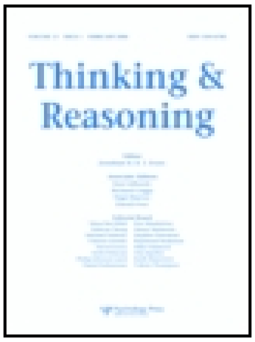

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Vittorio Girotto

Paolo Legrenzi & Phil Johnson-Laird

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OBITUARY

Vittorio Girotto

Vittorio Girotto (1957–2016)

Vittorio Girotto died in his sleep near dawn on April 23rd 2016 at his home outside Trieste. He was 59 years old and at the peak of his abilities. He is survived by his wife, Simonetta Fabrizio, and their two daughters, Alma and Ester. He was one of the leading figures in the contemporary study of reasoning and higher cognition, and a brilliant, inspiring researcher of profound scholarship. He took his undergraduate degree at the University of Padua in 1980, and his doctorate in social psychology at the University of Bologna in 1986 under the supervision of Luciano Arcuri. But, it soon became clear that he was a cognitive psychologist. His first position was as a post-doctoral researcher, and then as a researcher, at the Laboratory of Cognitive Psychology, CNRS, in Aix-en-Provence. There, he worked closely for many years with Michel Gonzalez. Later, he held positions in the Institute of Psychology, CNR, in Rome, and in the Department of Psychology at the University of Trieste. His final position from 2002 onwards was as a full professor at the University of Architecture, Venice, where with one of us (Paolo Legrenzi), he set up the study and teaching of cognition to architects and designers. He never taught students of psychology in any of his jobs, and he never had any Ph.D. students of his own. Yet, he carried out research with many colleagues, and advised many graduate and post-doctoral students.

In a dichotomy due to the ancient Greek poet Archilochus, but popularised by the philosopher Isaiah Berlin (1953), thinkers can be classified as hedgehogs or foxes. Hedgehogs know one big thing. Like Plato, Piaget, and Chomsky, their work embodies a single fundamental idea. Foxes, in contrast, know many clever things. Like Aristotle, William James, and George Miller, their works reflect multiple brilliances. Girotto was a fox. Just how many clever thoughts he had became apparent to us only at a conference in his memory at University College, London, in July 2016. They exceed the bounds of this obituary, and so we describe those most likely to be his legacy. For an account of the man, his personality, and his extraordinary memory, we refer readers to Legrenzi (2016).

Like many students of reasoning, Girotto investigated Wason's (1966) selection task. Readers will recall that in this task, the experimenter lays out four cards on a table, explaining that each of them has a letter on one side and a number on the other side. The task for the participant is to select just those cards, which, on being turned over, would reveal whether or not a particular hypothesis is true or false. For instance, the cards are, respectively: A B 2 3, and the hypothesis is:

> If a card has an A on one side, then it has a 2 on the other side.

Wason's inspiration was a Popperian view of scientific hypotheses—they should be falsifiable (Popper, 1959). On this account, the correct selections are the *A* card, because a *3* on its other side would refute the hypothesis, and likewise the *3* card, because an *A* on its other side would also refute the hypothesis. But, a robust result is that naive individuals—those who know neither logic nor the philosophy of science—tend to select the *A* card, perhaps the 2 card, but not the *3* card. This finding launched a thousand studies.

What Girotto discovered, working with Dan Sperber and Francesco Cara, was how to elicit the correct selection. For the example above, the counterexample to the hypothesis is *A & 3*. And the secret was to make the counterexample readily available to the participants. In terms of "relevance" theory (Sperber & Wilson, 1995), it should be both relevant to the task and easy to envisage. Four experiments corroborated this prediction (Sperber, Cara, & Girotto, 1995), and Girotto carried out the fourth and most convincing study in Padua. The hypothesis in the task referred to a machine printing letters and numbers on opposite sides of cards. The counterexample was made relevant with the instruction that the machine was designed to print cards according to a rule, e.g. *If a card has an A on one side then it has a 2 on the other side*, but the machine may have gone wrong. The participants had to check for this eventuality by selecting the appropriate cards. The counterexample was made easy to envisage by spelling out the various possibilities that could occur on the other sides of the cards. When the counterexample was both relevant and easy to envisage, 57% of the participants selected the cards corresponding to the counterexample, i.e. the *A* and *3* cards; when it was neither, less than 5% did so; and when it was one but not the other, around 38% did so.

The crux of the selection task is that its content and context can recruit knowledge that makes it easy for participants to construct a counterexample to the hypothesis and to use it to guide their selections. Knowledge can also lead to other interpretations of the hypothesis, e.g. as a biconditional, and to their counterexamples. Without salient counterexamples, individuals tend to select cards that match the clauses of the hypothesis (e.g. Evans & Lynch, 1973), or that correspond to the mental models of the hypothesis (Johnson-Laird & Byrne, 2002), or that maximise the expected gain in information (Oaksford & Chater, 1994). These competing accounts have yet to be teased apart, but Girotto and his colleagues were the first to show the critical role of counterexamples.

Counterexamples are crucial to deductive reasoning, at least according to the theory of mental models. Individuals can refute invalid inferences by thinking of a counterexample, i.e. a possibility to which the premises refer but that is inconsistent with the conclusion (see, e.g. Johnson-Laird, 1983). So, not long after his work on the selection task, Girotto joined the two of us in joint studies of mental models in reasoning.

One view of human beings is that they are rational and rely on logical rules of inference. They sometimes err in applying these rules, but their errors are haphazard (e.g. Rips, 1994). According to the model theory, however, reasoners construct mental models of what is possible given the premises, and these models fail to represent what is false in a possibility. As a result, they make systematic and predictable mistakes. Consider the following assertion:

There is a pin and/or a bolt on the table, or else a bolt and a nail on the table.

It is an exclusive disjunction (*or else*) of two clauses, the first of which is an inclusive disjunction (*and/or*). It has a set of mental models representing the first clause:

pin	
	bolt
pin	bolt

and the second clause adds another possibility:

	bolt	nail

Hence, the assertion appears to be consistent with a second assertion, which holds in the preceding model:

There is a bolt and a nail on the table.

Indeed, 99% of participants in an experiment judged that both the assertions could be true. They were wrong. Mental models do not represent clauses in possibilities when they are false in those possibilities, and so, like those above, they predict systematic "illusory" inferences—illusory, because reasoners are often convinced that their conclusions are correct. Unlike mental models, fully explicit models are accurate but difficult to construct. They use negation to represent what is false in a possibility, and the fully explicit models of the disjunctive premise above are as follows:

pin	not-bolt	nail
pin	not-bolt	not-nail
not-pin	bolt	not-nail
pin	bolt	not-nail

where "not-bolt" represents that it is false that there is a bolt on the table. These models represent the cases in which the first clause of the exclusive disjunction is true and the second clause is false. The case in which the second clause is true and the first clause is false adds no further possibilities. The disjunction is therefore not consistent with the second assertion, *there is a bolt and a nail on the table*, because it is inconsistent with each of the four fully explicit models above. The experiment examined a variety of such illusions and appropriate control inferences for which the model theory predicts that reasoners should reach the correct conclusions. Of the 129 participants, all but one of them made more errors with illusions than with controls, and the one exception was a tie. These results were reported in the first of Girotto's publications in *Science* (see Experiment 2, in Johnson-Laird, Legrenzi, Girotto, & Legrenzi, 2000). The morals of this study are twofold: first, individuals do make systematic errors in reasoning; and, second, the prediction of illusory inferences draws a sharp distinction between the model theory and theories based on formal rules of inference. Illusions are a signature of mental models.

The main line of Girotto's research was his investigations into the psychology of probabilities. It culminated in a great discovery published in his second paper in *Science*. But, we need to begin this story at its beginning. In the late 1990s, Girotto, Maria Sonino Legrenzi, and the two of us, were in Aix-en-Provence. Our project was to extend the model theory to inferences about probabilities. Estimates of probabilities are of two principal sorts. In an *extensional* estimate, the probability of an event is the sum of the probabilities of the mutually exclusive ways in which the event can occur; in a *non-extensional* estimate, the probability of an event depends instead on evidence or a heuristic (see Tversky & Kahneman, 1983). We began our project with extensional estimates from premises, such as:

> In a box, there is at least a red marble, or else a blue marble and a yellow marble, but not all three.

The premise has two mental models of the marbles is in the box:

red		
	blue	yellow

We made two assumptions: in the absence of evidence to the contrary, reasoners would treat models as equally probable; and they would infer the probability of an event as equal to the proportion of models in which it occurred. The resulting theory correctly predicted that the majority of participants made the following two estimates from the preceding premise:

> The probability that a blue marble and a yellow marble are in the box is around ½.

and:

> The probability that a red marble and a blue marble are in the box is zero.

The second of these inferences is an illusion. The fully explicit models of the premise take into account that if there is a red marble in the box, then there are three ways in which the conjunction, *there's a blue marble and a yellow marble in the box*, can be false:

red	blue	not-yellow
red	not-blue	yellow
red	not-blue	not-yellow

and if there is not a red marble in the box, there is a fourth possibility:

not-red	blue	yellow

The first of these four possibilities shows that it is possible for a red marble and a blue marble to be in the box. The probability of their conjunction is therefore not zero. That value is an illusion.

The model theory postulates that naive individuals estimate the conditional probability of *B* given *A*, not from Bayes's theorem, which is too difficult for most people, but from the subset of models of *A* in which *B* occurs. Hence, the following models:

A	B
A	B
A	

yield a probability of *B* given *A* equal to 2/3. The theory's principles apply to cases in which numerical probabilities are assigned to possibilities. Some theorists argue that only frequencies underlie probability, and in particular only those that individuals track in natural observations (e.g. Gigerenzer & Hoffrage, 1995). For the model theory, however, the chances of a unique event can be inferred in the same way. Consider this example:

> The chances that Pat has the disease are 4 out of 10. If she has the disease, then the chances are 3 out of 4 that she has the symptom. If she does not have the disease, then the chances are 2 out of 6 that she has the symptom.

Pat has the symptom. So, what are the chances that she has the disease?

The joint probability distribution is therefore:

		Chances out of 10
Pat has the disease	Pat has the symptom	3
Pat has the disease	Pat does not have the symptom	1
Pat does not have the disease	Pat has the symptom	2
Pat does not have the disease	Pat does not have the symptom	4

Hence, the chances that Pat has the disease given that she has the symptom are 3 out of 5. As Girotto and Gonzalez showed in a sequence of studies, estimates are much easier if individuals can estimate the numerator and denominator in the ratio separately:

$$\frac{\text{numerator}}{\text{denominator}}$$

From the previous information about Pat, participants had to fill in the two missing numbers in the following:

> Pat has __ chances [correct answer: 5] of having the symptom, and among them she has _ chances of having the disease [correct answer: 3].

As this example shows, natural frequencies are not necessary for correct inferences (see e.g. Girotto & Gonzalez, 2002). Other researchers have shown how to use the model theory for non-extensional estimates of the probabilities of unique events, such as the election of Hillary Clinton to the US Presidency (Khemlani, Lotstein, & Johnson-Laird, 2015). Had he lived, Girotto would have had his own insights into the origins of such estimates.

Indeed, one of Girotto's cleverest ideas led to the discovery that 12-month-old infants grasp the rudiments of probabilities. The infants watched a display of simple shapes bouncing around in a container, e.g. one red diamond and three blue circles. The display was hidden from them for a moment, and then one of the shapes emerged from the container's opening. The infants envisaged the events that could occur while the display was hidden, and so they looked longer—a standard measure of surprise—at more improbable events. For a very short occlusion, they were surprised only if the shape that exited had been distant from the container's opening. For an occlusion of one second, a little more bouncing around could have occurred, and so the infants were surprised at exits of rarer objects or those distant from the exit. And for an occlusion of two seconds, still more bouncing could have occurred, and so the infants were surprised only at the exit of rarer objects. Girotto's colleagues from the world of Bayesian modelling built a computer model that made a small number of simulations of the bouncing shapes exiting from the container, and Shannon's measure of the information in an individual event, 1−probability of the event, predicted the children's looking times. Hence, infants are sensitive to the relative improbability of events. This research was published in the second of Girotto's papers in *Science* (Teglas et al., 2011). A subsequent result showed paradoxically that children of 3–5 years were less successful in such tasks (Girotto, Fontanari, Gonzalez, Vallortigara, & Blaye, 2016). Most likely, Girotto would have resolved the paradox.

In another study, Girotto and his colleagues showed that the rudiments of extensional probability were available to adults and children in cultures without numbers or writing—two groups of indigenous Mayans in remote regions of Guatemala (Fontanari, Gonzalez, Vallortigara, & Girotto, 2014). The participants had to select one of two sets of mixed red tokens and black tokens, from which the experimenter would then draw a single token at random. If it was red, the participants won. The sensible strategy is to choose the set with the greater proportion of red tokens, even if it has the smaller absolute number of them. The Mayans did so, and their performance did not differ reliably between adults and children, or from their Italian counterparts. A further study was of conditional probabilities. The participants saw a display of four squares and four circles, and each square was red, whereas three of the circles were green and one was red. The experimenter chose one item from the display, and indicated its shape to the participant, who then bet on its colour. If the shape is square, it is sensible to bet red; if it is a circle, it is sensible to bet green. Mayan adults and children made about 80% of sensible bets, which did not differ reliably from Italian adults' bets.

You might suppose that the inferences under investigation in these studies do not concern real probabilities—after all, the estimates are not numerical. Yet, the rudiments of probabilities are based on the relations between sets and their subsets, and the results of the studies show that these rudiments are available to infants and do not appear to depend on literacy or numeracy.

Girotto studied counterfactual thinking, and, as Byrne pointed out at the conference in his memory, his research was seminal. When a character's actions in a brief narrative have led to unfortunate consequences, those who read the story tend to complete a counterfactual description, *if only* ____, with a description of the undoing of an action under the character's own control: *if only he hadn't stopped to have a drink on his way home* (Girotto, Legrenzi, & Rizzo, 1991; Byrne, 2005). But, in an innovative study, Girotto and his colleagues showed that when individuals make real decisions, their counterfactual thoughts afterwards differ from those who only read about the decisions: actors, unlike readers, change events outside their control (Girotto, Ferrante, Pighin, & Gonzalez, 2007; Pighin, Byrne, Ferrante, Gonzalez, & Girotto, 2011). No one had ever shown before that actors and readers differ in their counterfactual thinking.

Girotto's contribution to the cognitive foundations of reasoning, probability, and counterfactual thinking are likely to be long-lasting. But, many other of his clever ideas occurred in studies of political ideology (Legrenzi & Girotto, 1996), making decisions (Legrenzi, Girotto, & Johnson-Laird, 1993), finding lost objects (Legrenzi, Legrenzi, Girotto, & Johnson-Laird, 2001–2002), and the origins of supernatural and religious beliefs (Girotto, Pievani, & Vallortigara, 2008, 2014). Towards the end of his life, he remarked that he had demonstrated the strength of cognitive illusions twice over. He had revealed them in his experiments, and he had been their victim in his own life. He worked almost until his last breath, and his intellectual epitaph is perhaps what one of us wrote to him as he lay mortally ill:

> … as long as psychologists go on talking about reasoning, you are going to continue to be discussed as an outstanding researcher of the topic. You will not be forgotten.

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Paolo Legrenzi
University of Ca' Foscari, Venice, Italy

Phil Johnson-Laird
Department of Psychology, Princeton University and New York University
phil@princeton.edu