

## siz.1 Reduction

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We showed  $\wp(\mathbb{Z}^+)$  to be **non-enumerable** by a diagonalization argument. We already had a proof that  $\mathbb{B}^\omega$ , the set of all infinite sequences of 0s and 1s, is **non-enumerable**. Here's another way we can prove that  $\wp(\mathbb{Z}^+)$  is **non-enumerable**: Show that *if  $\wp(\mathbb{Z}^+)$  is **enumerable** then  $\mathbb{B}^\omega$  is also **enumerable***. Since we know  $\mathbb{B}^\omega$  is not **enumerable**,  $\wp(\mathbb{Z}^+)$  can't be either. This is called *reducing* one problem to another—in this case, we reduce the problem of enumerating  $\mathbb{B}^\omega$  to the problem of enumerating  $\wp(\mathbb{Z}^+)$ . A solution to the latter—an enumeration of  $\wp(\mathbb{Z}^+)$ —would yield a solution to the former—an enumeration of  $\mathbb{B}^\omega$ .

How do we reduce the problem of enumerating a set  $Y$  to that of enumerating a set  $X$ ? We provide a way of turning an enumeration of  $X$  into an enumeration of  $Y$ . The easiest way to do that is to define a **surjective** function  $f: X \rightarrow Y$ . If  $x_1, x_2, \dots$  enumerates  $X$ , then  $f(x_1), f(x_2), \dots$  would enumerate  $Y$ . In our case, we are looking for a surjective function  $f: \wp(\mathbb{Z}^+) \rightarrow \mathbb{B}^\omega$ .

**Problem siz.1.** Show that if there is an **injective** function  $g: Y \rightarrow X$ , and  $Y$  is **non-enumerable**, then so is  $X$ . Do this by showing how you can use  $g$  to turn an enumeration of  $X$  into one of  $Y$ .

*Proof of ?? by reduction.* Suppose that  $\wp(\mathbb{Z}^+)$  were **enumerable**, and thus that there is an enumeration of it,  $Z_1, Z_2, Z_3, \dots$

Define the function  $f: \wp(\mathbb{Z}^+) \rightarrow \mathbb{B}^\omega$  by letting  $f(Z)$  be the sequence  $s_k$  such that  $s_k(n) = 1$  iff  $n \in Z$ , and  $s_k(n) = 0$  otherwise. This clearly defines a function, since whenever  $Z \subseteq \mathbb{Z}^+$ , any  $n \in \mathbb{Z}^+$  either is **an element** of  $Z$  or isn't. For instance, the set  $2\mathbb{Z}^+ = \{2, 4, 6, \dots\}$  of positive even numbers gets mapped to the sequence 010101..., the empty set gets mapped to 0000... and the set  $\mathbb{Z}^+$  itself to 1111....

It also is **surjective**: Every sequence of 0s and 1s corresponds to some set of positive integers, namely the one which has as its members those integers corresponding to the places where the sequence has 1s. More precisely, suppose  $s \in \mathbb{B}^\omega$ . Define  $Z \subseteq \mathbb{Z}^+$  by:

$$Z = \{n \in \mathbb{Z}^+ : s(n) = 1\}$$

Then  $f(Z) = s$ , as can be verified by consulting the definition of  $f$ .

Now consider the list

$$f(Z_1), f(Z_2), f(Z_3), \dots$$

Since  $f$  is **surjective**, every member of  $\mathbb{B}^\omega$  must appear as a value of  $f$  for some argument, and so must appear on the list. This list must therefore enumerate all of  $\mathbb{B}^\omega$ .

So if  $\wp(\mathbb{Z}^+)$  were **enumerable**,  $\mathbb{B}^\omega$  would be **enumerable**. But  $\mathbb{B}^\omega$  is **non-enumerable** (??). Hence  $\wp(\mathbb{Z}^+)$  is **non-enumerable**.  $\square$

explanation

It is easy to be confused about the direction the reduction goes in. For instance, a **surjective** function  $g: \mathbb{B}^\omega \rightarrow X$  does *not* establish that  $X$  is **non-enumerable**. (Consider  $g: \mathbb{B}^\omega \rightarrow \mathbb{B}$  defined by  $g(s) = s(1)$ , the function that maps a sequence of 0's and 1's to its first **element**. It is surjective, because some sequences start with 0 and some start with 1. But  $\mathbb{B}$  is finite.) Note also that the function  $f$  must be surjective, or otherwise the argument does not go through:  $f(x_1), f(x_2), \dots$  would then not be guaranteed to include all the **elements** of  $Y$ . For instance,  $h: \mathbb{Z}^+ \rightarrow \mathbb{B}^\omega$  defined by

$$h(n) = \underbrace{000\dots 0}_{n \text{ 0's}}$$

is a function, but  $\mathbb{Z}^+$  is **enumerable**.

**Problem siz.2.** Show that the set of all *sets of* pairs of positive integers is **non-enumerable** by a reduction argument.

**Problem siz.3.** Show that  $\mathbb{N}^\omega$ , the set of infinite sequences of natural numbers, is **non-enumerable** by a reduction argument.

**Problem siz.4.** Let  $P$  be the set of functions from the set of positive integers to the set  $\{0\}$ , and let  $Q$  be the set of *partial* functions from the set of positive integers to the set  $\{0\}$ . Show that  $P$  is **enumerable** and  $Q$  is not. (Hint: reduce the problem of enumerating  $\mathbb{B}^\omega$  to enumerating  $Q$ ).

**Problem siz.5.** Let  $S$  be the set of all **surjective** functions from the set of positive integers to the set  $\{0,1\}$ , i.e.,  $S$  consists of all **surjective**  $f: \mathbb{Z}^+ \rightarrow \mathbb{B}$ . Show that  $S$  is **non-enumerable**.

**Problem siz.6.** Show that the set  $\mathbb{R}$  of all real numbers is **non-enumerable**.

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## Bibliography