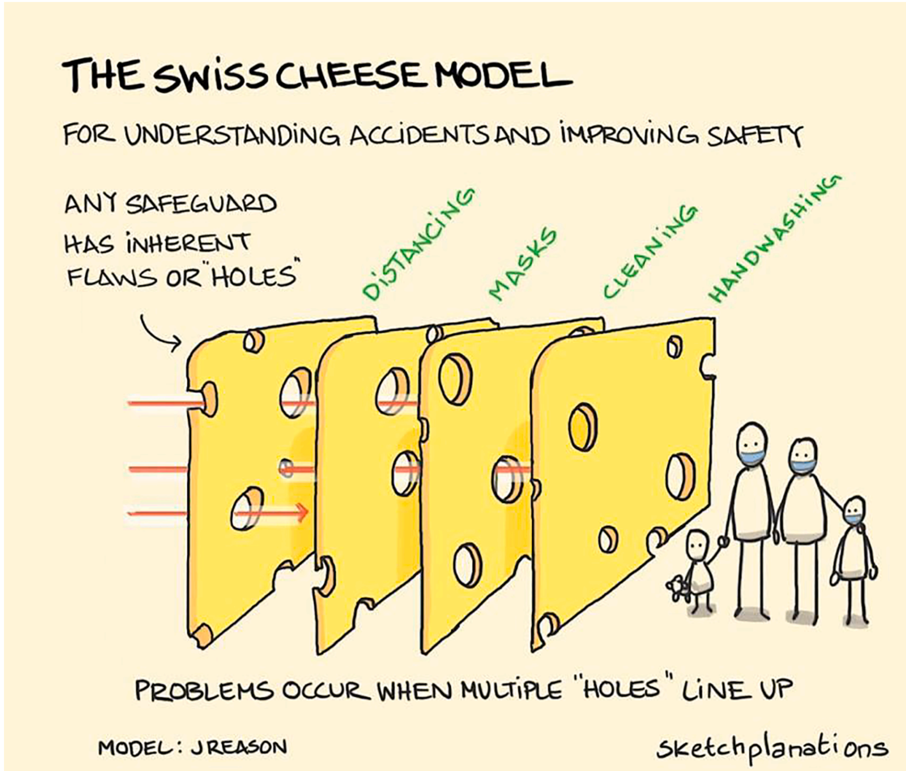

Fig. 5. A model of how health interventions can combine to lessen disease risk. Source: Jono Hey - sketchplanations.com. Licensed by Creative Commons.

4. Justice: distribute benefits, risks, and costs fairly.

Although these are problematic as a general ethical theory, I think that they provide a good start in dealing with some of the key ethical questions concerning medical treatments and political strategies for COVID-19.

Unfortunately, there are circumstances under which the four ethical principles are incompatible. For example, public orders to wear masks are justified by the third principle of nonmaleficence because they reduce the harm caused by the spreading of the disease. On the other hand, they restrict people's freedom and therefore violate the principle of autonomy. Hence ethics is a constraint satisfaction problem in which the principles generate constraints that must be balanced in a coherent fashion, just like the balancing of goals described in section 4.2. The principle of autonomy does not allow people to cause harm to others so that in this case wearing a mask could be judged to be ethically obligatory.

Questions of justice arise in dilemmas that occur in hospitals when there is a shortage of crucial medical equipment such as intensive care beds and ventilators. What is a fair distribution of these resources when patients differ dramatically in factors such as age, underlying conditions, and intensity of symptoms? Sometimes medical decision makers simply rely on intuitive judgments, but it is more responsible to try to make explicit the criteria that are used to determine fair distributions [48].

This is not the place to investigate these difficult ethical issues in dealing with COVID-19. My concern is to point out that all the people who are unavoidably making ethical decisions are using their minds in ways that can be investigated by psychology and neuroscience, sometimes aided by computer modeling. Moreover, deliberations about how to make these decisions more ethically have to engage with philosophical issues concerning the basis of right and wrong.

5. Changing minds

What can be done with people who do not recognize that the pandemic is a serious threat to be mitigated through public health intervention interventions such as wearing masks, keeping distance, and avoiding large gatherings? Cognitive science should provide guidance about how to deal with people whose beliefs and values get in the way of implementing the behaviors required to deal with COVID-19.

It would be naïve to suppose that merely presenting people with the relevant evidence is an adequate strategy. Scientists are trained to appreciate evidence-based reasoning and change their minds, for example when WHO officials reversed their earlier recommendation about wearing masks. But ordinary people have no similar education in how to evaluate hypotheses based on rigorous evidence. They are more likely to rely on dubious sources of information such as friends and social media. Moreover, in the absence of reliable evidence, they are especially prone to motivated conference that allows them to believe what makes them happy.

Another error tendency that makes people prone to false beliefs is fear-driven inference which runs in the opposite direction from motivated inference [49,41]. With fear-driven inference, people believe something because it scares them rather than because it makes him happy. It might seem ridiculous the people should be doubly irrational in believing falsities that make them miserable, but believing the worst is common in phenomena such as hypochondriacs who cannot help thinking that a freckle is cancer or in anxious parents who conclude that something horrible has happened to their children who are only moderately late. Conspiracy theories such as that the novel coronavirus originated as a Chinese bioweapon can be fueled by fear-driven inference.

No experimental studies have yet been done on how minds can be changed about COVID-19, but we can take some lessons from research on the equally controversial issues of vaccinations and climate change. A study at UCLA found that people who are convinced that measles vaccinations are dangerous are not much affected by evidence, but their minds can be changed by vivid illustrations of the harsh effects of measles on children [50]. A scary picture is more effective than a line of argument. Perhaps people who are skeptical about the dangers of

COVID-19 could be influenced by videos of victims gasping for breath. Fig. 5 shows a diagram that nicely illustrates the use of multiple strategies to prevent infection.

A less drastic intervention than the UCLA scare has succeeded in changing the minds of some climate change deniers. Science educators at UC-Berkeley found that short videos which clearly explain the underlying mechanisms for global warming caused by greenhouse gas emissions lead to belief change in some individuals [51]. Perhaps an effective video could show how small droplets containing the coronavirus spread from infected people into the air and then into the noses of other people nearby, with resulting infection, coughing, and lung failure. Understanding the mechanism of infection as a vivid causal process might help people to realize why masks can be helpful in blocking spread. A helpful technique for reducing spread of misinformation about COVID-19 is to remind people of their goal of being accurate [52]. Another potentially useful strategy is to inoculate people against fake news by preemptively exposing them to small doses of misinformation [53].

Much experimental psychological research needs to be done on what persuasion techniques are most effective in convincing people to change their beliefs [54]. Values are even harder to dislodge than beliefs because they not respond directly to evidence, but sometimes values can be influenced by balancing them against alternative values. For example, some people might be convinced that some restrictions on freedom are justified when they realize the awful harms caused by COVID-19.

Adam Grant suggests an alternative technique of changing minds that is based on psychotherapy-inspired methods for changing beliefs and behaviors [55]. The technique called Motivated Interviewing was developed in the 1980s to help people with alcohol problems and has since been applied to problems that include smoking and drugs [56]. Motivated interviewing is partly based on psychotherapy in the style of Carl Rogers with use of empathy and support, but differs in being short (1 or 2 meetings) and directed at a specific goal such as controlling alcohol consumption.

Here is how it could be used by an interviewer to deal with people reluctant to get vaccinated for COVID −19.

1. Understand people's concerns about vaccines by asking them open-ended questions and empathizing with their concerns.
2. Be affirmative, reflective, and non-judgmental about their concerns.
3. Identify discrepancies between people's current and desired behaviors such as staying healthy.
4. Summarize the issues and inform people while respecting their autonomy.

This method is not guaranteed to change people's minds but its success with many problematic behaviors suggests that it is worth trying as an antidote to misinformation.

Philosophy suggests a more aggressive logic-based method that would go like this.

1. Point out that prejudices against vaccines are based on bad evidence.
2. Describe the clinical trials that provide good evidence that the available vaccines are highly effective in preventing COVID-19.
3. Describe the huge costs of covid-19 infection including more than 2 million deaths world-wide.
4. Argue that these cost-benefit considerations make it highly rational to get vaccinated.

Whether this logical argument would convince as many people as motivational interviewing is an empirical question. But here are some theoretical reasons why I would bet on a technique that is more akin to therapy than logic.

Throwing an argument at people is an adversarial process designed to show that they are wrong. In contrast, motivational interviewing poses behavior change as a collaborative process. One of the major determinants of the success of psychotherapy is the establishment of an alliance between a client and a therapist. Arguing with people is likely to make them oppositional, whereas empathic interviewing encourages an alliance and increased appreciation of opposing views rather than sharp rejection.

Use of empathy rather than cold logic gets at the emotions and motivations that are behind people's beliefs and practices. Brains lack firewalls between cognition and emotion, and much psychological and neurological evidence supports the view that their thinking intermixes thoughts and feelings. Motivational interviewing respects such mixing while pure logic dismisses it as irrational. Changing minds is as much about emotional change as it is about belief revision [57]. Logic has no way of disarming motivated inference, whereas motivated interviewing can identify people's goals and help people to see how they are affecting their inferences and also to appreciate how their goals might be served by beliefs and practices that are in line with evidence.

Unfortunately, I also see problems that suggest that motivated interviewing might not be as successful in correcting misinformation as it is in overcoming addictions. Motivated interviewing assumes that people with problems such as alcohol overconsumption have some motivation to change which makes them at least slightly ambivalent about their behavior. Empathic conversation works with their motivation and ambivalence to shift their beliefs and attitudes. But people who are dogmatically misinformed may be totally lacking in motivation to change their beliefs and their absence of ambivalence leaves no room for the interviewer to work with them.

The best hope for changing beliefs in people who are avid anti-vaxxers or COVID-19 deniers would be to find in them some belief, attitude, or action that is incompatible with their firm convictions. This incompatibility would provide a wedge of ambivalence that could generate some internal motivation to change. For example, if early vaccination successes in countries like Israel produce dramatic drops in occurrence of COVID −19, then anti-vaxxers might be spurred to re-evaluate their position. Then logic might provide some of the motivation to change, making logic and empathy collaborative rather than competitive.

Still, alliance, emotion, and motivation might mean that motivated interviewing can do a better job of correcting misinformation than logical argument. The soft glove of empathic interviewing is more appealing than the bludgeon of logic. I hope to see experiments that examine what approaches are most effecting in changing people's minds about COVID-19 vaccines and other social issues such as climate change and political conspiracies.

6. Changing behavior

Sometimes people behave badly despite having true beliefs and appropriate values. There are people who are well aware of the dangers of COVID-19 and the effectiveness of social distancing but nevertheless engage in social gatherings such as parties and weddings. Similarly, some people who know the value of thorough handwashing just rinse their hands under the tap after handling groceries. Other people who understand the reasons for masks resort to a loose mask that droops below their nose. Adoption of responsible behaviors does not require such misbehavers to change their beliefs and attitudes, merely to put them into practice.

Everyone is familiar with times when our actions do not live up to our convictions. Typical cases include people who know a lot about nutrition but nevertheless gorge on junk food and people who are familiar with the dangers of alcoholism but go on binges. Philosophers since the ancient Greeks have been familiar with this phenomenon which they describe as weakness of will and self-deception. Psychologists similarly discuss intention-action gaps in people who have good intentions but fail to carry them out.

These phenomena raise two important questions for cognitive science. Why are intention-action gaps so common in human behavior, and how can such gaps be overcome? The occurrence of intention-action

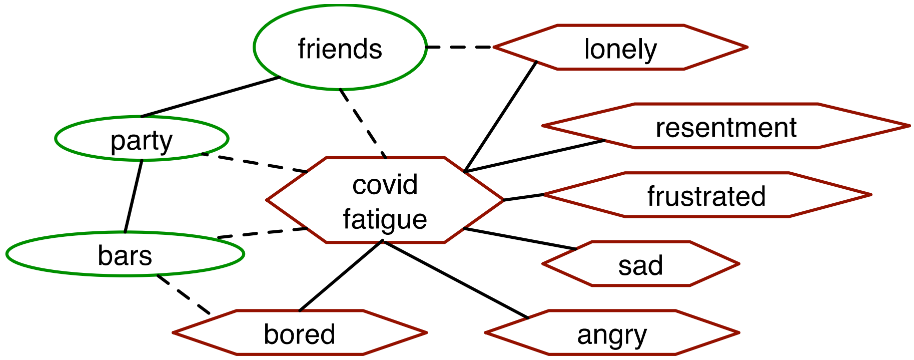

Fig. 6. Cognitive-affective map of pandemic fatigue. The mapping conventions are in the caption for Fig. 3.

gaps and self-deception is puzzling on the assumption that people are inherently rational through maximizing their expected utility. But irrationality becomes comprehensible when the neural complexity of intentional decision making is appreciated [58]. Brains are limited in size, speed, attention, consciousness, and emotional impacts on cognition. Forming intentions and implementing them in actions requires the interaction of numerous brain areas including the prefrontal cortex, amygdala, thalamus, anterior cingulate, basal ganglia, and motor areas [59]. There are many ways in which the path from intention to action can be obstructed, for example by intense emotional reactions such as craving social interactions despite knowing the dangers of partying.

Psychologists have identified an effective technique for overcoming intention-action gaps called implementation intentions, which are conscious if-then rules that can help people to overcome the temptation-driven unconscious decisions that go against what they reflectively want [60]. For example, someone who is worried about alcohol consumption can form the plan: if someone offers me a drink, I will have soda water instead of alcohol. A neurocomputational mechanism by which implementation intentions can help to overcome intention-action gaps has been identified [59]. Psychological research is required to determine whether such implementation intentions can improve people's behaviors with respect to COVID-19.

Failures to comply with health recommendations are often attributed to pandemic fatigue, which is not really fatigue because it does not involve being physically tired. Rather, COVID-19 fatigue is a complex of emotions that include boredom, loneliness, sadness, frustration, anger, fear, anxiety, and resentment, all brought on by the loss of activities and social relations produced by pandemic restrictions. People who are aware of the dangers of COVID-19 and appreciate the required public health interventions can nevertheless experience these negative emotions. Pandemic fatigue can lead to undesirable behaviors when people try to overcome negative emotions through actions that violate social restrictions. Fig. 6 shows a cognitive-affective map that models the attitudes of people who are tired of restricting their social and recreational behaviors. The term "COVID fatigue" can also refer to feeling tired as a symptom of the infection. The pandemic has also produced a kind of cognitive fatigue where people are overwhelmed with too many video meetings and family arrangements.

Cognitive science offers theories of emotions that suggest remedies for negative feelings that constitute pandemic fatigue. Emotions about a situation result when the brain integrates bodily signals such as rapid heart rate with cognitive appraisals of the significance of the current situation to one's goals [61,62]. Hence changing emotions is a matter of altering situations, bodily reactions to situations, and evaluations of situations. Accordingly, people suffering from pandemic fatigue can change their situations by adopting new safe activities, change their bodily states by techniques such as exercise and meditation, and change their appraisal of their situation by appreciating that pandemic restrictions are necessary and temporary. Psychological experiments are required to determine whether diminishing pandemic fatigue in these ways will help to reduce violation of public health restrictions. In cases where the sadness in pandemic fatigue is so severe that it amounts to persistent depression, people may need to be treated with psychotherapy and antidepressant medication. Another factor that needs to be investigated is the effects of peer influence on the contribution of pandemic fatigue in bad health practices.

7. Conclusion: Mind applied

There are other important psychological questions related to COVID-19. Some people with serious cases have long-term neurological effects such as fatigue, hallucinations, and confusion. The disease can also contribute to various mental illnesses such as anxiety, depression, and posttraumatic stress syndrome [63]. All of these problems need to be explained by psychological and neural mechanisms that can provide insights into their treatment.

My concern in this paper, however, has been with aspects of mind relevant to changing behaviors that contribute to the spread of the disease. I have looked at psychological and neural mechanisms that help to explain how scientists and others form and change beliefs about COVID-19. I used motivated inference as the primary mechanism to explain the adoption and perseverance of false beliefs concerning the disease. Dealing with the disease requires attention to the mental and social processes that produce good and bad decisions. Getting people to improve their public health behaviors requires an understanding of methods for changing the minds of people with faulty beliefs and values, and also of methods for improving the behaviors of people who fail to act on their good intentions.

These investigations illustrate the value of interdisciplinary cognitive science that integrates psychology, neuroscience, computer modeling, and philosophy. Psychological experiments are essential for identifying aspects of thinking and its modification, but explanations of how this works are deepened by computer modeling of neural mechanisms. Philosophy contributes key ideas such as coherence as well as attention to normative issues about how people ought to think about pandemic threats. Hence cognitive science belongs in the multidisciplinary arsenal of approaches to dealing with COVID-19.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Simulations about masks

Here is the LISP code that turns the structure in Fig. 1 into input for the program ECHO that simulates explanatory coherence.

; EVIDENCE

(proposition 'E1 "masks-worked-in-China")
(proposition 'E2 "masks-worked-in-US-hospitals")
(proposition 'E3 "hairdressers-with-mask-no-spread")
(proposition 'E4 "US-states-masks-less-spread")
(proposition 'E5 "models-predict-efficacy-of-masks")
(proposition 'E6 "masks-worked-for-SARS")

; HYPOTHESES

(proposition 'H1 "masks-prevent-covid-spread")
(proposition 'H2 "masks-dont-prevent-covid-spread")
(proposition 'H3 "masks-prevent-sars-spread")
(proposition 'H4 "covid-spreads-by-droplets")
(proposition 'H5 "masks-block-droplets")

; EXPLANATIONS

(explain '(H1) 'E1)
(explain '(H1) 'E2)
(explain '(H1) 'E3)
(explain '(H1) 'E4)
(explain '(H1) 'E5)
(explain '(H4 H5) 'H1)

; ANALOGY

(analogous '(H1 H3) '(E2 E6))

; CONTRADICTION

(contradict 'H1 'H2)

ECHO turns this input into a neural network that performs parallel constraint satisfaction and infers the acceptance of H1 that masks prevent COVID-19.

The simulation of Fig. 2 on motivated inference requires the program HOTCO that simulates emotional coherence. It adds the values FREEDOM, AVOID-GOVERNMENT, and SUPPORT-TRUMP which are associated with the hypothesis that masks do not prevent COVID-19, leading to its acceptance despite lack of explanatory coherence.

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