The Experience of Coincidence: An Integrated Psychological and Neurocognitive Perspective

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Abstract In this chapter, we focus on psychological and brain perspectives on the experience of coincidence. We first introduce the topic of the experience of coincidence in general. In the second section, we outline several psychological mechanisms that underlie the experience of coincidence in humans, such as cognitive biases, the role of context and the role of individual differences. In the third and final section we formulate the phenomenon of coincidence in the light of the unifying brain account of predictive coding, while arguing that the notion of coincidence provides a wonderful example of a construct that connects the Bayesian brain to folk psychology and philosophy.

1 Prelude

This book concentrates on the topic of coincidence. In this chapter, we focus on psychological and brain perspectives on the phenomenon of coincidence. Humans frequently experiences coincidences in life in the sense of the Oxford dictionary: A remarkable concurrence of events or circumstances without apparent causal connection. To shed light on this issue, we will first introduce the topic of coincidence in general. In the second section, we outline several psychological attri-

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butions that underlie the experience of coincidence in humans like cognitive biases, the role of context and the modulation of the experience of coincidence as a consequence of individual differences. In the third and final section we formulate the phenomenon of coincidence in the light of the unifying brain account of predictive coding, i.e., the assumption that brains are essentially prediction machines supporting perception and action by constantly attempting to match incoming sensory inputs with top-down expectations and predictions. In particular, we will show how the experience of coincidence can be understood as an example of Bayes-optimal model selection.

2 Introduction

In 2011 the newspapers reported the remarkable case of Joan Ginther from Texas.[1] Over several years she won four times a multi-million dollar jackpot, by buying scratch-off lottery tickets. It started in 1993 when she won $5.4 million, followed by $2 million in 2003, $3 million in 2005 and in 2010 she won a $10 million dollar jackpot.[2] Such an extraordinary pattern of wins cries out for an extraordinary explanation. Residents of the town of Bishop were convinced that Joan was born under a lucky star or that God was behind it. Statisticians estimated that the chances of winning such prizes four times in a row were 1 in 18 septillion.[3] Combined with the discovery that Joan had earned a Ph.D. in mathematics at the University of Stanford, this led to the suggestion that Joan had figured out the algorithm behind lotteries. Joan always bought her tickets at the same mini mart in Bishop. By figuring out the algorithm that determines the winner and the schedule by which lottery tickets are distributed across Texas, Joan could have predicted when to buy the winning ticket. Joan further contributed to the mystery, by refusing any interview.

In general, humans are remarkably bad at estimating chances and probabilities (Tversky and Kahneman 1974). As a consequence, coincidental events (i.e. a chance concurrence of events without apparent causal connection) are often imbued with special meaning and result in the search for an ultimate explanation (Brugger et al. 1995). In the case of Joan, the explanation turned out to be less extraordinary than initially thought: the first win was likely based on chance, as the number of the winning ticket matched the date of her birthday. The money that was won may have enabled Joan to buy large quantities of lottery tickets, up to tens of thousands of tickets

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[1]We would like to thank our colleagues Bastiaan Rutjens & Frenk van Harreveld for bringing this example to our attention in their book on 'Coincidence'.

[2]http://www.dailymail.co.uk/news/article-2023514/Joan-R-Ginther-won-lottery-4-times-Stanford-University-statistics-PhD.html.

[3]http://www.philly.com/philly/news/lottery/How_outrageous_were_the_odds_lottery_legend_Joan_Ginther_beat.html.

a year.[4] Given these large quantities the odds of winning a prize become less unlikely than initially thought. In addition, this strategy also explains the fact that Joan (and a friend with whom she collaborated) won a large number of smaller prizes that passed unnoticed by the media.

In this chapter we focus on the experience of coincidence, which can be defined as the remarkable co-occurrence of two events (e.g. being called by a friend you were just thinking about). In some cases the experience of coincidence results in the inference that a common cause underlies the two events (e.g. some unknown 'force' causing you to think about a friend and causing your friend to call you). In other cases, the co-occurrence of events is attributed to chance. The experience of coincidence thus implies a meta-cognitive perspective, in which the most likely explanation for the events being observed is inferred. The experience of coincidence likely underlies a wide range of human behaviors and beliefs, ranging from belief in conspiracy theories, magic and superstition to belief in faith healing and ultimately belief in supernatural agents, like God. National surveys indicate that the tendency to experience coincidence and to engage in superstitious behavior are widespread, with a prevalence of 26 up to 74 percent in the UK for instance, even among scientists (Wiseman 2003).

3 The Psychology of Coincidence

In this section we will discuss basic psychological mechanisms that underlie the experience of coincidence. First, we will argue that the experience of coincidence is related to the over-generalization of predictive models, which in turn are based on fundamental cognitive biases that may actually confer an adaptive advantage. Next, we will focus on the role of context and individual differences in the experience of coincidence.

3.1 Cognitive Biases and Predictive Models

The experience of coincidence may be considered a specific example of the idea that humans construct a predictive model of the world (Friston and Kiebel 2009). This idea, first articulated by Helmholtz assumes that agents perform inference based on a generative model of the world (Clark 2013; Friston 2010; Friston et al. 2012; Gregory 1980; Rao and Ballard 1999; Schwartenbeck et al. 2013). Such models incorporate associations, which can be used to predict future events (e.g. learning that dark clouds often predict rain) and to predict the consequences of our

[4] http://www.philly.com/philly/news/lottery/Lotterys_luckiest_woman_Joan_Ginther_bet_flabbergasting_sums_on_scratch-offs.html.

own and others' actions (e.g. learning how to throw a ball in a basket). Psychological experiments have shown that in many cases, these models are based on fast and frugal heuristic processes, that may be advantageous in specific limited circumstances, but that may be difficult to generalize across different domains (Gigerenzer 2012). Furthermore, it has been suggested that predictive models may come to dominate perception, such that reality is perceived in accordance with the constraints imposed by the model, rather than that the sensory input determines the updating of the model. An extreme example of the dominance of predictive models over perception can be found in research on hypnosis, in which proneness to and acceptance of suggestibility manipulations can result in an altered perception of the environment (Raz et al. 2005). Similarly, it has been suggested that an over-reliance on predictive models and a failure to update these models in accordance with the available sensory evidence may be the basis of illusion in normal perception and delusions and hallucinations in psychopathology (Adams et al. 2013; Corlett and Fletcher 2012).

At a very basic level the experience of coincidence and the construction of a predictive model may be related to basic principles of reinforcement learning and classical conditioning. The behaviorist Skinner already noted that pigeons, when food was presented at a random reinforcement schedule, tended to display superstitious-like behavior (Timberlake and Lucas 1985). The co-occurrence of a specific behavior (e.g. pecking at the wall of the cage) with a specific consequence (e.g. receiving food) resulted in the subsequent reinforcement of that behavior—as if it resulted in the presentation of the food. Similar principles of random reinforcement learning likely play a role in human experiences of coincidence and superstitious behavior as well. For instance, imagine buying a lottery ticket at a specific shop and at a specific time of the day and winning a prize. The next time when you buy a lottery ticket, you may be inclined to buy the ticket at the same shop at the same time—even though you know that the chances of winning at this specific shop are as low as buying a ticket somewhere else.

An over-generalization of the principles of reinforcement learning may often be adaptive, as it enables the learning of novel action-effect contingencies. The so-called 'false positives' generated by learning illusory contingencies based are relatively harmless. Evolutionary psychologists have thus argued that the emergence of superstitious behavior and the belief in coincidence is the consequence of adaptive cognitive biases (Foster and Kokko 2009). In a relatively stable and predictable environment, failing to detect a specific contingency between two events (e.g. knowing that smoke often signals fire) is typically more costly than erroneously inferring a relation between two unrelated events (e.g. believing that drumming causes rain). The evolution of superstition is a specific example of the error management principle (Haselton and Nettle 2006), according to which if there is an asymmetrical distribution between type I errors (i.e. a 'false positive') and type II errors (i.e. a 'false negative'), a bias develops toward committing the least costly error. The experience of coincidence may be related to the overestimation of contingencies in a predictive model. As long as the environment is relatively stable such a model is adaptive, but it may become maladaptive in a different context.

For instance, in young children at home an over-estimation of the amount of control over the environment may be adaptive, as they still need to learn which aspects of their environment can be controlled, but may become maladaptive during adolescence, leading to increased risk taking (Heckhausen and Schulz 1995). Similarly, it has been pointed out that in games of chance, people often rely on the over-generalization of principles of skill and practice: they approach a dice throwing or gambling task for instance with a skill-oriented approach, as if their specific movements or choices influence an outcome that is in fact uncontrollable (Langer 1975). Such a bias is adaptive as long as the losses are small and the potential gains are relatively high, but in specific contexts (e.g. casinos) this behavior may become maladaptive, leading to risky gambling and excessive risk taking.

In psychological research, many other cognitive, reasoning, social, memory and attentional biases have been described that may directly contribute to the experience of coincidence and the construction of mental models that influence subsequent decision making (for an overview, see Kahneman 2011). The *self-attribution bias* reflects the general tendency to over-attribute positive outcomes to oneself and negative outcomes to external factors (Mezulis et al. 2004). The self-attribution bias underlies the experience of coincidence, by incorrectly attributing two unrelated events to a common cause (i.e. oneself). For instance, when throwing a dice or when performing a card guessing game, people tend to take credit for positive outcomes, while they externalize negative outcomes (van Elk, Rutjens and van der Pligt 2015). A well-known example of the self-attribution bias can be observed in John McEnroe, a famous tennis player in the nineteen-eighties who attributed wins on a match to his own capacity and training methods, but losing to bad performance of the umpire. Basically, it has been argued that the self-attribution bias reflects a distorted perceptual process, which is driven by the need to maintain and enhance self-esteem. As such, the selective and biased perception of the world has a strong motivational significance, by avoiding people from becoming passive (e.g. 'learned helplessness'). It has even been argued that an over-optimistic perception of one's own capabilities and the amount of control that can be exerted over the environment, may be adaptive and psychologically healthy (Taylor and Brown 1988).

In formal treatments of the predictive or Bayesian brain, it is fairly straightforward to show that the self-attribution bias is, mathematically, Bayes optimal. This self-attribution bias, also known as optimism bias (Sharot 2012), is a natural consequence of making inferences about the state of the world generating sensory information (Friston et al. 2014). In active (Bayesian) formulations of decision making and choice behavior, we act to realize preferred outcomes by sampling from beliefs about the way that we will behave. Usually, these beliefs are informed by sensory evidence. However, when that evidence is ambiguous the most likely state of the world is the state that is consistent with our ongoing behavior (Friston et al. 2014). Because we believe our behavior will lead to preferred outcomes (that actions can fulfill), this necessarily implies that inferences in an uncertain world are optimistic and are inherently biased by beliefs about our purposeful behavior (FitzGerald et al. 2014). A formal (mathematical) treatment of this issue can be found in FitzGerald et al. (2014) and Friston et al. (2014). In this treatment, the neurobiological correlates of the confidence in beliefs about policies are associated with dopaminergic discharges in the brain—a theme that we will return to later.

Also, it has become quite clear that we do not perceive the world as it is. Above all, the information provided at any moment in time is so abundant that we have to be selective in what we attend to. The question how people are able to attend to the most important information, while ignoring other sources of information has been widely studied in psychology and is typically labeled *selective attention*. Donald Broadbent started his investigations of this phenomenon after working with air-traffic controllers during the second world war (Broadbent 1958). In that situation numerous competing messages from departing and incoming aircraft are arriving continuously, all requiring attention. His basic finding was that air traffic controllers can only deal effectively with one message at a time and so they have to decide which is the most important. Based on his and other findings, cognitive scientist argued that we must have a kind of sensory buffer and the input has to be selected based on the physical characteristics for further cognitive processing. However, this bottom-up approach to information processing was challenged, and for example the attenuation model of Anne Treisman suggested that although we can indeed only limitedly process multiple sensory inputs at once, attention is attenuating specific sensory information rather than applying an early filter on the non-attended sensory information (Treisman 1964). The next step in attention research continued this line of thinking and actually argued that attention is able to select information at a very late stage of processing. MacKay (1973) presented participants information via both ears with a specific instruction, which ear to attend. He found that shadowed ambiguous passages with information on the unattended channel that clarified the ambiguity (ear 1—bank; ear 2—river or money) helped the subsequent memory test regarding the relevant channel; participants were better in recalling sentences for which the un-shadowed word was meaningful, thereby further challenging the bottom-up nature of attention. The research of MacKay nicely illustrates that attention is serving a goal—in his experiment acquiring information from any source available to predict the information relevant for the task. Thus, perception is subjective by nature and the feeling of coincidence based on cognitive biases can be considered in the light that we selectively attend to certain stimuli in the context given while ignoring other information available.

This form of selective attention can also be cast in terms of hypothesis selection. In other words, we are compelled to select among a number of competing hypotheses and search out confirmatory (or dis-confirmatory) sensory evidence for those hypotheses. Clearly, the evidence or stimuli that we attend (or ignore) will be highly sensitive to the current hypothesis entertained by the brain: Humans are biased to selectively attend and recall information that is highly salient or informative (Mcdaniel et al. 1995). In addition, people often rely on representativeness and availability heuristics when judging the likelihood of situational descriptions (Tversky and Kahneman 1974) and may use counterfactual thinking to regulate affect in response to unexpected positive or negative outcomes (Roese 1997).

In general, people are characterized by a misperception of chance events (Tversky and Kahneman 1974), as shown for instance by the tendency to perceive an 'irregular' coin-toss sequence like 'H-T-H-T-T-H' as more likely than a regular sequence like 'H-H-H-T-T-T'. In this example, chance events are considered as a self-corrective process and on each consecutive toss of the coin people take into account the past history of 'heads' and 'tails'—even though the coin obviously has no memory. The latter bias is another good example of the general tendency to construct predictive models of the world—even in cases when such a model is not applicable or appropriate (or in which the model should classify the coin toss as a 'chance event').

In sum, we argue that the experience of coincidence may be considered a specific instance of the tendency to construct and rely on predictive models of the world. These models may often be based on adaptive biases or prior beliefs to detect contingencies (Foster and Kokko 2009) and/or may be supported by other domain-specific biases that confer an adaptive advantage (i.e. heuristics) in specific settings. An over-reliance on internal models and the over-generalization of models to contexts in which they do not apply, may contribute to the experience of coincidence.

3.2 Context and Model Adjustment

In the preceding section we have argued that perception of events in the world is subjective and that cognitive biases at the personal level may result in the experience of coincidence. Specific situations or a given situational context, may also alter your perception of the world dramatically. As has been argued before (FitzGerald et al. 2014), agents have to determine what model to use in the first place and secondly to make inferences about hidden variables to evaluate the likelihood of a model and the precision of the parameters of any plausible model. A given situational context is likely to affect both aspects: which model to use and/or how to weight the parameters within the specific models.

A famous example was demonstrated in a Candid Camera television show in the 1960s (the example is also mentioned in Liebermann 2007). An uninformed individual enters an elevator filled with multiple confederates working with the show. These confederates stand all collectively facing the back of the elevator rather than facing the front. Almost all individuals would look quickly around at the others and then change their orientation in order to stand in line with the confederates. This example is presented in social psychology as one of the fundamental insights of social cognition: "people look to the social environment and external context to guide their behavior, particularly when the appropriate course of action is ambiguous or undefined." This example nicely illustrates how our behavior is context-dependent, but it also nicely illustrates how different models compete for different inferences. Relying on previous knowledge of elevators, you have learned that the door that opened for you when you entered the elevator is also likely the door that will open again when you need to leave the elevator. However, occasionally, you find elevators with two doors, one entrance and one exit door typically at the opposite side of the elevator. The fact that all others are facing the back might strike you as too obvious to be coincidence. Thus, multiple inferences are produced by your brain; the elevator model which activates probabilities about potential door locations that you might perceive to open to allow you to exit the elevator, but also the social model, i.e., the probability that several people all face one direction that is likely going to be the direction at which relevant information will appear. In other words, in a causal model of the world, you expect other agents to anticipate what will happen next, and thus you assume they are directed to the location they expect the door to open—or, you could even infer the candid camera model, i.e., how likely is it that people are making a joke on me. Based on the precision of these different models in terms of what is the best inference on what I can perceive next, most people might make an active inference and turn their side in alignment with the others. Interestingly, this Bayesian approach on a social phenomenon like this emphasizes "the power of the situation" as much as many other well-studied concepts in social psychology, like the confirmation bias (Asch 1956), or the famous obedience to authority phenomenon (Milgram 1965), from a unified framework, predictive coding. Depending on the precision of parameters from different models in your mind you infer what you will perceive next based on the (social) context you are in. Again, we see the emergent theme of selecting among plausible hypotheses that explain the sensory evidence at hand. Above, we have discussed this in terms of perceptual inference, very much along the lines of perception as hypothesis testing (Gregory 1980). Here, the same notion emerges in the context of social inference. We will return to the central role of selecting hypotheses and Bayesian model selection below.

In ambiguous and uncertain contexts, the need for predictive models and the need for making predictions including situational constraints increases. In line with this suggestion, the experience of coincidence and the engagement of superstitious behavior are often strongly related to significant life events that have important consequences, such as well-being, illness or death. It has been found for instance that belief in luck and coincidence increased during times of stress and in potentially threatening situations (Keinan 1994, 2002). Similarly, superstitious behavior is quite prevalent among the performing arts and in sports, and the occurrence of superstitious acts typically increases with the importance of the outcome (e.g. playing the finals; cf. Burger and Lynn 2005). Interestingly, large cultural differences exist in the experience of coincidence and in probabilistic thinking (Wright et al. 1978): Asians compared to westerners typically engage less in probabilistic thinking in terms of 'cause-and-effect' and this may be related to the 'fate-oriented' view in Eastern religion and philosophy. These findings highlight the role of context in the experience of coincidence. Again, these findings make sense in a broader evolutionary framework, according to which the detection of (illusory) contingencies and the need for predictive models is especially important in potentially ambiguous or threatening situations.

Specific contexts may trigger an over-reliance on internal models and a failure to update these models in accordance with the available sensory information, may cause the experience of ‘coincidence’. An extreme example of a failure to update one’s cognitive model may be found in the phenomenon of *cognitive dissonance* (Festinger et al. 2008). In his seminal work, Festinger describes a religious sect believing that the earth would be flooded and that they would be rescued by extraterrestrials in a flying saucer. When the critical time had passed and the prophecy did not come true, rather than giving up their beliefs, the sect became even more fervent in their faith. Many psychological studies have shown that, rather than changing one’s model based on new evidence, humans respond to cognitive dissonance by discarding the evidence or assimilating the evidence to one’s current model (Elliot and Devine 1994). For instance, many believers put their trust in a religious leader, who in turn imposes their views on his followers. An increased reliance on religious authority results in a reduced process of error monitoring and a failure to update one’s model based on the available evidence. Recently it has been argued that religious rituals are specifically aimed at reducing the process of error monitoring, thereby enhancing people’s willingness to uncritically adopt a prevailing worldview (Schjoedt et al. 2013). In line with this suggestion, it has been found for instance that believers are characterized by a reduced activation of the frontal executive monitoring network when listening to a religious authority (Schjoedt et al. 2011). In such contexts, a failure to update one’s model may result in the experience of coincidence, as observed for instance during faith healing in which a common cause is inferred (e.g. ‘God’) for two scientifically unrelated events (e.g. prayer by the religious authority and the (often) temporary recovery of illness).

3.3 Individual Differences and Precision

In addition to contextual effects, individual differences in personality traits and beliefs also play an important role in the experience of coincidence. Some people may prefer more certainty and precision in their predictions than others. In addition some people may more strongly rely on their predictive models than others and may be characterized by systematic biases with respect to taking sensory information into account.

It has been found that the tendency to perceive coincidences is related to the individual trait of need for control (Hladkyj 2001). People scoring high on the need for control (and likely requiring a higher precision in their prediction models) were more likely to experience unusual coincidences as personally significant (c.f., the self-attribution and optimism bias above). In addition, belief in a meaningful world and the imbuement of random events with meaning has been associated with a stronger visual attention capture (Bressan et al. 2008): this finding could reflect that the tendency to perceive coincidences as meaningful is related to a process of error detection of information that is conflicting with one's cognitive schema's.

Several studies have suggested that individual differences in the reliance on internal predictive models of the world are also related to the experience of coincidence. Participants scoring high on schizotypal personality traits are characterized by an increased reliance on internal predictive models and by difficulties to update their model based on new sensory evidence (Corlett and Fletcher 2012). In addition, a relation has been suggested between schizotypy, the perception of coincidence, magical ideation and paranormal beliefs (Williams and Irwin 1991). It has been found, for instance, that people scoring high on schizotypy and magical ideation are more prone toward detecting illusory contingencies (Brugger and Graves 1997). In this task, participants were required to discover the rule whereby navigating a virtual mouse through a maze would result in a reward. In fact, the reward was directly coupled to the amount of time spent navigating: if the participants spent more than three seconds in the maze, they would receive the reward, whereas if they spent less time no reward was provided. Many participants developed beliefs in illusory contingencies (i.e. the belief that moving the mouse repetitiously along a specific path would result in the reward) and the amount of illusory hypotheses that were believed were directly related to magical ideation. In another study using a dice throwing task it was found that the perception of chance events as meaningful is related to a tendency for repetition-avoidance e.g. in guessing outcomes (Brugger et al. 1995). Interestingly, in the same study it was found that the tendency to avoid semantically related guesses was associated to a stronger belief in extrasensory perception. Finally, it has been reported that paranormal believers show fallacies in probabilistic reasoning task and tend to underestimate the likelihood of chance events (Rogers et al. 2009). In addition, paranormal believers are more prone to reporting frequent experiences of coincidence during their life (Bressan 2002). These findings illustrate that individual differences in model selection and the reliance on internal models can have a strong effect on the experience of coincidence.

In summary, when we use internal models to make inferences about the causes of our sensations, we are in the difficult game of carefully balancing the precision of, or confidence in, sensory evidence relative to prior beliefs. In hierarchical models (with multiple levels of abstraction), each level is equipped with a precision that determines how much it predominates over other levels. Crucially, the precision at each and every level of the hierarchy has to be optimized. This optimization itself depends upon biases or priors about expected precision (or expected uncertainty) that can lead to very different inferences and behavior. This may be manifest as normal intersubject variation in cognitive biases or, indeed, provide a formal explanation for false inference in psychopathology (Adams et al. 2013).

4 Predictive Coding and Coincidence

We have defined the experience of coincidence as an inference about the remarkable co-occurrence of two events (Brugger et al. 1995). To conclude, we present a more theoretical view on how Bayesian models, implemented in our brain, can lead to the experience of coincidence. The experience is labeled as a coincidence, when our explanation appeals to the notion of a 'coincidence', as opposed to some underlying common cause. When a causal inference is made, the experience is labeled as coincidence; in contrast, 'non-causal' inference makes the concurrence coincidental. This means that we must have the capacity to infer that an improbable (remarkable) concurrence was or was not causally mediated. This entails the capacity to postulate two concurrent hypotheses (improbable events may or may not have a common cause), and we must also have a (meta-representational) concept of this inferential dilemma.

In this section, we turn to a formal treatment of coincidences from the perspective of the Bayesian brain. To set the scene, it would be useful to rehearse the simplicity of the formal perspectives we have been appealing to. The most general principle guiding action and perception is presumed to be a maximization for the evidence of models used to explain the sensorium. The inverse or complement of model evidence is surprise, prediction error or a quantity called variational free energy. This means that the brain is trying to minimize prediction error (or maximize model evidence). A popular scheme for implementing this minimization is predictive coding, for which there is a substantial amount of circumstantial evidence in terms of neuroanatomy and neurophysiology (Friston and Kiebel 2009). So what does it mean to maximize model evidence? To understand this, we have to appreciate that model evidence has two components:

$$\text{Log evidence} = \text{accuracy} - \text{complexity}$$

Where, mathematically:

$$\begin{aligned}
\text{Log evidence} &= \ln \Pr(\text{consequence}|\text{hypothesis}) \\
\text{Accuracy} &= \mathrm{E}\left[\ln \Pr(\text{consequence}|\text{cause, hypothesis})\right] \\
\text{Complexity} &= \mathrm{D}[\Pr(\text{cause}|\text{consequence, hypothesis})|\,|\Pr(\text{cause}|\text{hypothesis}))
\end{aligned}$$

where E[] denotes an expectation or average and D[] the relative entropy or Kullback-Leibler divergence. This mathematical formulation of the goodness of fit of a model is interesting because it says that complexity is the divergence between our prior beliefs (i.e., cognitive biases and preconceptions) and the (posterior) beliefs adopted after seeing sensory information.

Crucially, a high model evidence requires a parsimonious but accurate explanation for sensory consequences (of inferred causes). Generally, these explanations rest upon internal or generative models with a deep hierarchical structure (possibly reflecting the hierarchical organization of cortical areas in the brain). This deep structure is particularly important from the point of view of coincidences, because appealing to a common cause adds an extra level or depth to the hierarchical explanation that can minimize its complexity (and maximize model evidence). To see this clearly, we need to see why complexity is so important.

If we explained all our sensations with a multitude of independent causes, we would have a very accurate (low prediction error) explanation; however, the complexity of this explanation or hypothesis would be very high. This is because complexity increases with the degrees of freedom or number of causes invoked to explain data (the divergence above). The problem with complex but accurate models is that they do not generalize to other situations—a problem known as over-fitting in statistics. This means a good model should also be parsimonious and use the smallest number of causes to explain (sensory) consequences. In turn, this means we are compelled to construct unifying hypotheses about common causes that reduce the cardinality of the causes of our sensory explananda.

It is therefore entirely Bayes-optimal to select hypotheses or models that ascribe a common cause to coincident events; particularly those that are generated by some agency (e.g., oneself, a deity or the CIA). In fact, several studies have shown that the tendency to attribute coincidental events to external agents is universal and may underlie supernatural and conspiracy beliefs (Banerjee and Bloom 2014; Imhoff and Bruder 2014). It is at this point we see the utility of 'coincidence' as an alternative hypothesis for the co-occurrence or succession of coincident events. To make this concrete, consider a situation where you are meeting a friend for coffee and he arrives at exactly the same time as you. This coincidence is surprising and will call for an explanation in your (Bayesian) brain. This is because surprise has to be minimized. There will be a number of competing hypotheses; for example, your friend has been waiting for you, your friend knew exactly when you would arrive because he has been spying on you, you both caught the same tram to the café, the meeting was ordained by God and, finally, it was a coincidence. All of these competing hypotheses or models provide an accurate explanation for the events you have witnessed; however, they differ profoundly in terms of their complexity as scored by the number of (implausible) deviations from your prior beliefs. As we have noted above, selecting the best hypothesis corresponds to accepting the model with the greatest evidence (this is known as Bayesian model selection in statistics). This will be the hypothesis with the minimum complexity; namely the explanation that requires the least divergence from your prior beliefs. In other words, an a priori plausible explanation is most likely inferred (e.g., you arrived on the same tram). However, if there are no tram stops near the café, then the most plausible hypothesis could be a coincidence; provided you believe, a priori, coincidence is plausible. The hypothesis you select will determine whether coincident events (in the real world) are experienced as a coincidence.

The key insight provided by the above treatment is that we are equipped with the hypothesis or heuristic that things can be explained by 'coincidences'. This is a constructive explanation—as opposed to simply ignoring co-occurrences. If this is true, then the way that we deal with (real-world) coincidences depends strongly on our prior disposition to 'coincidence' as a causal explanation. The very fact that we have this hypothesis at hand to explain surprising contingencies is a testament to the sophistication of our hierarchical generative models and may not be seen in lower animals (like pigeons). It also may provide one perspective on the formation of delusional systems in psychosis, where the coincidence hypothesis is simply not available.

There are some other interesting predictions that follow from our line of argument. Above, we have noted that the confidence in our beliefs about chosen outcomes may be signaled by dopamine in the brain. This stands in contrast to alternative explanations based upon dopamine discharges reporting rewards or preferred outcomes. Coincidences may offer an interesting resolution to the competing explanations for dopamine responses. If coincidences resolve surprise, then realizing something is a coincidence should resolve uncertainty and increase precision resulting in elevated dopamine firing. Conversely, if dopamine reports preferred outcomes, even when they are surprising, dopamine should show a response to unexpected rewards that are entirely coincidental.

5 Conclusions

In this chapter we have provided an analysis of the experience of coincidence from a psychological and neurocognitive perspective. As humans we construct predictive models of the world that enable us to generate predictions and to minimize surprise. The experience of coincidence may result from cognitive biases, such as the self-attribution bias and attentional biases, which are Bayes-optimal. Thereby the notion of coincidence provides a wonderful example of a construct that connects the Bayesian brain to folk psychology and philosophy.

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