

infinite.1 Dedekind Algebras

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sec

We not only want natural numbers to be infinite; we want them to have certain (algebraic) properties: they need to behave well under addition, multiplication, and so forth.

Dedekind's idea was to take the idea of the *successor function* as basic, and then characterise the numbers as those with the following properties:

1. There is a number, 0, which is not the successor of any number
i.e., $0 \notin \text{ran}(s)$
i.e., $\forall x s(x) \neq 0$
2. Distinct numbers have distinct successors
i.e., s is an **injection**
i.e., $\forall x \forall y (s(x) = s(y) \rightarrow x = y)$
3. Every number is obtained from 0 by repeated applications of the successor function.

sfr:infinite:dedekind:
repeatedapplication

The first two conditions are easy to deal with using first-order logic (see above). But we cannot deal with (3) just using first-order logic. Dedekind's breakthrough was to reformulate condition (3), set-theoretically, as follows:

- 3'. The natural numbers are the smallest set that is *closed under the successor function*: that is, if we apply s to any **element** of the set, we obtain another **element** of the set.

But we shall need to spell this out slowly.

sfr:infinite:dedekind:
Closure

Definition infinite.1. For any function f , the set X is *f-closed* iff $(\forall x \in X) f(x) \in X$. Now define, for any o :

$$\text{clo}_f(o) = \bigcap \{X : o \in X \text{ and } X \text{ is } f\text{-closed}\}$$

So $\text{clo}_f(o)$ is the intersection of all the f -closed sets with o as an **element**. Intuitively, then, $\text{clo}_f(o)$ is the *smallest* f -closed set with o as an **element**. This next result makes that intuitive thought precise;

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closureproperties
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Lemma infinite.2. For any function f and any $o \in A$:

1. $o \in \text{clo}_f(o)$; and
2. $\text{clo}_f(o)$ is f -closed; and
3. if X is f -closed and $o \in X$, then $\text{clo}_f(o) \subseteq X$

Proof. Note that there is at least one f -closed set, namely $\text{ran}(f) \cup \{o\}$. So $\text{clo}_f(o)$, the intersection of *all* such sets, exists. We must now check (1)–(3).

- (1). $o \in \text{clo}_f(o)$ as it is an intersection of sets which all have o as an **element**.
- (2). Let X be f -closed with $o \in X$. If $x \in \text{clo}_f(o)$, then $x \in X$, and now $f(x) \in X$ as X is f -closed, so $f(x) \in \text{clo}_f(o)$.
- (3). This follows from the general fact that if $X \in C$ then $\bigcap C \subseteq X$. \square

Using this, we can say:

Definition infinite.3. A *Dedekind algebra* is a set A together with a function $f: A \rightarrow A$ and some $o \in A$ such that:

1. $o \notin \text{ran}(f)$
2. f is an injection
3. $A = \text{clo}_f(o)$

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ded:proper
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ded:closure

Since $A = \text{clo}_f(o)$, our earlier result tells us that A is the smallest f -closed set with o as an element. Clearly a Dedekind algebra is Dedekind infinite; just look at clauses (1) and (2) of the definition. But the more exciting fact is that any Dedekind infinite set can be turned into a Dedekind algebra.

Theorem infinite.4. *If there is a Dedekind infinite set, then there is a Dedekind algebra.* fr:infinite:dedekind:
thm:DedekindInfiniteAlgebra

Proof. Let D be Dedekind infinite. So there is an injection $g: D \rightarrow D$ and an element $o \in D \setminus \text{ran}(g)$. Now let $A = \text{clo}_g(o)$, and note that $o \in A$. Let $f = g \upharpoonright_A$. We will show that this constitutes a Dedekind algebra.

Concerning (1): $o \notin \text{ran}(g)$ and $\text{ran}(f) \subseteq \text{ran}(g)$ so $o \notin \text{ran}(f)$.

Concerning (2): g is an injection on D ; so $f \subseteq g$ must be an injection.

Concerning (3): Let $o \in B$. By Lemma infinite.2, if $B \subsetneq A$, then B is not g -closed. So B is not f -closed either, as $f = g \upharpoonright_A$. So A is the smallest f -closed set with o as an element, i.e., $A = \text{clo}_f(o)$. \square

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Bibliography