You Can't Go Home Again – or Can You? 'Replication' Indeterminacy and 'Location' Incommensurability in Three Biological Re-Surveys

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Abstract

Reproducing empirical results and repeating experimental processes is fundamental to science, but is of grave concern to scientists. Revisiting the same location is necessary for tracking biological processes, yet I argue that 'location' and 'replication' contain a basic ambiguity. The analysis of the practical meanings of 'replication' and 'location' will strip of incommensurability from its common conflation with empirical equivalence, underdetermination and indeterminacy of reference. In particular, I argue that three biodiversity re-surveys, conducted by the research institutions of Harvard, Berkeley, and Hamaarag, all reveal *incommensurability* without *indeterminacy* in the smallest spatial scale, and i*ndeterminacy* without *incommensurability* in higher scales.

Key words: replication, location, biodiversity, incommensurability, indeterminacy and empirical equivalence.

Acknowledgment: I deeply thank the people who's ideas and personal example inspired this work – Yemima Ben Menahem, Elihu Gerson and James Griesemer – and the organization that supported it: the Israeli Science Foundation (ISF grant no. 960/12).

1) Replication

Replication - "the set of technologies which transforms what counts as belief into what counts as knowledge" (Shapin and Schaffer 1985, 225), is fundamental to science. Repeatability of a scientific experiment and reproducibility of its results is a common scientific practice ever since Boyle (1660/1999)[1] and Redi (1668/1909), and is widely accepted that one cannot fully explain a biological process nor empirically confirm a generalization without it (Shavit and Griesemer 2009; Shavit 2013).

Philosophers of science were traditionally more skeptical of the possibility and relevance of replication. Problems concerning replication were initially presented as epistemic absurdities, from Wittgenstein's 1953 rule-following paradox: "No course of action could be determined by a rule because every course of action could be made out to accord with the rule" (Ibid. I: 201); to Popper's note of the relativity of similarly, "But if repetition is thus based upon similarity...[it] means that anything can be made to a repetition of anything, as long as we adopt the appropriate point of view" (Popper 1959, 422), to Collins's 1985/1992 experimental regress: "The problem is that, since experimentation is a skillful practice, it can never be clear whether a second experiment was conducted sufficiently enough to be considered as check on the results of a first. Some further test is needed to test the quality of the experiment - and so forth (Ibid. 2). Hacking (1983) concludes that the concern with replication is a philosophical pseudo-problem

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[1] The challenge of replication may date back to Heraclitus's metaphor of stepping into the same river twice (Hearclitus DK22B91, DK22B12 translation: Robinson 1987), yet such straightforward comparisons are clearly problematic (Hadot, 1995/2002.)

"…because, roughly speaking, no one ever repeats an experiment (Ibid. 231)".

Given this long tradition of skepticism, it is apparently surprising to learn about the scientists' widespread and genuine concern, or what *Nature* editors referred to as "the plague of non-reproducibility in science" (Hayden 2013): the fact, that widely-published research in many scientific fields is never replicated, and may not even be replicable nor become generalizable (in "Nature" see: Bissel 2013; Baker 2012; Gun 2014; Russell 2013; Sanderson 2012). The bulk of attention is focused on biomedical research, but owing to the overwhelming variability in scope, scale, data structure, and semantics for studying the dynamics of our environments, the problem of reliable replication is clearly applicable to ecological and biodiversity research (Michener and Jones 2011), as well as agriculture, molecular biology, bioinformatics and other biological disciplines (Shavit and Ellison (eds.) 2014 accepted for publication). Furthermore, in biological research, the spatial and temporal contexts – the *location* of a genome, cell, organism, population, habitat or ecosystem – as well as the researcher's questions, methods, and available means of funding are constantly changing. Since biological research is contingent on the historical and social context in which it is being conducted, biologists are confronted with this key *challenge*: how do we both conceptualize and implement (operationalize) replication?

The term 'replication' refers to wide-ranging practices: a) *repeating* the same exploration process (sampling, experimentation, and so on), and obtaining comparable results; b) *reproducing* the same result from the same analysis on the resultant data without a new exploration process (Cassey and Blackburn 2006); and c) *retrieving* the individual entity, a physical item (specimen, photo, blood tissue etc.) or a data record (stored in a field-journal, excel spreadsheet, SQL database and so forth) for aggregating, comparing, and interoperating the data.[2] In the section bellow, I will make the case for an unavoidable ambiguity that will prevent the *repeatability* of a biodiversity survey at the smallest spatial scale. The third section explains why that much ambiguity does not threaten the *reproducibility* of biodiversity data in higher spatial scales, as long as scientists are mindful of the serious problem of repeatability and therefore record the wider context and the history of their work, as they make this context easily and automatically *retrievable*.

2) Location

Ever since biodiversity (or "scientific natural history") became engulfed in a range of scientific disciplines (Kohler 2006, 2012; Strasser 2008), revisiting the same location was necessary for the scientific study of ecological systems sensu lato (Latour 1999 Ch. 2). Any explanation in ecology, biogeography, or biodiversity requires at the minimum, an identified location, a description of the distribution patterns of a population or species, and a comparison of location patterns for one or more spatial scales. Variables that correspond to changes in pattern, such as the location's average temperature, may therefore point to the process or processes that caused such a change in the distribution of organisms and groups of organisms (populations, species etc.). In response to a global climatic change (Lloyd 2010) and a global crisis of species' extinction (Willson 1992, Ch.12), the biological

[2] "Interoperability is the ability of two or more systems or components to exchange information and to use the exchanged information." IEEE (Institute of Electrical and Electronics Engineers) 1990, 42.

community was intensely engaged in meticulously tracing a species' location back to its geographical position (Tingley 2009), as they made sure that their information will be kept available and interoperable for others or for individual use in the future (Bowker 2005; Ellison et. al 2006).

The inherent vagueness of 'location' is discussed in depth, although in very different contexts, in the philosophy of quantum physics (Barad 2007), in Science and Technology Study of maps (Black 1997; Gugerli 1998) and in eco-feminist studies of the politics of inscribing places (Shiva 2000; Code 2006). However, a study of the various non-metaphorical meanings of 'location' on multiple scales is relatively new to the philosophy of biology (Shavit and Griesemer 2009, 2011ab).

In order to clarify the concepts of 'location' and 'replication', in addition to literary analysis, three case studies involved a philosopher, who for at least three years participated in fieldwork, lab meetings, and workshops. The case studies involved the research institutions of Harvard Forest, Harvard University, the Museum of Vertebrate Zoology (MVZ), Berkeley and Hamaarag, and Israel's Academy of Sciences – which have conducted rigorous repeated surveys to designated locations across New England, California, and Israel respectably. The concepts, working protocols, and conclusions of these case studies set national and international standards in biodiversity research (Shavit 2013); hence the analysis of their use of 'location' and 'repeated sample' and their debates is expected to be highly relevant for science and the philosophy of science alike.

The problem is that two concepts of space – exogenous and interactionist – are each committed to different epistemic values and standards of replication, and are both necessary for a rigorous repetition of a survey to the same location. An "exogenous" concept of space assumes that organisms' impact their environment - through their physiology, metabolism, behavior, or sheer existence - can be safely ignored for successfully predicting their distribution (Hutchinson 1978, 159-60; Guisan and Thuiller 2005). An alternative "interactionist" concept of space raises the assumption that organisms and their environments are mutually co-determined (Levins and Lewontin 1985, 1-2).[3]

Adopting a specific concept of space signifies a commitment; an actual expenditure of resources (Gerson 1998) to specific constitutive and contextual values, cognitive and social constrains (Longino 2004), and to generatively entrenched (Wimsatt 2007, Ch. 7) work procedures for coordinating the scientific work (Gerson 2007). An exogenous concept of space is committed to revealing general distribution patterns, hence values *representative* data. On the other hand, an interactionist concept of space presumes that one cannot typically ignore organism-environmental interactions, as sometimes they make a relevant casual difference in a species' location, hence values *comprehensive* data on that particular location and species.

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[3] Other philosophical traditions that explore the codetermination of organism and environment include the developmental systems theory (Oyama 1985/2000 ;Griffiths and Gray 1994), the scaffolding perspective (Griesemer 2014) and Sterelny's (2001) environmental engineering approach. The biological literature an interactionist concept of space reveals in niche construction (Odling-Smee et al. 2003), foundational-species (Ellison et. al 2010) and eco-engineer (Jones et al. 2007) models.

Given the goal of representativeness, an exogenous partition of space strives to locate a measuring device (e.g. climatic chamber, trap, camera, etc.) on a preselected random point that defines the longitude, latitude and angle of a regular shape (e.g. rectangle, hexagon, transact line, etc.) and deliberately attempts to ignore any hypothetical prior knowledge on the historical and biological context of the species, location and the studied field. On the other hand, an interactionist partition of space seeks to set that exact device in an irregular polygon to form according to a preselected, non-random environmental stratification (e.g. microhabitats, patch-type, participation gradient etc.) hypothesized to be relevant for understanding the dynamics of a particular biological system. The scientists in all three cases, who jointly wrote the research grant and/or agreed on the sampling method only days before venturing outdoors, were surprised to learn that these practices became *mutually exclusive*. It raises the question: what to do first? An exogenous protocol for identifying a location requires to randomly[4] preselect longitude, latitude, depth/elevation and an angle for an individual's measuring device, and only after its point-location was established and entered for recording its microhabitat surroundings. An interactionist protocol requires the opposite: to firstly identify outdoors the location of a preselected microhabitat suspected of being casually relevant to the species and/or the environment, then set up the measuring device within/outside of the micro-habitat, and only then record its lat./long. coordinates.

Since both concepts of space are necessary for rigorous biodiversity surveys, each

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[4] Most sampling is haphazard, uniform or hierarchical rather than purely randomized (Shrader-Frechette and McCoy 1993).

concept however binds the researcher to different work practices for maintaining its standard, and since one cannot utilize both procedures for the same set of location data collected on the same spatial scale, 'location' ambiguity is inevitably created (Shavit and Griesemer 2009). Furthermore, when performing an individual measurement in the smallest spatial scale of that study, a) the measurement device had to be typically relocated to different longitudinal and latitudinal coordinates when positioned according to different concepts of space (even in the uncommon incidents when the device maintained its lat./long. coordinates, its location was empirically different as its description as a 'location');[5] and b) a barrier for communication was clear, translation was lost, and decisions were based upon hierarchy[6] or complete separation of the data[7]. On a later

[5] For example, there were two different maps of the Harvard Forest – with and without the location of each tree – which were deliberately kept separate. Choosing a location was made by randomly selecting a block on the blank map, yet when positioning a trap in the field, one repeatedly had to change its position because of the trees.

[6] At the MVZ resurvey, the lead researcher in the field acknowledged the dissatisfaction of his colleague from his interactionist space. Observation on August 25, 2007. In the Harvard Forest, the lead researcher decided on the locations beforehand and the traps were constantly maintained - interview from May 27, 2010. In that sense, there were no independent revisits so it is unclear if there was replication or one very long survey.

[7] The same applied to the Israeli resurveys: observation on May 16, 2005, June 6-7 2005 and September 3, 2008, interviews on April 23, 2009 and July 6, 2009. At Harvard Forest, observations and interviews conducted on May 26-28, 2010; June 6-8, 2012, July 30, 2012.

reflection, the researchers did not say that the work procedures used by their colleagues required more time or effort[8] or that the statements delivered by their collaborators were false, but rather: "it did not make any sense"[9], or "he is smart, I simply could not understand why he was so stubborn on this issue"[10], and often they only smiled gently and said: "I'm sorry, I could not do it the way they [or: he] wanted it".[11]

This clear-cut empirical gap, however, within all these biodiversity studies, do not lead to any disagreements on the overall answer to the question on species location and species distribution, since that answer was provided by aggregating results across higher spatial scales – that is, the plot/s or transact/s that encompass multiple individual measurements – and it was easily agreed that there are incompatible ways to validate/select and analyze that aggregated data. Acknowledging the barrier at the individual trap made

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[8] Although one can interpret what the MVZ scientist said: "it would have been a total waste of time" (August 25, 2007) as a strictly practical or heuristic criticism, I understood it as a criticism on meaning, a precursor to the follow-up sentence: "it just made no practical sense!" (Ibid.)

[9] Interview with MVZ scientist March 23, 2007.

[10] Interview with Israeli scientists on April 23, 2009.

[11] Interview with Israeli scientists on July 6, 2009, February 9, 2010, and MVZ scientists on March 23, 2007 and August 25, 2007. For an exact citation: only one of the two Israelis used the word "sorry" and both MVZ scientists said "he" rather than "they".

scientist frequently alternate between spatial scales as “the relevant smallest scale”.[12] They juxtaposed different concepts of space rather than seek a single concept for all levels (Shavit and Greisemer 2009), which facilitated the emergence of a productive scientific discourse (Shavit 2013;[13] Shavit and Ellison 2014, accepted for publication) and for different models to be recognized as useful alternatives (Shavit and Griesemer 2011b).

The philosophical literature on the concepts of incommensurability (Kuhn 1962; Feyerabend 1962), underdetermination (Duhem 1969; Quine 1953) and indeterminacy of translation (Quine 1960, 1990) seems especially relevant in this case. For both incommensurability and indeterminacy of translation "the paradoxical situation stems from meaning variance – the same terms have different meanings in the seemingly incompatible theories" (Ben Menahem 2006, 11), yet only "incommensurability implies that from the perspective of one paradigm (theory), the alternative is not simply false, but makes no sense at all" (Ibid). Listening to biologists debate, frequently surveying the same location

[12] The relevant smallest spatial scale for the theoretical MVZ ecologist, was the average of a transact line with 50 traps, while for the collector, it was the individual trap on that line (September 4, 2006); the smallest relevant scale for the Hamaarag was a single trap for the hierarchical sampling and a patch-type with three such traps for the landscape sampling (February 7, 2009) and at Harvard Forest, the smallest relevant scale was the experimental block with multiple traps (June 8, 2012).

[13] During a follow up symposiums on April 18, 2013 in Jerusalem (Israel), and on August 8, 2014 in Minneapolis (Minnesota), museum collectors, experimental ecologists and bioinformatics discussed their mutual problems of replication.

creates the impression that this is indeed a clear case of incommensurability.

In the next section, I will employ these concepts for describing a basic problem of replication in a manner that makes the scientists' disagreement more sensible than bizarre, which is presumably a better description.[14] In addition, taking note of the routine details of the scientific practice would clarify a common philosophical conflation between incommensurability and empirical equivalence (Ben Menahem 1990, 2006) and should therefore assist in avoiding it. That is, philosophical involvement in the routine scientific work not only helps to better describe and understand science – the standard role for the philosophy *of* science – but may also illustrate the benefits of philosophy *for* science (Griesemer 2011), at least for some scientists and philosophers of science.

3) Indeterminacy and Incommensurability

Philosophical discourse is replete with conflation of 'incommensurability' with 'empirical equivalence' (Ben Menahem, 1990). Given the time and space constraints, I will not address the longstanding controversy over 'incommensurability', the more recent debates over its history (Agassi 2002; Oberheim 2005), or its compatibility with scientific realism or progress (Demir 2008; Davis 2013).

Instead, I will rely on Ben Menahem's (1990, 2006) successful disconnection of a particular conflation regarding 'incommensurability': its association with empirical equivalence between semantically non-equivalent theories, and, as a result, the conflation of 'incommensurability' with 'indeterminacy of translation' and the common phrase "no fact of the matter". The blame could be placed on Kuhn's 1962/2005 explicit claim that

[14] To rationalize these assumptions, see Quine's 1960 and Davidson's 1984 "Principle of charity."

paradigms are incommensurable – i.e. not inter-translatable (Kuhn 1990) – and are *therefore* equivalent in the sense that there is “no fact of the matter” as to which paradigm to adopt (Ibid.194). However, as Ben Menahem (2006) had demonstrated, this conclusion does not follow, nor does it conform to other well-known examples of equivalence (for example Poincaré's argument for the empirical equivalence of different geometries (Ibid. Ch. 2). Briefly stated, incommensurability and indeterminacy are *not* closely related.

Then what is ‘indeterminacy of translation’? "The thesis is then this: manuals for translating one language into another can be set up in divergent ways, all compatible with the totality of speech dispositions, yet incompatible with one another” (Quine 2004, 120). There is *no barrier* of communication. However, due to the lack of logical inference from observational to theoretical sentences – i.e. the underdetermination of theories – very different sentences can fit the same observation sentence rather than a one-to-one relationship between theory and data. That is, the ‘meaning’ of the data is not a determined entity that is somehow “captured in our minds” and is independent from its translation.

In our case studies, a “repeatable survey to the same location” – i.e. the practical meaning in terms of a detailed protocol in recording the location of our measurement – was constantly translated. Such explicit discussions between adherents of the different concepts of ‘location’ – prioritizing different practices at different spatial scales – occurred when theoretical considerations of diverge statistical packages, based on drawing aggregated results from higher spatial scales, came to the forefront. Although the exogenous and interactionist concepts of space were evaluated differently by various researchers and cultural-research bodies, and unlike the breakdown of communication outdoors at the single trap scale, in all of the three cases at the lab, researchers could agree on a manual of translating this concept into routine practices to ensure “valid replication” and “high quality data”.

Quine distinguishes the indeterminacy of translation, which is manifested when different (and incompatible) sentences correlate to the same empirical data from the indeterminacy of reference (what he terms "ontological relativity"). A reference is indeterminate when the terms of the *same* sentence (or theory) could be correlated with the world in different ways (Quine, 1990). In this case, different empirical content may fit the same theatrical sentence, and there is no fact of the matter. In all of our case studies, such indeterminacy of reference have occurred, and researchers could easily agree on the truth value of sentences describing the survey results, as they were alternating between their incompatible interpretations. For example, researchers agreed on the number of organisms and species detected on a transact line, as they were alternating between models that hold incompatible assumptions on the causes of species detection on that transact. To test if a new survey of species' occupancy repeats the old survey well enough, one also has to model the variance in detection. Even if thirty *Peromyscus maniculatus* (deer mouse) were actually taken from Yosemite Valley in 2013 and 1913 - whether or not this truthful sentence implies that the deer mouse population did not change after spending a century in Yosemite, depends on the modeling of the variance of the collectors’ detection efforts, method era, or other parameters. Different environments – where the deer mouse population grows, declines, or unchanged– can correlate the same result, and researchers maintained their skepticism on the ontological interpretation of their models.

Such indeterminacy of reference is differentiated from indeterminacy of translation, as the former is involved with interpreting model results and the latter with outlining a protocol, yet they both relate to validation of survey repeatability and both are clearly different from the incommensurability of ‘location’ mentioned earlier.

4) Conclusion

In this article, I argued for a closer look at the seemingly mundane concepts of replication and location, by unfolding their divergent meanings, conceptual interties and impact on longstanding confusions in the philosophy of science. On that note, the common conflation between ‘incommensurability’ and ‘empirical equivalence’, ‘indeterminacy of translation’, ‘indeterminacy of reference’, ‘incommensurability’, and ‘indeterminacy of reference’, were easily and forthrightly avoided when taking note of the very different behaviors and procedures biologists use in the context of their work when re-surveying the same location. To clarify them and perhaps other controversial concepts, involvement in the scientific work seem to alleviate philosophical confusion. Observing the manner in which biologists use the terms ‘location’ and ‘replication’ revealed new distinctions on two different concepts of space – exogenous and interactionist – which adhere to different working standards without a common measurement, and to three different senses of replication – repeatability, reproducibility and retrieval – used differently at various stages of their work. Observing the scientists enabled the philosopher to raise new questions, find new conceptual distinctions and problematize the obvious. The benefits of this approach should not surprise us. After all, it has already been said that: " ‘To give a new concept’ can only mean to introduce a new deployment of a concept, a new practice" (Wittgenstein, 1978, 432). The aim of such a dialog between a practically involved philosopher and reflective scientists is not to transform either of which, but to build disciplinary bridges while closely minding the gaps between them.

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