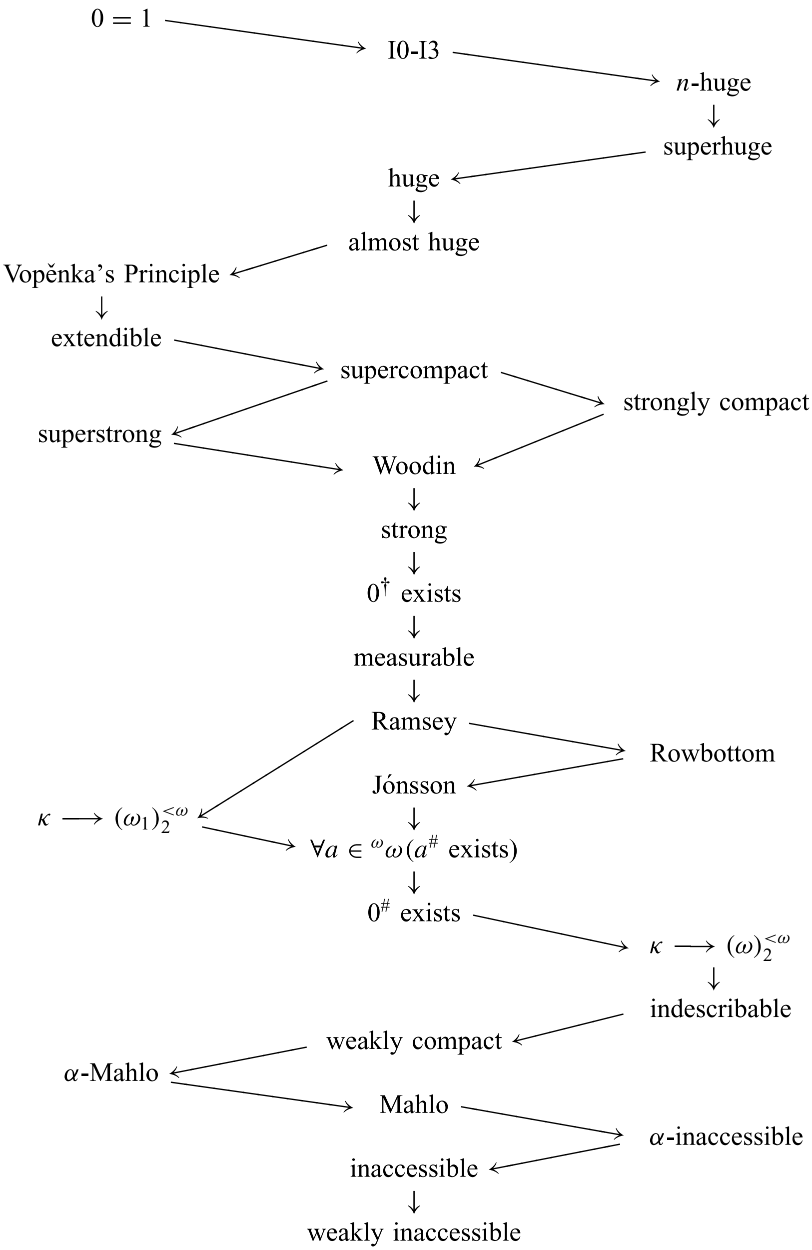
Chart of Cardinals

The arrows indicates direct implications or relative consistency implications, often both.



Appendix

(With apologies to Burton Dreben)

This appendix addresses several larger and more discursive issues that may be raised by set theory and made more acute by the theory of large cardinals. An attempt is made to deflate their significance, and thereby to forestall moves that end up in metaphysics. The history and practice of mathematics in general and set theory in particular affirms that they have achieved an evident autonomy, one that should resist external explanations, extrapolations, or prescriptions.

Although there have been strong metaphysical motivations for doing mathematics, it has steadily emerged through a thinning process to achieve a degree of invariance that distinguishes it from other human endeavors. As Laplace replied to Napoleon when asked why God did not appear in his work, "I have no need of that hypothesis!" This invariance is evident in the universality of mathematical language and acceptance of a body of results and procedures, and is arguably part of the sense of being mathematical. Moreover, it is this invariance that has led to the cumulative progress of mathematics, one more sustained than in science and very different from the dialectical to and fro of philosophy.

On the other hand, the broader history of mathematics undercuts any suggestion of orderly progress and moreover features sudden spurts, the major ones brought about by successively new contexts – complexes of terms, approaches, and procedures. These contexts provided new senses that transformed or refined older concepts and resolved previous questions thus recast, eventually stabilizing at new levels of invariance. To frame a discussion of set theory, we shall review (with interpretive twists) the salient features in the evolution of the continuum to the real numbers, i.e. the so-called "arithmetization of the continuum".

The most momentous mathematical discovery made by the classical Greeks was that the side and the diagonal of a square are incommensurable, in our terms that $\sqrt{2}$ is irrational. Filtering through the mysteries of the Pythagorean school in the 5th Century B.C., this first impossibility result, reputedly due to one Hippasus of Metapontum, overturned their belief that geometry can be investigated in terms of ratios of (the natural) numbers. With the situation further accentuated by Zeno's paradoxes, collectively an attack on the intelligibility of infinitary dynamic processes, the response was one of the great achievements of Greek mathematics: Eudoxus's theory of geometrical proportions as described in Book V of Euclid's *Elements*. This context provided for the ordering of possibly incommensurable magnitudes, and was thus the first mathematization of the continuum. But geometry was dominant to the extent that numbers had the sense of geometrical magnitudes, the product of two numbers *qua* lengths being an area and so forth, and multiplication in practice was not iterated more than a few times.

Almost two millenia later, the emergence of mercantile arithmetic and quantitative scientific investigation proceeded hand in hand with the introduction of basic arithmetical notation. By the early 17th Century $+$, $\times$, $=$, $<$ were in common usage, and also $\sqrt{}$ and variables x, y. This amounted to a new context in which long calculations became surveyable, particular irrational numbers gained an operative legitimacy, and algebra could develop systematically. Even before this standardization, the study of equations in streamlined notations had suggested new combinations like $\sqrt{-1}$ that outstripped sense but pointed to new possibilities.

In the mid-17th Century the great philosopher René Descartes set the stage for the subsequent expansionary period in mathematics with his advocacy of a new framework, analytic geometry, for the study of the continuum. Establishing the primacy of algebra over geometry, not only did Descartes make the conceptual move to the familiar coordinate system, but he loosened the connection of multiplication to dimension so that polynomials could be investigated without e.g. x^2 being regarded as an area, and he shifted attention from closed curves to those given by functional variation.

Surely the greatest advance in mathematics since antiquity was the independent creation of the calculus by Newton and Leibniz in the late 17th Century. Newton viewed curves as representing physical motion and made liberal use of infinite series. Leibniz articulated curves with infinitesimals and emphasized the larger possibilities for symbolic manipulation. Both arrived at the fundamental connection between tangents to curves and areas underneath, Newton from the former and Leibniz from the latter. But even in this very multiplicity genius is contextual, not ineffable, and there is something to Newton's remark that he saw farther because he had "stood on the shoulders of giants". What Newton and Leibniz had done was to forge a general approach that subsumed previous piecemeal results, an approach that not only resolved, in the new terms, a host of problems inherited from the Greeks, but suggested new problems and possibilities for the emerging field of mathematical analysis.

With the legacies of Newtonian mechanics and Leibnizian generative symbolism, mathematics expanded tremendously in the 18th Century, especially into the new domains of functions, infinite series, and differential equations. The latter provided a language to describe physical phenomena, and there was overwhelming empirical reinforcement, particularly in celestial mechanics. The century was epitomized by Euler, whose staggering output featured great strides in inductive mathematics bolstered by appeals to empirical evidence, as in physics today, and remarkable computational powers, foreshadowing recent trends in mathematics.

In the 19th Century mathematics not only continued to expand at a tremendous rate, but it also underwent a transformation based on new structural initiatives, a transformation beginning in analysis. In the previous century the vibrating string had been much discussed; the physics suggested the superposition of many frequencies, leading symbolically to infinite trigonometric series, as well as the possibility of an arbitrary initial configuration, which in turn led to the extension of the concept of function beyond those given by analytic expressions. The tension thus created by this juxtaposition of "infinite series" and "function" in new expanded senses was to lead to the arithmetization of analysis initiated by Cauchy and eventually to the creation of set theory by Cantor.

In order to pursue his study of series of functions, Cauchy in the 1820's articulated the concept of limit, and in its terms, convergence of series and continuity of functions. This amounted to a reorientation of mathematical analysis in that divergent series were excised and the ground laid for the deniability of a property of functions that had been implicit in their geometric sense. Indeed, a discontinuous counterexample to one of Cauchy's own assertions, that the sum of a convergent series of continuous functions is continuous, spurred a more careful analysis.

Karl Weierstrass in the 1850's introduced the familiar $\forall\epsilon$-$\exists\delta$ style of formulating limits, and eliminated once and for all the justificatory procedures in terms of infinitesimals. With mathematicians in the process of making their subject free from appeals to physical or geometric intuition, this new language was quickly accepted because of its ability to draw finer distinctions. By this means Weierstrass was able to rectify Cauchy's assertion by incorporating the concept of uniform continuity, and moreover to formulate a continuous yet nowhere differentiable function, driving a wedge between continuity and differentiability.

With infinitesimals replaced by the concept of limit and that cast in the ϵ-δ language, a level of deductive rigor was incorporated into mathematics that had been absent for two millenia. This may be surprising, but the concept of proof as first advanced by the Greeks had not remained crucial to mathematics. With the creation of the calculus, the available calculational procedures and the steady reinforcement of empirical evidence had been sufficient to propel mathematics inductively forward. But with the function concept steadily outgrowing the Newtonian basis in physical motion, a new calculus became imperative. Sense for the new functions given in terms of infinite series could only be developed through carefully specified deductive procedures, and these amounted to a new calculational technique. Just as proof for the Greeks had implicitly been the vehicle for demonstrating geometric constructibility, proof reemerged as an extension of algebraic calculation and soon became intrinsic as the basis for mathematics in general.

With the new articulations to be secured by proof and proof in turn to be based on prior principles, the regress lead in the early 1870's to the appearance of several independent formulations of the real numbers, of which Cantor's and Richard Dedekind's are the best known. It is at first quite striking that the real numbers as a class came to be developed so late, but this can be viewed against the background of the foregoing account as part of a larger conceptual shift from intensional to extensional mathematics, that is from rules to objects:

The geometric investigation of the continuum as transformed by the calculus had made functional variation central to mathematics. But functions were initially identified with analytic expressions, so that they were viewed intensionally as rules, whether generating geometric figures or representing physical motion. Although infinitesimal change served to motivate differentiation and integration as transformations of these rules, there was no mathematical need to analyze the continuum itself. Mathematics has consistently maintained invariance with such minimal commitments, but the 19th Century articulation of limits and continuity to be demonstrated by proof brought to bear new pressures toward an extensional view of functions as acting on points. With geometric assumptions made more explicit and infinite series outstripping sense, it became necessary to adopt an arithmetical view of the continuum given extensionally as a collection of points.

Cantor's formulation of the real numbers appeared in his seminal paper [72] on Fourier series; proceeding in terms of fundamental sequences, he laid the basis for his theorems on sequential convergence. Dedekind [72] formulated the real numbers in terms of his cuts to express the completeness of the continuum; deriving the least upper bound principle as a simple consequence, he thereby secured the basic properties of continuous functions. In the use of arbitrary sequences and infinite collections, both Cantor's and Dedekind's objectifications of the continuum helped set the stage for the subsequent development of that extensional mathematics *par excellence*, set theory. Cantor was led to his formulation rather pragmatically to secure specific results, but they were also the results that suggested the enumerations leading to the investigation of the transfinite. Dedekind [72] describes how he came to his formulation much earlier, but also acknowledges Cantor's work.

Neither Cantor nor Dedekind regarded their respective formulations and its correlation with an antecedent continuum as automatic. Cantor [72: 97] wrote:

> In order to complete the connection ... with the geometry of the straight line, one must only add an *axiom* which simply says that conversely every numerical quantity also has a determined point on the straight line, whose coordinate is equal to that quantity ... I call this proposition an *axiom* because by its nature it cannot be universally proved. A certain objectivity is then subsequently gained thereby for the quantities although they are quite independent of this.

Dedekind [72] (see [63: 11ff]) wrote:

> If all points on the straight line fall into two classes such that every point of the first class lies to the left of every point of the second class, then there exists one and only one point that produces this division ...
>
> ... I am glad if everyone finds the above principle so obvious and so in harmony with his own ideas of a line; for I am utterly unable to adduce any proof of its correctness, nor has anyone the power. The assumption of this property of the line is nothing else than an axiom by which we attribute to the line its continuity, by which we find continuity in the line.

Dedekind was not above "proving" basic principles (cf. his (in)famous proof of Theorem 66 in his [88], that there is an infinite set), but here he advocates an axiomatic correlation as does Cantor. Dedekind's circumlocutions in terms of "creation" via cuts led to Russell's [03: 279ff] criticism. However, Russell's extensional solution of simply defining the real numbers as the cuts, while consistent with his reductionism, obscures an antecedent sense of the continuum that both Cantor and Dedekind were trying to accommodate. Neither theft nor honest toil sufficed; both Cantor and Dedekind recognized the need for a sort of Church's Thesis, a thesis of adequacy for the new construal of the continuum as a collection of points.

Set theory emerged out of this setting, with the larger backdrop of mathematics also featuring new extensional initiatives in the development of algebraic and geometric structures. The birth of set theory was attended by the metaphysics of Cantor's Absolute; it was raised on the more subtle metaphysical initiatives from logic; and throughout, the mathematization of the infinite confronted concerns about its very possibility.

The numerical infinite of indefinite progression had long been held to be incoherent as a completed totality. With Aristotle's potential infinite vs. actual infinite a traditional demarcation, the occasional excursions into the latter had only been morality tales clinched by apparently paradoxical one-to-one correspondences. In particular, the only possibility for an answer to the question "how many points are there on a line?" had been "potentially infinite", with "infinite" in the decidedly negative, etymological sense of "not finite". It was Cantor's incisive work that made of the infinite a positive concept and provided a structured sense to the question with the answer, $2^{\aleph_0}$. Cantor charted out the transfinite with simple generative and arithmetical rules, and thereby provided a mathematical context for the investigation of infinite collections. The infinite, thus cast, was after all mathematically coherent.

As before in mathematics the new language suggested a host of new possibilities, most notably $2^{\aleph_0} = \aleph_1$, but the whole transfinite landscape was slow in gaining acceptance. Philosophical skepticism about the actual infinite may have played an inhibitory role, just as Kant's dogma of the *a priori* of Euclidean geometry may have done for non-Euclidean geometry, but the main factor may have simply been the mathematical reluctance to contemplate a proliferation of new entities. Whereas the natural numbers were as old as time and at the heart of the intuitive underpinnings of mathematics, the transfinite numbers seemed at first to be contrived and of little mathematical use. While Cauchy's formulation of continuity had been quickly accepted as the articulation of geometric assumptions, there was no comparable backing to the transfinite numbers. That reinforcement was to be secured by the steadily increasing use of the transfinite leading eventually to the full-blown theory of large cardinals, and the explicit extensional casting of set theory through axiomatization.

As described in the introduction, Zermelo axiomatized set theory in order to make explicit some underlying set existence assumptions and thereby advanced a combinatorial view of sets structured solely by $\in$ and simple operations. The vagueness of the *definit* property in the Separation Axiom invited Skolem's proposal to base it on first-order logic, and the addition of the Replacement Axiom figured in von Neumann's reformulation of the transfinite numbers as the ordinals, transitive sets well-ordered by $\in$.

Beginning as a mathematical theory of extensions, axiomatic set theory has carried the weight of a larger significance having to do generally with the existence of mathematical objects. However, just as Euclid's axioms for geometry had set out the permissible geometric constructions, the axioms of set theory set out the specific conditions for set generation, and this in a new calculus based on first-order logic. Unlike the emergence of mathematics from marketplace arithmetic and Greek geometry, sets and transfinite numbers were neither laden nor buttressed with substantial antecedence. Like strangers in a strange land, stalwarts developed a familiarity with them guided hand in hand by their axiomatic scaffolding, which served as new rules of procedure. In particular, existential propositions of set theory are closely tied, even in practice, to the $\exists$ of first-order logic whose sense is determined by its logical rules, and do not call for correlation with "existence" in some larger sense.

As for the contextualized existence of infinite sets, the Axiom of Infinity in its usual formulation is just the extensional counterpart to the principle of mathematical induction as a rule for deriving the universal $\forall n\varphi(n)$. In so far as the natural numbers do have an antecedent sense, $\forall n\varphi(n)$ should be correlated with the informal counterparts to $\varphi(0)$, $\varphi(1)$, $\varphi(2), \ldots$. However, the correlation here is less direct than that for the continuum with formulations of the real numbers, since number-theoretic assertions are being made. *Contra* Poincaré, Hilbert distinguished between *contentual* (inhaltlich) induction proceeding recursively from one number to the next and *formal* induction by which $\forall n\varphi(n)$ follows immediately from the $\varphi(0) \wedge \forall n(\varphi(n) \rightarrow \varphi(n+1))$ and "through which alone the mathematical variable can begin to play its role in the formal system" (Hilbert [28]; see van Heijenoort [67: 473]). With Cantorian metaphysics thinned out by axiomatization, there is no larger sense of existence beyond the use of formal induction in which the infinite has been domesticated; a telling observation is that if there is some doubt about some $\forall n\varphi(n)$ purportedly established by the rule, no search is undertaken for a particular natural number a so that $\varphi[a]$ fails, but rather the putative proof is carefully scrutinized much as an arithmetical calculation is checked. There is no larger sense to the Axiom of Infinity other than providing the extension of formal induction; one consequence is that the Cantorian move against the natural numbers as having no end in the traditional "after" sense is neatly rendered by extensionalizing induction itself with the ordinal ω, with "after" recast as "$\in$".

The transfinite is similarly contextualized by Replacement and the principle of transfinite induction. Recalling Cantor's unitary view of the finite and the transfinite, the principle is a simple extension of induction through limit points, and the seeming exacerbation of the breach into the actual infinite amounts to just contextual deductions from this new rule. From this viewpoint, the Axiom of Choice can be regarded as a similarly necessary principle for infusing the contextualized transfinite with the order already inherent in the finite.

As described in the introduction, the Foundation Axiom and the iterative conception of set converted set theory into a study of well-foundedness. After the infusion of model-theoretic techniques, the development of forcing and inner model theory established set theory as a sophisticated and distinctive field of mathematics. And to repeat, formalized versions of truth and consistency became matters for combinatorial manipulation as in algebra, with large cardinals providing an elegant and fully sufficient superstructure for the study of consistency strength.

Large cardinal hypotheses as existential propositions have a distinctive status in so far as relative consistency results have made of them a gauge, the interplay between forcing and inner models becoming part of their collective sense in set theory. Just as large finite numbers became surveyable through arithmetical notation, so also did large cardinals through their set-theoretic formulations as part of the calculus of Zermelian set theory. And just as large finite numbers seem hopelessly inaccessible in terms of counting one by one, so also do large cardinals in terms of hierarchically simpler processes. But just as we can work with $10^{1,000,000}$ in the proper context, so we can work with a measurable cardinal.

What about the role of set theory as a foundation for mathematics? As a mathematical theory of extension, a small part of Zermelian set theory can serve as an ambient framework for most of ongoing mathematics. Recapitulating the history above, rules can be extensionalized and then further recast in terms of sets, $\in$, and $=$. Be this as it may, this reduction does not necessarily clarify, for generally speaking, mathematics operates at various levels of organization and articulation: Number theory thrives first at the level of arithmetical rules and then at the level of analytic superstructures, far above Frege and even Peano. Mathematical analysis thrives first at the level of Weierstrass and then at the level of functional superstructures, with only a faint nod to Cantor and Dedekind. Like the relation of organic chemistry to particle physics, reducibility is acknowledged, but the emphasis is rather on the possibilities afforded by specific conceptual schemes at different levels of organization.

On the other hand, as a study of well-foundedness ZFC together with the spectrum of large cardinals serves as a court of adjudication, in terms of relative consistency, for mathematical propositions that can be informatively contextualized in set theory by letting their variables range over the set theoretic universe. Thus, set theory is more of an open-ended framework for mathematics rather than an elucidating foundation. It is as a field *of* mathematics that both proceeds with its own internal questions and is capable of contextualizing over a broad range which makes of set theory an intriguing and highly distinctive subject.

What then is left for philosophy? Existence, truth, and knowledge, when taken in the large, are ultimately contentious subjects for debate rather than concepts for explication. The subjects of much philosophizing, these as well as the whole package of dichotomies like objective/subjective, realist/anti-realist, and contingent/necessary are of unlimited fluidity and variability. For example, a table, the moon, and unicorns exist in such plainly different ways that existence *per se* cannot have sense as a prior category. It is only through communication and learning that we become familiar with the various uses of the term as part of our language. This being the case, such general terms cannot serve, unreflectively or with short "definitions", as the beginning of some analysis, but must themselves be subject to contextualized description. Mathematics has long been held up as a paragon of clarity and knowledge, but even then, assertions like "mathematics is true" or "numbers exist" are without antecedent sense and must be developed and argued for *in toto*, each like a new sentence formed from familiar words.

But where to begin, and how far to go? Considerations of assertions like "a sea-battle will take place in the Aegean tomorrow", "the evening star is the morning star", or even "$7 + 5 = 12$" should begin with their evidently invariant feature, the words themselves. And such considerations can arguably proceed at most to a description of their interplay as part of how we use language, if they are not to overleap the bounds of invariance and become enmeshed in metaphysics. According to Wittgenstein in *Philosophical Investigations* (§109):

> . . . We must do away with all *explanation*, and description alone must take its place. And this description gets its light, that is to say its purpose, from the philosophical problems. These are, of course, not empirical problems; they are solved, rather, by looking into the workings of our language, and that in such a way as to make us recognize those workings; *in despite of* an urge to misunderstand them. The problems are solved, not by giving new information, but by arranging what we have always known. Philosophy is a battle against the bewitchment of our intelligence by means of language.

A historical account was given above "arranging what we have always known" to describe existence as contextualized in set theory. As for truth, the attitude is similar. To be bold, *mathematical truth is what we have come to make of it.* As for knowledge, description ultimately provides no insights beyond description. To be bolder still, it may be that we cannot say anything other than that *the acquisition of mathematical knowledge may be just what happens.* Like morning lilies opening at dawn or squirrels saving up nuts in trees, *we just do it.*

To pursue an analogy, the world of mathematics is like a great cathedral. The thick stone walls along the stately aisles still show the lines of the ancient church that predated the grand edifice. The central dome is supported by high arches of vaulting stone, resilient reminders of the anonymous master masons. Whatever their design, the arches have easily supported the elegant latter-day spires reaching high into the sky. The first adornments can still be seen in the oldest chapels; there in continuing communion with the past steady additions are made, each new age imparting its own distinctive style. In recent memory large new side chapels have been constructed, and new flying buttresses for extra support. Every day the curious enter through the great door of polished wood with the attractive inset figures. Several venture down the long nave seeking instruction, and a few even initiation, quite taken by the the order and beauty of the altar. And the work continues: The architects attempt to chart out large parts of the cathedral, some even proposing vast renovations. The craftsman continue the steady work on the new wood paneling, the restoration of the sculpture, and the mortaring of the cracks that appear with age. And supported by high scaffolding, the artisans continue to work on the fine stained glass. They try to coordinate with their colleagues in the adjoining frames, but sometimes the heady heights inspire them to produce new gems. Those who step back see a larger scheme, but they cannot see across the whole breadth. And they are so high up that they can no longer see their supports. Nevertheless, they are sustained as a community, as part of the ongoing human adventure.

To append an apocryphal tale: A host of industrious spiders started to build an elaborate network of webs in newly excavated vaults beneath the cathedral. It quickly grew so thick and complex that no one could venture across without getting enmeshed. One day, a fearful wind came howling in and blew a gaping hole through the network, and in desperate response the spiders worked frantically to reestablish the connections. For you see, the spiders had become convinced that their carefully constructed webbing was the foundation without which the entire cathedral would totter. Of course, the craftsmen above hardly raised an eyebrow.

There are some remaining possibilities for metaphysical appropriation that should be forestalled. Mathematicians themselves have often described a feeling of dealing with autonomous objects, some professing an avowedly realist view of mathematics. The reply is that this objectification is part of the practice of mathematics, the sense of existence here to be described as in any other concerted human activity. Among many examples of the sort, one should remember how roundly Edward Gibbon was criticized by the faithful for having presented the emergence of Christianity as part of history. And there is the analogy with the blindfold chess player who can play out entire games; he may visualize the pieces on a particular chessboard, but in the end what remains is the structure of the game as communicated by him through the notation. Finally, Gödel's realist arguments in [47] have been much discussed, no doubt in part because of the significance of his mathematical results. But again, it is the invariance of those results that lies at the heart of the matter. Gödel himself much admired the work of Robinson and wanted him as his (Gödel's) successor at the Institute for Advanced Study; that Robinson [65] was a committed formalist was never of mathematical consequence.

But even with the metaphysics thinned out, there is still the recurrent feeling, familiar to the working mathematician, of questions being induced by a context, and once resolved, a gripping sense of inevitability about their solutions. This suggests the possibility of a new metaphysical appropriation, as the mathematician seems to be impelled to extend the boundaries of order against a chaos of possibilities. But this feeling is also familiar to the artist, who can proceed straightforwardly at various junctures once the context has largely precipitated; as James Joyce in *Ulysses* (17: 1012-15) describes Dedalus,

> He affirmed his significance as a conscious animal proceeding syllogistically from the known to the unknown and a conscious rational reagent between a micro and a macrocosm ineluctably constructed upon the incertitude of the void.

Even with this said, there may still be lurking some inchoate feeling that the fact of mathematics still calls for some kind of explanation. Beyond any concerns about its unreasonable effectiveness in the natural sciences, there may remain a larger feeling of *mystery* about how the world of mathematics has come about and fits together into a coherent whole. But this final possibility for metaphysical appropriation, along with the more traditional musings about the starry heaven above or the moral law within, are not in the world but of the mystical, part of the feeling for the unity of experience in the large. According to Wittgenstein in the *Tractatus* (6.41):

> The sense of the world must lie outside the world. In the world everything is as it is and happens as it does happen. *In* it there is no value – and if there were, it would be of no value.
>
> If there is a value which is of value, it must lie outside all happening and being-so. For all happening and being-so is accidental.
>
> What makes it non-accidental cannot lie *in* in the world, for otherwise this would again be accidental.
>
> It must lie outside the world.

Again from the *Tractatus* (6.44):

> Not *how* the world is, is the mystical, but *that* it is.

And this in Wittgenstein's dialectical distinction can at most be *shown*, not *said*, leading in one direction to his admonition to silence at the end of the *Tractatus*. Neither metaphysics nor solipsism, it is that part of human experience beyond human discourse. The *Tao Te Ching* of Lao-Tzu begins:

> The Tao that can be told is not the eternal Tao.
> The name that can be named is not the eternal name.

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The following abbreviations are used for long titled or frequently cited journals:

AAMS	Abstracts of papers presented to the American Mathematical Society
ALS	Acta Litterarum ac Scientiarum Regiae Universitatis Hungaricae Francisco-Josephinae, Sectio Scientiarum Mathematicarum (from 1946: Acta Scientiarum Mathematicarum, Szeged).
AdM	Advances in Mathematics
AM	Annals of Mathematics
AMAH	Acta Mathematica Academiae Scientiarum Hungaricae
AMM	American Mathematical Monthly
AML	Annals of Mathematical Logic (continued from 1983 by Annals of Pure and Applied Logic)
APAL	Annals of Pure and Applied Logic (continues Annals of Mathematical Logic from 1983)
BAMS	Bulletin of the American Mathematical Society
BAPS	Bulletin de l'Académie Polonaise des Sciences, Série des Sciences Mathématiques, Astronomiques et Physiques (continued from 1983 by Bulletin of the Polish Academy of Sciences. Mathematics.)
BKSG	Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig, Mathematisch-Physikalische Klasse
BLMS	Bulletin of the London Mathematical Society
CMUC	Commentationes Mathematicae Universitatis Carolinae
CRP	Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, Paris.
FM	Fundamenta Mathematicae
IJM	Israel Journal of Mathematics
JAMS	Journal of the American Mathematical Society
JSL	The Journal of Symbolic Logic
MA	Mathematische Annalen
NAMS	Notices of the American Mathematical Society
PAMS	Proceedings of the American Mathematical Society
PJM	Pacific Journal of Mathematics
PLMS	Proceedings of the London Mathematical Society
PNAS	Proceedings of the National Academy of Sciences U.S.A.
RMS	Russian Mathematical Surveys
TAMS	Transactions of the American Mathematical Society
ZML	Zeitschrift für Mathematische Logik und Grundlagen der Mathematik

The italicized numbers after a publication refer to those pages in the text where it is cited. The italicized numbers directly after a person refer to those pages in the text where he or she is cited, but not only in connection with a publication or specific result.

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Shelah, Saharon, and Lee J. Stanley

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Shelah, Saharon, and W. Hugh Woodin

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Shepherdson, John C.
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Shioya, Masahiro
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Shoenfield, Joseph R. *174, 312, 313*
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Sierpiński, Wacław *XVI, 22, 147, 148, 151, 167*
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Sikorski, Roman
See Rasiowa, Helena, and Roman Sikorski.

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See also Jensen, Ronald B., and Robert M. Solovay.

See also Kechris, Alexander S., and Robert M. Solovay.

See also Kechris, Alexander S., Robert M. Solovay, and John R. Steel.

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See also Martin, Donald A., and Robert M. Solovay.

Solovay, Robert M., William N. Reinhardt, and Akihiro Kanamori

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Solovay, Robert M., and Stanley Tennenbaum

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Sós, Vera T.

See Hajnal, András, Richard Rado, and Vera T. Sós.

Specker, Ernst

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Spector, Clifford *114*
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Spencer, Joel H.
See Graham, Ronald L., Bruce L. Rothschild, and Joel H. Spencer.

Stanley, Lee J.
See Shelah, Saharon, and Lee J. Stanley.

Stanley, Mack C.
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Steel, John R. *XXII, 276, 330, 367–369, 415, 437, 443, 450, 462, 463, 468, 470*
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81a Closure properties of pointclasses. In: Kechris-Martin-Moschovakis [81], 147–163.
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83 Scales in $L(\mathbb{R})$. In: Kechris-Martin-Moschovakis [83], 107–156. *430–433, 436*
88 Long games. In: Kechris-Martin-Steel [88], 56–97. *467*
See also Kechris, Alexander S., Robert M. Solovay, and John R. Steel.
See also Martin, Donald A., Yiannis N. Moschovakis, and John R. Steel.
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Steel, John R., and Robert A. Van Wesep
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Steprāns, Juris, and Stephen Watson
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Stewart, Frank M.
See Gale, David, and Frank M. Stewart.

Sureson, Claude
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89 About Prikry generic extensions. APAL **51** (1989), 247–278. *238*

Suslin, Mikhail Ya. *145–149, 151, 166, 183*

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Swierczkowski, Stanisław *378*

See Mycielski, Jan, and Stanisław Swierczkowski.

See also Mycielski, Jan, Stanisław Swierczkowski, and A. Zieba.

Szekeres, György

See Erdős, Paul, and György Szekeres.

Takeuti, Gaisi *378*

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Tan, It Beng

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See also Barbanel, Julius B., Carlos A. Di Prisco, and It Beng Tan.

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See also Nagel, Ernest, Patrick Suppes, and Alfred Tarski.
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Tarski, Alfred, and Robert L. Vaught

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See also Baumgartner, James E., Alan D. Taylor, and Stanley Wagon.

Teichmüller, Oswald

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Tennenbaum, Stanley *116*

See Solovay, Robert M., and Stanley Tennenbaum.

Thompson, S. *83*

Todorčević, Stevo B. *80, 87, 98, 320*

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Ulam, Stanisław M. *15, 22, 39, 56, 87, 151, 294, 371*

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Van Wesep, Robert A.

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See also Steel, John R., and Robert A. Van Wesep.

Vaughan, Jerry E.

See Kunen, Kenneth, and Jerry E. Vaughan.

Vaught, Robert L. *311*

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See also Tarski, Alfred, and Robert L. Vaught.

Veblen, Oswald

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Vitali, Giuseppe *132*

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von Neumann, John, and Oskar Morgenstern

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Vopěnka, Petr *116, 234*

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Vopěnka, Petr, and Karel Hrbáček

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Wadge, William W. *442*

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Wagon, Stanley

See Baumgartner, James E., Alan D. Taylor, and Stanley Wagon.

Wang, Hao

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Watro, Ronald J.

See Henle, James M., Eugene M. Kleinberg, and Ronald J. Watro.

Wehrung, Friedrich

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Weierstrass, Karl *475, 479*

Weitkamp, Galen

See Mansfield, Richard B., and Galen Weitkamp.

Welch, Philip *445*

See Beller, Aaron, Ronald B. Jensen, and Philip Welch.

Weyl, Hermann *XIII*

Whitehead, Alfred N. *XIII, 2*

Wittgenstein, Ludwig *70, 480, 482*

Wolfe, Philip

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Woodin, W. Hugh *XXII, 96, 243, 310, 320, 322, 329, 344, 363, 367–369, 431–434, 437, 449, 450, 453, 457–464, 466–471*

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See also Feng, Qi, Menachem Magidor, and W. Hugh Woodin.

See also Judah, Haim (Jaime Ihoda), Winfried Just, and W. Hugh Woodin.

See also Kechris, Alexander S., Eugene M. Kleinberg, Yiannis N. Moschovakis, and W. Hugh Woodin.

See also Kechris, Alexander S., and W. Hugh Woodin.

See also Shelah, Saharon, and W. Hugh Woodin.

Woodin, W. Hugh, Adrian R.D. Mathias, and Kai Hauser

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Yankov, Vladimir

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Young, William H.

03 Zur Lehre der nicht abgeschlossenen Punktmengen. BKSG **55** (1903), 287–293. *147*

Zeno *473*

Zermelo, Ernst *XIV, 21, 371, 372*

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Subject Index

This index concentrates on definitions (occurring on the italicized pages), basic properties, and those significant but singular occurrences of larger subjects that might otherwise be difficult to find. Greek letters and other symbols are alphabetized according to their English transliterations.

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