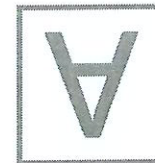


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Publications of the
Austrian Ludwig Wittgenstein Society.
New Series

Volume 11

Reduction – Abstraction – Analysis



ontos

verlag

Frankfurt | Paris | Lancaster | New Brunswick

tions can be *represented* by equivalence classes of lines, they should not be *identified with* such equivalence classes. Doing so would ascribe to the semantic values properties that go beyond the contribution that the relevant terms make to the truth-values of sentences in which they occur. For instance, equivalence classes have set theoretic elements, which is a notion that is completely foreign to the geometrical language in question. Accordingly the third claim of the sufficient condition, (c), says that it is permissible to assign to the expressions in question semantic values that are primitive and *sui generis* and not just set theoretic constructs. These semantic values are nothing more than the contributions made by the relevant singular terms. This provides a good beginning of a response to what I called the problem of existence. In other work I argue that this version of minimalism allows for good responses to the other three problems as well.

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RUSSELL'S MANY POINTS

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Abstract

Bertrand Russell was one of the protagonists of the programme of reducing "disagreeable" concepts to philosophically more respectable ones. Throughout his life he was engaged in eliminating or paraphrasing away a copious variety of allegedly dubious concepts: propositions, definite descriptions, knowing subjects, and points, among others. The critical aim of this paper is to show that Russell's construction of points, which has been considered as a paradigm of a logical construction *überhaupt*, fails for principal mathematical reasons. The constructive aim of this paper is to show that one can save Russell's programme by using the conceptual resources of modern pointless topology.

1 POINTS IN RUSSELL'S PHILOSOPHY

Bertrand Russell was one of the protagonists of the programme of reducing "disagreeable" objects to philosophically more respectable ones. Throughout his life he was engaged in eliminating or paraphrasing away a copious variety of suspicious objects: propositions, definite descriptions, knowing subjects, and many others.

For Russell, the method of scientific philosophy was logical analysis. The aim of logical analysis was the elimination of suspicious or otherwise undesired entities from the discourse of scientific philosophy. In *Our Knowledge of the External World as a Field for Scientific Method in Philosophy* (Russell 1914) Russell attempted to show

"by means of examples, the nature, capacity, and limitations of the logical-analytic method in philosophy. ... The central problem by which I have sought to illustrate method is the problem of the relation between the crude data of sense and the space, time and matter of mathematical physics." (Russell 1914, p.10)

More precisely, Russell attempted to show that the basic mathematical structures of physical spacetime – conceived as structured sets of spatial points and temporal points – could be reconstructed from "crude sense data", later to be characterized as "events". He credited Whitehead with the

basic ideas of this approach characterizing his own version as a “rough preliminary account”:

“I owe to Dr. Whitehead the definition of points, the suggestion for the treatment of instants and “things”, and the whole conception of the world of physics as a construction rather than an inference. What is said on these topics here is, in fact, a rough preliminary account of the more precise results which he is giving in the fourth volume of our *Principia Mathematica*.” (ibidem, pp.10, 11)

Actually, points had played a role in Russell’s thinking already before he had started his collaboration with Whitehead on *Principia Mathematica*. From his youthful *Essay on the Foundations of Geometry* (Russell 1897)¹ up to *My Philosophical Development* (1959) “points” were a recurrent theme in many of his writings. The most detailed account of spatial points can be found in *The Analysis of Matter* (Russell 1929), the last original work on matters of points (more precisely on temporal points) was the paper *On Order in Time* (Russell 1936), but still in the retrospective *My Philosophical Development* (Russell 1959) he ascribed to the issue of points an important place in his philosophical development:

“As regards points, instants, and particles, I was awakened from my “dogmatic slumber by Whitehead. Whitehead invented a method of constructing points, instants, and particles as sets of events, each of finite extent. This made it possible to use Occam’s razor in physics in the same sort of way in which we had used it in arithmetic. I was delighted with this fresh application of the methods of mathematical logic.” Russell (1959, p.77).

Taking into account Russell’s assertion that “the question of the construction of point-instants ... was already very much in my mind in 1911” (Russell 1959, 121) one may say that Russell considered the topic of the logical construction of spatial and temporal points as an important philosophical topic for almost 50 years. Nevertheless, he never got it right, although he was quite clear about the general idea of how the construction of points from less queer entities such as regions or events should be carried out. In *The Analysis of Matter* (Russell 1927) he compared his reductionist pro-

¹ In the *Essay on the Foundations of Geometry*, still under the spell of Bradley’s idealism, Russell conceived points cryptically as “contradictory” objects that evidenced the “dialectical structure” of science according to which the most basic science (= geometry) was not an independent science but pointed to some “higher” science, i.e. physics: “The antinomy of the Point proves the relativity of space, and shows that Geometry must have some reference to matter ...” Russell (1897, pp.196–199).

gram with the standard approach of point set topology and differential geometry:

“In *analysis situs* (= topology, T.M.) both points and neighborhoods are given. We, on the other hand, wish to define our points in terms of “events”, where “events” will have a one-one correspondence with certain neighborhoods. ... We have to assign to our events such properties as will enable us to define the points of a topological space as classes of events, and the neighborhoods of the points as classes of points. (Emphasis mine, T.M.) But we have to remember that we do not want to construct merely a topological space: what we want to construct is the four-dimensional space-time of the general theory of relativity.” (Russell 1927, p.298)

It should be noted that this constructional programme has a circular structure: we start with a certain set E of events that are assumed to have certain (relational) properties. Then we construct points as certain classes of events and the neighborhoods of these points (classes of events) as certain classes of points (classes of classes of events). There is no reason to stop here: we may consider the newly constructed neighborhoods of constructed points as events in their own right and consider them as building blocks for the construction of new “second order” points. For these second order points we may construct neighborhoods again, i.e., second order events, and so on. Continuing in this way, things tend to be complicated, or so it seems. Therefore it seems advisable to confine this undesired profusion of higher order points and events. The simplest one is the assumption that iterating the construction of points and events from already constructed points and events does not yield anything new. That is to say, the classes of points and events of higher order are required to be isomorphic to the classes of points and events of first order. This is a reasonable assumption, since the constructions of points of modern pointless topology do satisfy it. Thus, from now on, this requirement of “stability” is considered as a condition that every good construction programme has to satisfy. One of the main negative results of this paper is that Russell’s original construction is *not* stable, rather, it produces a diverging profusion of points and events of ever higher order.

Notwithstanding this flaw I think it is remarkable fact that already in 1927 Russell quite explicitly formulated here the programme of what later was to become “pointless topology”, namely, “to assign to events such properties as will enable us to define the points of topological spaces as classes of events, ...” (ibidem). Although Russell identified the task of that future discipline with admirable clarity, he did not much to accomplish it.

He never offered any elaborated proposal of what the “properties of events” might be that would “enable us to define points in terms of events”. Rather, he was content to conceive the class E of events as a similarity structure (E, \sim) , i.e. as a set E endowed with a binary relation \sim to be interpreted as non-trivial overlapping.

Consequently, his programme never really got off the ground. Russell never gave a correct definition of points in terms of events, to say nothing about the envisaged construction of the topological and differential structures of the space-time manifolds. In the following we leave aside the projected higher layers of this construction and concentrate on its most basic level – the construction of points and their topological neighborhoods.

Cast in terms of some appropriate set theory (instead of the framework of *Principia Mathematica* as Russell did), his plan for the construction of points (spatial, temporal, and spatio-temporal points) may be outlined as follows: One starts with a set E of events, whereby the concept of “event” is assumed to be a primitive term, i.e. there is no explicit definition of what an event is to be, rather, only some intuitive and informal hints are given. The reader may think of events as more or less well-formed regions of the Euclidean plane, or in the special case of purely temporal events, of intervals of the real line \mathbb{R} endowed with its usual order structure. For the moment, he may take those regions as certain point sets, but it is important to keep in mind that finally events are not to be thought as point sets – rather, points have to be constructed from events in such a way that events and their relations are faithfully *represented* by appropriate point sets and set-theoretical relations.

Let $pt(E) := \{p; p \text{ is a point of } E\}$ denote the set of points to be constructed from E . For the moment, the only thing we know about points is that they are to be sets of events, i.e., the set $pt(E)$ of points is a subset of PE , PE being the power set of E . In the next sections we are going to determine more precisely, what kind of subsets are points to be. The basic idea of constructing points as sets of events is intuitively appealing and simple. This is not to say, that the constructions to be carried out are simple. Actually they are not, and for reasons of space it is not possible to present all the concepts and arguments in full detail. The underlying mathematical facts may be succinctly described as follows. The general mathematical framework is provided by topology and lattice theory, more precisely the theory of Heyting algebras. From a modern point of view, Russell’s programme of defining points in terms of events is located in a conceptual space that is determined by the following facts:

FACT 1: Let H be a regular continuous Heyting algebra. The elements of H are to be intuitively conceived as “events” in the sense of Russell. Up to isomorphism there is a unique topological space $(pt(H), O(pt(H)))$ such that the Heyting algebra $O(pt(H))$ of its open sets and H are isomorphic. Hence, without loss of generality one can assume that H can be thought of as a set-theoretical Heyting algebra, i.e. the elements of H are isomorphic to subsets of $pt(H)$, and the lattice-theoretical operations of H are just the familiar set-theoretical operations of union and intersection.

FACT 2: Russell’s construction of ersatz points as maximal co-punctual subsets of H yields a profusion of undesired ersatz points of which only a small minority corresponds to real points, i.e. to elements of $pt(H)$. In order to show this, we will not rely on Russell’s original construction but on a slightly improved variant, but even this improved construction is doomed to fail.

FACT 3. Russell’s programme of defining “points in terms of events” can be saved by using some more sophisticated concepts of modern pointless topology. The most important device is the notion of an “interior parthood” relation \ll . This relation is used to define maximal *round* filters as ersatz points for which a 1-1-correspondence with the real points of H , i.e. the elements of $pt(H)$, can be established.

Before we go on some explanatory remarks on FACTS may be in order:

Remark 1: It is the definition of a regular continuous Heyting algebra, which encapsulates the “appropriate properties of our events” that allow us to “define points in terms of events”. The explicit definition of this structure from scratch is rather complicated and would need more several pages. Thus some hints to the literature must suffice. Davey and Priestley (1990) provide a useful introduction to general lattice theory. The basics of the theory of complete Heyting algebras may be found in chapter II of Johnstone (1982), for a rather exhaustive treatment of continuous Heyting algebras the reader may consult the authoritative treatise of Gierz et al. (2003).

Important examples of regular continuous Heyting algebras, which will be treated in some detail in the following sections, are the Heyting algebras OX of open sets of “nice” topological spaces (X, OX) . Again, the

exact definition of “niceness” used here is somewhat involved. Be it sufficient to state that Euclidean spaces belong to the class of nice spaces whose Heyting algebras of open sets are regular continuous Heyting algebras (cf. Gierz et al. 2003). On the other hand, the rational numbers \mathbb{Q} endowed with their standard order do *not* form a continuous Heyting algebra.

Remark 2. In section 3 we give an elementary example that shows that Russell’s construction yields too many ersatz points, i.e., at least some of the constructed points do not correspond to real points. This and other examples were known to mathematicians and logicians such as Hausdorff and Tarski, probably already to Cantor. Thus, Russell could have known that his method was doomed to fail if he had paid attention to the then contemporary mathematics.

Remark 3: The “new methods” alluded to in FACT 3 belong to the realm of mathematics sometimes called “pointless topology”. As a forerunner of this discipline one may consider Stone’s work on the representation of Boolean algebras B by topologically defined subsets of their Stone spaces $St(B)$ (cf. Stone (1936, 1938)). For a brief but complete account of Stone’s representation theorem see Davey and Priestley (1990); for some remarks on the history of pointless topology see Johnstone (1982) and Gierz et al. (2003).

The outline of this paper is as follows: in the next section we discuss the basic properties of Russell’s construction of points. For intuitive reasons, this construction may be dubbed the “onion construction”; mathematically, it is characterized as the construction of maximal filters for appropriate structures. Applying the axiom of choice to an appropriately structured set of events allows us to define ersatz points in the sense of Russell’s programme. In section 3 we consider a very simple set-theoretical model of space and show that it has too many ersatz points. This may be taken as evidence that Russell’s programme is doomed to fail for principal reasons. In section 4 concepts of pointless topology are used to overcome the difficulties of Russell’s original approach. In particular it is shown that the replacement of ordinary filters by “round” filters suffices to eliminate the profusion of ersatz points Russell’s original construction was plagued with.² We conclude with a general assessment of Russell reconstructive programme in section 5.

² For reasons of space the special case of temporal points, i.e. instants, cannot be dealt with in this paper. For temporal points *mutatis mutandis* the same arguments apply as to spatial points. Russell treated the case of instants in *On Order in Time* (Russell 1936).

Let us take the Euclidean plane P as a typical example of a well-behaved topological space and take as the set $E (= E(P))$ of events an appropriate set of well-formed regions of P . For the moment we need no worry about what precisely is meant by “well-formed region”. The reader may think of parts of the plane with “nice” boundaries and without interior crackles and holes, for instances circles, ellipsoids, and similar figures. Intuitively, these figures may be arranged in such a manner that they form an “onion” or a nested system of neighborhoods such that the elements of this system “approximate” a point x of E that lies in the interior of all of them.

The system $N(x)$ of nested neighborhoods of can be taken as a representative of the point x , since at least for nice spaces such as Euclidean ones two different points x and y give rise to two different “onions” $N(x)$ and $N(y)$, respectively, since we may always find a neighborhood of x that does not contain y , and vice versa.

If we could characterize systems like $N(x)$ independently from and without reference to the points x of which they are neighborhood systems we would have met Russell’s challenge of “defining points in terms of events”. In modern terms, Russell’s proposal for achieving this task amounts to something like this. The class of events E is considered as a not just a set with some kind of a mereological or lattice-theoretical structure: given two events a and b , they may overlap, i.e. there may be a region $(a \wedge b)$ such that $(a \wedge b)$ is a part of the regions a and b , and every region c that is part of a and b has $(a \wedge b)$ as part. The concept of overlapping should be structurally well behaved. For instance, the overlapping $(a \wedge b)$ of a and b should be the same as the overlapping $(b \wedge a)$ of b and a etc. In sum, the class of events should be conceived (at least) as a (semi)lattice $E = (E, \wedge, 0)$, 0 being the bottom element of E (cf. Davey and Priestley 1990, Chapter 3, p.58). Then we can as usual define “overlapping” in terms of the lattice-theoretical operation by defining that a and b overlap if and only if $(a \wedge b) \neq 0$.³

After these conceptual preparations we are ready to approach Russell’s proposals of defining ersatz points solely in terms of events:

³ Russell did not traffick with these technicalities but took them for granted.

(2.1) Definition (Russell (1928, p.299)) Let E be the class of events. A set $F \subseteq E$ is called *co-punctual* if and only if every five regions a_1, \dots, a_5 of F overlap:

$$a_1 \wedge \dots \wedge a_5 \neq 0.$$

A *Russell point* is a maximal co-punctual subset F of E , i.e. a subset that cannot be enlarged without ceasing to be co-punctual. ♦

This definition is the very core of Russell's programme of reducing spatio-temporal points to some more respectable entities such as events or regions. Thus, some explanatory remarks may be in order.

The first question that probably comes to mind is whether there is any deeper meaning why co-punctual F are defined via the non-trivial overlapping of *five* regions – why not two, three, or seventeen? Obviously one can define “co-punctuality” with respect to every n , $n \geq 1$. The answer is that Russell wanted to reconstruct the points for the four-dimensional space-time manifold of relativity theory. For some not very clear reasons he believed that for the construction of an n -dimensional space one needed co-punctuality with respect to $(n+1)$ regions. Indeed, he explicitly asserted that for ordinary three-dimensional space one needed co-punctuality with respect to four regions, and for the reconstruction of temporal points (instants) of the one-dimensional time manifold he required co-punctuality with respect to two events (intervals), see Russell (1936).

Secondly, an interesting problem arises with respect to maximal co-punctual subsets of E , i.e. Russell points. How do we know that they exist? Can we construct them in some explicit sense? Russell was well aware that for the construction of maximal co-punctual subsets F of E the axiom of choice or a similar principle was necessary. Points are not for free, rather, one has to rely on a logical (or set-theoretical) principle that is far from trivial. Even the modern constructions of points have to use such a principle.

The details are as follows. Let S be any well behaved space, e.g. Euclidean space. Assume that S has points in the usual sense, i.e., S is as a point set endowed with some further geometrical or topological structure. Defining the set of regions of S as a set of well behaved subsets of S we may then attempt to apply Russell's recipe of (re)constructing the points of S as sets of maximal co-punctual regions. The result turns out to be a failure since there are many more Russell points than real points, i.e., elements

of S . Describing the outcome as “many more ersatz points than real points” is to put it mildly. Actually, the cardinality of ersatz points is the cardinality of the power set of the power set of real points! Thus, Russell's construction is quite off the mark as it is much too prolific in generating ersatz points. The first step to prove this is the following definition:

(2.2) Definition Let E be a lattice. A *Stone point* of E is a subset F of E satisfying the following conditions:

- (1) $0 \notin F \neq \emptyset$.
- (2) If $a, b \in F$, then $a \wedge b \in F$.
- (3) If $a \in F$ and $a \leq b$, then $b \in F$.
- (4) F is maximal with respect to (1)–(3), i.e. if $x \notin F$, there is an $a \in F$ such that $a \wedge x = 0$. ♦

Defining as usual $a \leq b := a \wedge b = a$ one may succinctly characterize a Stone point as a maximal upper subset of E closed under finite intersections. Usually a “Stone point” of E is called *maximal filter* or *ultrafilter* of E .⁴

Filters are quite common mathematical objects considered in many realms of logic, lattice theory, topology and elsewhere. The following elementary lemma shows that for our purposes we may replace the Russell points by the more manageable Stone points:

(2.3) Lemma Let E be a lattice. Then every Stone point of E is a Russell point of E .

Proof: Let F be a Stone point of E . Let a_1, \dots, a_5 be five regions of F . By the very definition of a Stone point $(a_1 \wedge a_2)$ is a region that belongs to F . Hence $((a_1 \wedge a_2) \wedge a_3)$ is an element of F . Iterating this argument, one obtains that the regions a_1, \dots, a_5 are co-punctual in the sense of Russell. In order to show that F is a maximal set of copunctual elements we proceed by reductio. Assume that F is not a maximal co-punctual subset of E . Then there is a maximal co-punctual set G that properly contains F . Moreover, there is a region x in G that is not a region of F . Since F is a maximal Stone point, there is a y in F such that $x \wedge y = 0$. Hence $x \wedge y \wedge y \wedge y \wedge y = 0$. Hence G is not a maximal co-punctual set in the sense of Russell. This is a

⁴ I'd propose to call maximal filters “Stone points” because in the special case of E being a Boolean algebra, the maximal filters of E are just the points of a topological space $St(E)$ which is usually called the Stone space or the Boolean space of E (cf. Davey and Priestley 1990, Chapter 10, p.197).

contradiction. Thus already F is a maximal co-punctual set, i.e. a Russell point. ♦

In the next sections we will prove that a space X has more Stone points than real points (cf. Proposition (3.3)). In other words, the set $St(X)$ of Stone points of X , to be called the Stone space of X , is not isomorphic to X . Roughly, the basic flaw of Russell's construction programme may be diagnosed as the error of confounding the Stone space $St(X)$ with X . Thus we obtain from (2.3) and (3.3):

(2.4). Corollary If X is a space, then X has Russell points that do not correspond to real points of X . In other words, Russell's recipe for constructing ersatz points fails. ♦

In the next few sections we will forget about Russell points and concentrate on the mathematically better behaved Stone points. Before we deal with the technicalities it may be helpful to point out that the neighborhood systems of points of "nice" spaces define Stone points in a natural way. In some more detail, this may be spelt out as follows.⁵ Let (X, OX) be a topological space, i.e. a set X endowed with a topological structure $OX \subseteq PX$. The elements of OX are called the open sets of X . $A \in OX$ with $x \in A$ is called an open neighborhood of x . The system $N(x)$ of all open neighborhoods of x is a filter, i.e. $N(x)$ satisfies the following conditions:

- (1) $\emptyset \notin N(x) \neq \emptyset$.
- (2) $A \in N(x) \ \& \ A \subseteq B \Rightarrow B \in N(x)$.
- (3) $A, B \in N(x) \Rightarrow A \cap B \in N(x)$.

Invoking the axiom of choice it is easily proved that there exists a maximal filter $F(x)$ containing $N(x)$.⁶ For nice topological spaces two different points x and y have neighborhood filters $N(x)$ and $N(y)$ that contain neighborhood $A(x)$ and $A(y)$ of x and y , respectively, such that the intersection $A(x) \cap A(y)$ is empty. Then one can easily prove that x and y define different Stone points $F(x)$ and $F(y)$, i.e. maximal filters that contain $N(x)$ and

⁵ For a succinct presentation of the basic topological concepts used in this paper, the reader may consult the Appendix of Davey and Priestley (1990) or any textbook of topology.

⁶ There is no reason to expect that $F(x)$ is unique. As it seems, Russell was not aware of the analogous fact for sets of co-punctual events.

$N(y)$, respectively, are different. "Nice" spaces in this sense are Euclidean spaces, and more generally, Hausdorff spaces.

In the following section we show that nice spaces X have more Stone points than real points, i.e. $X \neq St(X)$. More precisely, we will show that for a space X every real point x defines a Stone point $F(x)$, but there is a wealth of Stone points that do not correspond to any real points. Actually, Stone points related to real points turn out to be an exception. Since all Stone points are Russell points, this implies that Russell's original construction programme is flawed.

3 A MINIMALIST MODEL OF SPACE

In this section we consider a simple set-theoretical model of space and show that it has too many Stone points, and a fortiori, too many Russell points. In later sections it will be shown that this simple model does indeed reflect the essential features due to which every construction based on Stone or Russell points *must* fail. Moreover, we show how to modify the construction of points such that the profusion of ersatz points is cut down in such a way that there can be established a 1-1 correspondence between modified Stone points and real points.

Let X be a set, and let us regard X as a topological space (X, OX) by endowing it with the discrete topology $OX = PX$. (X, PX) is called a discrete topological space. With respect to this special topological structure just any $Y \subseteq X$ with $x \in Y$ is an open neighborhood of x . Moreover, the system $N(x)$ of all open neighborhoods of x is the set of all subsets of X containing x . This implies that in this case the system $N(x)$ has the following properties:

- (1) $\emptyset \notin N(x) \neq \emptyset$.
- (2) $A \in N(x) \ \& \ A \subseteq B \Rightarrow B \in N(x)$.
- (3) $A, B \in N(x) \Rightarrow A \cap B \in N(x)$.
- (4) $C \notin N(x) \Rightarrow A \cap C = \emptyset$ for some $A \in N(x)$.

Since $\{x\} \in N(x)$ one has $C \in N(x) \Leftrightarrow x \in C$. In other words, for every real point $x \in A$ the neighborhood system $N(x)$ is a Stone point. Moreover two real points x and y are equal iff the neighborhood systems $N(x)$ and $N(y)$ are equal. Hence for (X, PX) the neighborhood systems $N(x)$ are faithful representatives for real points $x \in X$. Since neighborhood systems are

maximal filters on PX , and maximal filters on PX can be characterized without explicit reference to points by (2.2) we seem to have made great progress on our way of defining points as systems of events – at least in the special case of X being a discrete topological space (X, PX) . There is missing only one piece: Although we know that every “real” point $x \in X$ defines a unique Stone point $N(x)$, it might be that there are still other maximal filters that do *not* correspond to any real point x . Russell assumed without argument that this is not the case. As it seems, he took it for granted that all maximal filters on a set X arise as the neighborhood system $N(x)$ of some point x of X . Actually, this assumption is true only for X with finitely many elements. For infinite sets X it is false. For them there are many more abstract neighborhood systems N than real points.

It would take us too long to prove this result in full generality, instead, let us prove that an infinite set X has at least one Stone point that does not correspond to any real point x of X .

(3.1) Proposition (The Finite/Infinite Filter) Let X be a set with infinitely many elements, and define F to be the set of subsets Y of X whose complements consist of finitely many elements:

$$F := \{Y; Y \subseteq X \text{ and } \mathbf{C}F \text{ finite}\}$$

There is a Stone point $N(F)$ that contains F but there is no element $x \in X$ such that $N(F) = N(x)$.

Proof. Clearly F is non-empty since $X \in F$ and $\emptyset \notin F$ since X is infinite. Since the finite union of finite sets is finite, F is closed with respect to finite intersections. Moreover F is upward closed. In other words, F is a filter. Invoking the axiom of choice or a similar principle one infers that there is a maximal filter $N(F)$ containing F . But $N(F)$ cannot come from some principal filter $N(x)$. If this were the case, x would be an element of all elements of $N(F)$, a fortiori it would be an element of all elements of F . But clearly $X - \{x\}$ is an element of F that does not contain x . Hence there is at least one abstract neighborhood system that does not correspond to a real point $x \in X$. ♦

One might hope that the maximal filter $N(F)$ is somehow an exception and that “usually” a Stone point of X comes from some real point of X . This hope is shattered by the following classical result due to Hausdorff and Tarski:

(3.2) Proposition Let X be an infinite set with cardinality $\langle X \rangle$. Then the set of Stone points $St(X)$ of X has the cardinality of the power set of the power set of X , i.e. $\langle St(X) \rangle = \langle PPX \rangle$. In other words, there are many more Stone points than real points.

Proof. Bell and Slomson (2006, p.108, Theorem 1.5). ♦

Remark. The proof of (3.2) is somewhat complicated but elementary in the sense that it can be carried out using only the concepts that are already available to us. Its essential ingredient is, of course, the axiom of choice. Without it, or some similar principle, one cannot show the existence of even one maximal filter. This was known already to Russell (cf. Russell (1936)).

One may object that (3.2) can hardly count as a refutation of a Russellian programme of constructing points from events since the topological structure PX of X is just too meager as to capture the relevant features of the topological relations between “points” and “neighborhoods” that Russell wanted to put to use. Prima facie, this suspicion is not unreasonable; nevertheless it turns out to be wrong. More precisely it can be shown that for every reasonable space X (in particular for the Euclidean space E) and every reasonable set of events of X an analogous theorem to (3.2) holds according to which the cardinality of Stone points is much larger than the cardinality of real points of X :

(3.3) Proposition (Theorem of Balcar-Franěk) Let B be an infinite complete Boolean algebra. Then the cardinality of the set of maximal filters on B is the cardinality of the power set PB of B .

Proof. Koppelberg (1989, Theorem 13.6, p.197). ♦

Every maximal filter on O^*X gives rise to at least one maximal filter on OX , since the inclusion $O^*X \xrightarrow{i} OX$ is a monomorphism that preserves overlapping, i.e. $i(x \wedge y) = i(x) \wedge i(y)$. This implies that there are at least as many maximal filters on OX as there are maximal filters on O^*X . For X a nice space, the cardinality of O^*X is at least the cardinality of X . Hence, Russell’s construction yields too many points not just for the discrete topological structure (X, PX) but for every nice topological space (X, OX) . In other words, the trivial topological structure of minimalist set theoretical model of space cannot be blamed for the failure of Russell’s programme. Rather, as will be shown in the next section, the culprit for the

profusion of undesired ersatz points is the too primitive “non-topological” notion of a filter employed.

4 TOPOLOGY TO THE RESCUE

Let us take stock what we have achieved so far, and what remains to be done. Given a topological space (X, OX) with a system of regions OX we did the first step to realize Russell’s programme, namely, improving upon Russell’s own account of ersatz points as maximal copunctual sets of regions, we defined ersatz points as maximal filters of X . In a sense, this works quite well – for every real point $x \in X$ we can construct an ersatz point. In the case of $\text{OX} = \text{PX}$ this ersatz point is even unique. The only flaw in this construction is that it yields too many ersatz points.

In this situation it is natural to attempt to restrict somehow the profusion of ersatz points by singling out a small class of particularly “nice” ersatz points. This is indeed possible, if we put to use the topological structure of the space X . It is here, where we encounter something new that has no counterpart in Russell’s original attempt to “define points in terms of events”.

In order to use the topological structure of a space as a tool for cutting down the profusion of ersatz points we have to delve somewhat deeper into the details of topology. Recall that given a topological space (X, OX) the closed subsets of X are defined as the set-theoretical complements of the open sets. Every subset Y of X there is the smallest closed subset $\text{cl}(Y)$ containing Y , where $\text{cl}(Y)$ is defined as the intersection of all closed subsets containing Y . This defines an operator $\text{PX} \rightarrow \text{PX}$ mapping each subset Y to its closed hull $\text{cl}(Y)$. Complementarily the open kernel $\text{int}(Y)$ of a set Y is defined by $\text{int}(Y) := \text{Ccl}(CY)$, C being the set-theoretical complement of Y in X . A set Z is called regular open if and only if $Z = \text{int}(\text{cl}(Z))$. If Y is any subset of X , an open covering of Y is a family U_i of open subsets of X such that $Y \subseteq \cup U_i$. The covering is finite if and only if it consists of finitely many elements U_i . A subset Y is compact if and only if every open covering contains a finite subcovering. Now we are ready to define the crucial concept of interior parthood:

(4.1) Definition Let a, b open sets of the topological (X, OX) . The region a is an interior part of the region b , $a \ll b$, if and only if the closure $\text{cl}(a)$ of a is contained in b , and $\text{cl}(a)$ is compact:

$$a \ll b := \text{cl}(a) \subseteq b \text{ and } \text{cl}(a) \text{ is compact. } \blacklozenge$$

Intuitively, the relation $a \ll b$ is to convey the meaning that the region a plus its boundary $\text{bd}(a)$ is fully contained in b , and moreover, that a is somehow “small”. Compactness may indeed be interpreted as a topological version of “smallness” or even “finiteness” as the following topological analogue of the finite/infinite filter (see Proposition (3.1)) shows:

(4.2) Example (A topological version of the Finite/Infinite Filter)

Let (X, OX) be a nice non-compact space, for instance the real line \mathbb{R} or an Euclidean space. Define the filter F as a maximal filter that contains all sets of the form $X - K$, K compact. Then it is easily seen that F does not contain the open neighborhood filter $N(x)$ of any $x \in X$: if x and y are two different points of X , since x has an open neighborhood $U(x)$ such that $\text{cl}(U(x))$ is compact and does not contain y . This proves that there is a Stone point of (X, OX) that does not correspond to any real point $x \in X$. In other words, Russell’s construction yields too many points. \blacklozenge

The concept of interior parthood can be used to single out a special class of filters as follows:

(4.3) Definition Let (X, OX) be a topological space with interior parthood relation \ll .

(a) A subset $F \subseteq \text{OX}$ is a round filter (with respect to \ll) if and only if F is a filter and satisfies the further condition that for all $b \in F$ there is an $a \in F$ with $a \ll b$.⁷

(b) A maximal round filter F is called a (round) ersatz point. \blacklozenge

As is easily shown by the axiom of choice, round ersatz points exist. Moreover, under some mild conditions on the topology of X the filters $N(x)$ of open neighborhoods of real points x are round filters. Indeed, the class of

⁷ For a detailed discussion of “round filters” see Gierz and Keimel (1981) and Gierz et al. (2003).

maximal round filters is the class of ersatz points we were looking for. Let us first deal with the special case (X, PX) :

(4.4) Proposition Let (X, PX) be a discrete topological space. Then the real points of X are in a 1-1-correspondence with the maximal round filters of X .

Proof. First let us prove that for (X, PX) $a \ll b$ if and only if a is a finite subset of b . Assume that $a \ll b$. By definition this means that $\text{cl}(a)$ is a compact subset of b . But $\text{cl}(a) = a$, since the topology of X is trivial; using this fact once again, we observe that every singleton $\{x\}$ is open. Hence, a set is compact if and only if it has only finitely many elements. By definition a round maximal filter F must contain a finite set. But then it is easily seen that in order to be maximal F must even contain a singleton $\{x\}$. Hence it is the principal filter $F(x)$ generated by x . The other direction is trivial. ♦

In other words, in the case of a discrete topological space (X, PX) the topologically defined round maximal filters correspond in a 1-1-fashion to the real points of X .

This result not only holds for discrete topological spaces (X, PX) , but for a large class of “nice” topological space (X, OX) . The task of defining exactly what is meant by “nice”, would lead us to far away.⁸ Be it sufficient to state that the class of nice spaces comprises the class of metrical spaces, in particular the Euclidean spaces:

(4.5) Proposition Let (X, OX) be a nice topological space with interior parthood relation \ll . Then there is a 1-1-correspondence between the real points $x \in X$ and the round ersatz points of X , i.e., the maximal \ll -round filters on OX .

Proof (Sketch). The proof of this proposition naturally falls into two parts. First, one has to show that each real point gives rise to a uniquely defined maximal round filter, secondly one has to show that each maximal round filter comes from a uniquely defined real point. Let x be a real point of X . Then we can consider the filter $R(x)$ of regular open neighborhoods of x . Due to niceness, $R(x)$ is easily shown to be a round filter with respect to the interior parthood relation \ll . By the axiom of choice there is a maximal

⁸ For the cognoscenti: locally compact regular Hausdorff spaces will do as “nice” spaces. Russell seems to have overlooked this completely.

round filter $N(x)$ containing x . Again by niceness (Hausdorff property) for two different points x and y maximal round filters $N(x)$ and $N(y)$ must be different. Hence, if X is nice, every real point gives rise to (at least) one ersatz point such that the ersatz points are different for different points.

It remains to show that every maximal round filter corresponds exactly to one real point. Assume that N is a maximal round filter. Consider the intersection $\bigcap \text{cl}(Y_i)$ of the closed hulls $\text{cl}(Y_i)$ of all elements of N . Since N is round, we may assume that X is compact without loss of generality. The set $\bigcap \text{cl}(Y_i)$ is not empty, since otherwise there would be a finite family of sets $\text{cl}(Y_i)$ with empty intersection. This is impossible, since N is a filter. Choose a point $x \in \bigcap \text{cl}(Y_i)$. Since for every Y there is a Y' with $\text{cl}(Y') \subseteq Y$ we obtain $x \in Y$ for every element of N , i.e. x is an element of every element of the filter N . In other words, N is contained in the neighborhood filter of x . In other words, the neighborhood filter $N(x)$ of x is the only maximal round filter containing x . This establishes a 1-1-correspondence between real points and maximal round filters as ersatz points. ♦

This is an important step on the path of realizing Russell’s programme of defining “points by events”. It should be noted, however, that we yet we have not accomplished our final goal. Up to now, we have assumed that the events we employ for the construction of ersatz points are point sets, namely, the open sets of a topological structure OX defined on the set X . In other words, in the definition of ersatz points as maximal round filters the real points of X still play an essential role, or so it seems. Actually this is not the case. But it needs some extra effort to show this.

Roughly, it works like this: one starts from a topological space (X, OX) endowed with an interior parthood relation \ll and constructed the ersatz points as maximal round filters. To get rid of the underlying point structure, one forgets about the point set X and retaining only the topological structure OX , conceived of not as a set of open sets, but as an abstract lattice. As is well known, the lattice OX is a complete Heyting algebra. For topologically nice spaces the lattice OX is even a regular continuous Heyting algebra (cf. Johnstone (1982), Gierz et al. (2003)). The point is that these structures can be defined without reference to points, i.e. the elements of such algebras need not be conceived of as point sets. Moreover, every regular continuous Heyting algebra H comes along with a binary relation \ll (the way below relation) that may be interpreted as an interior parthood relation. Then one can define the set $pt(H)$ of maximal round filters of H as ersatz points of H . Next one shows that the set $pt(H)$ can be endowed with a topology $O(pt(H))$ such that $(pt(H), O(pt(H)))$ is a topologi-

cal space. Finally it is proved that $O(pt(H))$ and H are naturally isomorphic as Heyting algebras. Thus one has obtained a *stable* (see section 1) method of defining points in terms of events: starting with the algebra H of events, one constructs the topological space $(pt(H), O(pt(H)))$, taking $O(pt(H))$ as a system of events in its own right one constructs a set $pt(O(pt(H)))$ of points of second order, for which one can construct neighborhoods $O(pt(O(pt(H))))$ etc. Fortunately these iterations yield nothing new, due to the isomorphism between H and $O(pt(H))$ (see FACT 1).

Conceiving H as the class of events this construction may be considered as a mathematically rigorous reconstruction of Russell's programme of "defining points in terms of events" that he envisaged some 80 years ago in *The Analysis of Matter* (Russell 1927) or even earlier in *Our Knowledge of the External World* (Russell 1914). Conceptually, this construction is not too difficult to understand – it amounts to an enhanced onion construction discussed in section 2, but technically it is somewhat involved. Hence, the details cannot be given here, see Gierz et al. (2002), Johnstone (1982), Mormann (1997).

Russell never imagined the technical complexity of this endeavor, since he never cared about the details of the relational structure of the set E of events. He simply assumed that the class E of events was endowed with some binary relation of overlapping whose structural properties he never specified. In contrast, the definition of a continuous Heyting algebra, which provides the true basis for a rigorous construction of points, is a non-trivial task.

Finally, it should be noted that our reconstruction only accomplishes a part of Russell's programme: we only defined the topological structure "in terms of events" while Russell planned to reconstruct not only that structure but also the geometrical and differential structure of the space-time manifold as well.

5 CONCLUSION

We are left with a mixed assessment of Russell's programme of defining points in terms of regions. On the one hand, it is clear that Russell did not have the technical skills to realize this programme in a mathematically satisfying and rigorous manner. With respect to higher dimensional spaces he never got beyond some informal sketches that might be intuitively appealing but that did not hit upon the conceptual essence of the matter. His

attempted construction of instants, i.e. temporal points, scores somewhat better, but this is a special case that depends on the linear order of time, and therefore cannot be applied to the case of general topological spaces. On the other hand, Russell had a surprisingly clear vision of the general task of what today is called "pointless topology".

It was the American mathematician M.H. Stone, who laid the foundations for this discipline in the thirties. Stone's famous representation theorem of Boolean algebras may be considered as the first successful example of constructing points for something (Boolean algebras) that at first view exhibited no spatial features at all (cf. Stone (1936, 1938)). According to the experts Stone's theorem is one of the most important theorems of 20th century mathematics that has influenced an ever-growing variety of mathematical disciplines (cf. Johnstone 1982). For an informal account of Stone's mathematical achievements, see Piazza (1995). Unfortunately, the spaces that Stone constructed as representations for Boolean algebras are quite remote from any intuitive interpretation. In particular, Stone's spaces were quite different from Euclidean and other familiar spaces. Hence, his work, although highly appreciated by mathematicians and logicians (for instance Tarski), remained virtually unknown to philosophers during the following decades.⁹ In particular, Russell never took notice of Stone's work, although this would have helped him a lot in the task of coming to terms with the task of "defining points in terms of events". In philosophy, Russell's topological sketches were received with respect. But there were not many attempts to develop it further. Consequently, up to how, topology – to say nothing of pointless topology – can hardly be said to belong to a philosopher's toolkit even when he is accustomed to use formal methods. If Russell's reconstructive programme, in particular his attempt of developing pointless topology, had been taken up more seriously by his fellow philosophers, topology might have played a major role – to the benefit of philosophical disciplines such as metaphysics, epistemology and ontology. In sum, then, I'd contend that Russell has had a point with his early programme of pointless topology – despite its mathematical flaws.

⁹ The collection *Topology for Philosophers* (Smith and Zelaniec (eds.) 1996) still provides ample evidence for this claim: Stone and his work is not mentioned even once.

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FROM DESCRIPTIVE FUNCTIONS TO SETS OF ORDERED PAIRS¹

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In this paper I respond to one of the familiar objections to the project in *Principia Mathematica* of reducing mathematics to logic. In particular, I want to refute the notion that *PM* is inferior to a non-logical axiomatic theory such as Zermelo-Fraenkel set theory as a foundation for mathematics because it relies on the obscure notion of “propositional function” in contrast with set theory which provides a simple account of functions as sets of ordered pairs, themselves reduced to certain other sets. Below I will present the theory of “descriptive” functions presented in *PM* and suggest that it was Russell’s view that the account of descriptive functions provides a logicist account which is superior to both the Frege’s account of functions, and the notion of functions as sets of sets. There was a deliberate choice made in *PM* not to found the theory of functions in set theory, and not to identify functions with sets of ordered pairs. In tracing the history of this topic, I will show that current treatments of functions in logic are more sensitive to these issues than one might at first think. Below I will first review the account of “descriptive functions” in *PM*, and then compare this with Frege’s analysis of functions, then show how functions are treated in contemporary logic. Next, I will describe Norbert Wiener’s reduction of relations to sets and then review the evidence that Russell proposed his own account deliberately as an improvement over Frege’s, and finally conclude with some discussion of what this reveals about propositional functions.

¹ An earlier version of this paper was presented at the 31st International Ludwig Wittgenstein Symposium. Thanks to Allen Hazen, James Levine, Paul Oppenheimer and Ed Zalta for discussion of this topic and George Bealer for comments at the conference. A companion to this paper, “Russell and Frege on the Logic of Functions” was presented at the 4th International Symposium for Cognition, Logic and Communication: 200 Years of Analytic Philosophy, at the University of Latvia in Riga, August 29, 2008, and will appear in the 4th issue of the *Baltic International Yearbook for Cognition, Logic and Communication*.