

## int.1 Constructive Reasoning

In contrast to extensions of classical logic by modal operators or second-order quantifiers, intuitionistic logic is “non-classical” in that it restricts classical logic. Classical logic is *non-constructive* in various ways. Intuitionistic logic is intended to capture a more “constructive” kind of reasoning characteristic of a kind of constructive mathematics. The following examples may serve to illustrate some of the underlying motivations.

Suppose someone claimed that they had determined a natural number  $n$  with the property that if  $n$  is even, the Riemann hypothesis is true, and if  $n$  is odd, the Riemann hypothesis is false. Great news! Whether the Riemann hypothesis is true or not is one of the big open questions of mathematics, and they seem to have reduced the problem to one of calculation, that is, to the determination of whether a specific number is even or not.

What is the magic value of  $n$ ? They describe it as follows:  $n$  is the natural number that is equal to 2 if the Riemann hypothesis is true, and 3 otherwise.

Angrily, you demand your money back. From a classical point of view, the description above does in fact determine a unique value of  $n$ ; but what you really want is a value of  $n$  that is given *explicitly*.

To take another, perhaps less contrived example, consider the following question. We know that it is possible to raise an irrational number to a rational power, and get a rational result. For example,  $\sqrt{2}^2 = 2$ . What is less clear is whether or not it is possible to raise an irrational number to an *irrational* power, and get a rational result. The following theorem answers this in the affirmative:

**Theorem int.1.** *There are irrational numbers  $a$  and  $b$  such that  $a^b$  is rational.*

*Proof.* Consider  $\sqrt{2}^{\sqrt{2}}$ . If this is rational, we are done: we can let  $a = b = \sqrt{2}$ . Otherwise, it is irrational. Then we have

$$(\sqrt{2}^{\sqrt{2}})^{\sqrt{2}} = \sqrt{2}^{\sqrt{2} \cdot \sqrt{2}} = \sqrt{2}^2 = 2,$$

which is rational. So, in this case, let  $a$  be  $\sqrt{2}^{\sqrt{2}}$ , and let  $b$  be  $\sqrt{2}$ . □

Does this constitute a valid proof? Most mathematicians feel that it does. But again, there is something a little bit unsatisfying here: we have proved the existence of a pair of real numbers with a certain property, without being able to say *which* pair of numbers it is. It is possible to prove the same result, but in such a way that the pair  $a, b$  is given in the proof: take  $a = \sqrt{3}$  and  $b = \log_3 4$ . Then

$$a^b = \sqrt{3}^{\log_3 4} = 3^{1/2 \cdot \log_3 4} = (3^{\log_3 4})^{1/2} = 4^{1/2} = 2,$$

since  $3^{\log_3 x} = x$ .

Intuitionistic logic is designed to capture a kind of reasoning where moves like the one in the first proof are disallowed. Proving the existence of an  $x$

satisfying  $\varphi(x)$  means that you have to give a specific  $x$ , and a proof that it satisfies  $\varphi$ , like in the second proof. Proving that  $\varphi$  or  $\psi$  holds requires that you can prove one or the other.

Formally speaking, intuitionistic logic is what you get if you restrict a [derivation](#) system for classical logic in a certain way. From the mathematical point of view, these are just formal deductive systems, but, as already noted, they are intended to capture a kind of mathematical reasoning. One can take this to be the kind of reasoning that is justified on a certain philosophical view of mathematics (such as Brouwer's intuitionism); one can take it to be a kind of mathematical reasoning which is more "concrete" and satisfying (along the lines of Bishop's constructivism); and one can argue about whether or not the formal description captures the informal motivation. But whatever philosophical positions we may hold, we can study intuitionistic logic as a formally presented logic; and for whatever reasons, many mathematical logicians find it interesting to do so.

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# Bibliography