Chapter 1

Rethinking universality

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For a discrete infinity of reasons, Ian Roberts is to be celebrated. Here we discuss how his important work has caused us to rethink what could be, arguably, the most unbelievable and extraordinary aspect of language: its *universality*. In particular, we proffer Roberts' theory of parameter hierarchies to corroborate an *economy thesis* – a thesis implying that the quiddities of language transcend *human* language, and would obtain of *any* language *anywhere* in the universe.

1 Beyond the infinite

> As far as anyone knows, spaceships have been successfully built by exactly one civilisation in the entire history of the universe: by post-1957 humans (the Space Age actually happens to coincide exactly with my lifetime, although I had nothing to do with it) (Roberts 2017: 1)

Ian Roberts may not have been amongst those to *engineer* the Space Age, but he is one of the best to have *explained* (indirectly) how it was possible, and *explanation* is the prerequisite for all progress in scientific understanding and its technological applications. Specifically, Roberts has over his career explained how *human language* – its structure, acquisition, and historical change – has propelled our species to being the paragon of animals – to go "beyond the infinite" in Kubrick's words.

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> Chimps, who allegedly share around 98 percent of their genes with us, […] show no interplanetary ambitions […]. Our extra 2 percent makes us extremely good – by the standards of everything else in the known universe, unbelievably, extraordinarily, *cosmically* good – at generating, storing and transmitting knowledge. How do we do it? With *language*.
>
> (Roberts 2017: 1–2)

In this, the sixth decade of Roberts' cosmic existence, we celebrate him and how his work has caused us to rethink what could be, arguably, the most unbelievable and extraordinary aspect of language: its *universality*. In particular, we proffer Roberts' theory of parameter hierarchies to corroborate an *economy thesis* – a thesis implying that the quiddities of language transcend *human* language, and would obtain of *any* language *anywhere* in the universe.

2 A universal instrument

The human mind, Descartes argued, is undoubtedly in some sense a "universal instrument". We cannot know with certainty what he intended by this provocative comment, but we do know that the Cartesians would have understood language as fundamental to any nontrivial notion of "universality" because it is language that empowers humans to generate an unbounded set of hierarchically structured expressions that can enter into effectively infinitely many thoughts and actions – that is, the competence of every human, but no beast or machine, to use language in creative ways appropriate to situations but not caused by them, and to formulate and express these thoughts coherently and without bound, perhaps "incited or inclined" to speak in particular ways by internal and external circumstances but not "compelled" to do so. Of course in the pre-Turing world, the Cartesians did not know how a finite "machine" such as the brain could generate the infinity of expressions of natural language, and therefore posited a soul where we need only posit a neurobiological Turing machine (obviously idealized with unbounded memory, etc.). Nevertheless Descartes intuited the essence of Turing universality: "Only a spiritual entity could achieve the limitlessness of interactive language, putting words together in indefinitely many ways", and to do so in ways that are "free" (i.e., not compelled by internal or external conditions) and intelligible and appropriate to situations, and to do so over an unbounded range in different domains.

> Any material machine must specialize: while a machine might do very well some of the things people do, it would necessarily be unable to do others.

> Any part or organ needed a particular configuration to achieve a task, and it was impossible to have enough different parts with the requisite configurations in a single machine to make it act in all the contingencies of life in the same way that our reason makes us act. Only disembodied reason could be 'a universal instrument'. (Riskin 2017: 63)

Of course the genius of Turing was to discover that "[i]t is possible to invent a single machine which can be used to compute any computable sequence"; he called this mathematical object, appropriately, the "universal machine" (Turing 1937: 243).

Linguistic competence (and especially its creative use), in concert with other mental faculties, establishes the general intelligence necessary for the evolutionary "great leap forward" of our species (see Chomsky 2016). As Roberts (2017: 182) conjects, "there might have been a crucial mutation in human evolution which led, in almost no time from an evolutionary perspective, from [humans living in] caves to [their creating knowledge of such sophistication as to enable us to imagine and construct things as complex as, say,] spaceships. It's a plausible speculation that the mutation in question was whatever it is that makes our brains capable of computing recursive syntax, since it's the recursive syntax that really gives language – and thought – their unlimited expressive power. It's one small step from syntax to spaceships, but a great leap for humans". A great leap for humans – and *only* humans, evidently (see Berwick & Chomsky 2016). The architecture of intelligence necessitates "provisions for recursive, hierarchical use of previous results" as manifested in the "articulation" of a complex structure into descriptions of "elementary figures" and "subexpressions designating complex subfigures", with a "figure first divided into two parts; and then with each part described using the same machinery" (Minsky 1963: 16). The recursive capacity of intelligence is most manifest in natural language:

> Whatever we can express or describe, we can treat its expression or description as though it was a single component inside another description. In languages, this corresponds to using embedded phrases and clauses. That final trick – of representing prior thoughts as things – gives our minds the awesome power to use the same brain-machinery over and over again, to replace entire conceptualizations by compact symbols, and hence to build gigantic structures of ideas the way our children build great bridges and towers from simple separate blocks. It lets us build new ideas from old ones; in short, it makes it possible to think. The same is true of our [future] computers. (Minsky 1985: 124)

Thus we might expect any (super-)human-level intelligence anywhere in the universe – including any genuine artificial intelligence ("our [future] computers") we create – to be recursive in this way.

It has been assumed that the essential properties of human language are not only unique, but *logically contingent*:

> Let us define "universal grammar" (UG) as the system of principles, conditions, and rules that are elements or properties of all human languages not merely by accident but by necessity – of course, I mean biological, not logical necessity. Thus UG can be taken as expressing "the essence of human language". (Chomsky 1975: 29)

> There is no *a priori* reason to expect that human language will have such properties; Martian could be different." (Chomsky 2000: 16)

This assumption, we submit, merits rethinking in light of Roberts' work and progress in the Minimalist program more generally (Chomsky 1995). Recent work demonstrating the *simplicity* (Watumull et al. 2017) and *optimality* (Chomsky et al. 2019) of language increases the cogency of a conjecture that at one time would have been summarily dismissed as absurd: "the basic principles of language are formulated in terms of notions drawn from the domain of (virtual) conceptual necessity", the domain defined by "general considerations of conceptual naturalness that have some independent plausibility, namely, simplicity, economy, symmetry, nonredundancy, and the like" (Chomsky 1995: 171, 1) that render linguistic computation interestingly optimal. To the extent that this *strong Minimalist thesis* (SMT) is true, the essential – computational (even mathematical) – properties of language would derive from laws of nature – language- and even biology-independent principles that, once realized in the mind/brain, *do* entail particular properties as logically necessary. For instance, it is simply a fact of logic that the simplest (optimal) form of the recursive procedure generative of syntactic structures, Merge, has two and only two forms of application (i.e., external and internal). Relatedly, *given* the nature of the structures Merge generates, minimal structure distance is *necessarily* the simplest computation for the structure dependence of rules. And so on and so forth (see Berwick et al. 2011; Chomsky 2013; Watumull 2015 for additional examples).

Research in the Minimalist program starts with the optimality conjecture and proceeds to inquire whether and to what extent it can be sustained given the observed complexities and variety of natural languages. If a gap is discovered, the task is to inquire whether the data can be reinterpreted, or whether principles of simplicity and optimal computation can be reformulated, so as to solve the puzzles within the framework of SMT, thus generating some support, in an interesting and unexpected domain, for Galileo's precept that nature is simple and it is the task of the scientist to demonstrate it.

As we discover more and more of "the essence of human language" to be defined by (virtual) conceptual necessity, the less and less absurd it is to question just how contingent a phenomenon human language really is. It may well be with language as with other phenomena studied in the natural sciences that, in the words of the sage physicist J.A. Wheeler, "[b]ehind it all is surely an idea so simple, so beautiful, that when we grasp it – in a decade, a century, or a millennium – we will all say to each other, how could it have been otherwise?" (Wheeler 1986: 386). In other words, there may well be some a priori reasons to expect human language to have the (essential) properties it does; or, to put it whimsically, the Martian language might *not* be so different from human language after all. In short, the *universality* of universal grammar needs to be rethought.

3 Simplicity itself

Our rethinking is based on a rethinking – or reminding – of *simplicity* as originally conceived in generative linguistics. "[S]implicity, economy, compactness, etc." were proffered in the first work on generative grammar as criteria the grammar of a language must satisfy: "Such considerations are in general not trivial or "merely esthetic". It has been recognized of philosophical systems, and it is, I think, no less true of grammatical systems, that the motives behind the demand for economy are in many ways the same as those behind the demand that there be a system at all" (Chomsky 1951: 1, 67). This proposition echoed that of Goodman (1943: 107): "The motives for seeking economy in the basis of a system are much the same as the motives for constructing the system itself". The idea is elementary but profound: if the theory is no more simple, economical, compact, etc. than the data it is proffered to explain, it is not a theory at all; hence the more compressed the theory, the more successful – i.e., the more explanatory – it is.

The mathematician Gregory Chaitin (2005: 64) has formalized this idea in terms of algorithmic information theory: "a scientific theory [can be thought of] as a binary computer program for calculating observations, which are also written in binary"; a generative grammar can thus be thought of as a program for generating syntactic structures. "And you have a law of nature if there is compression, if the experimental data is compressed into a computer program", equivalently a grammar, "that has a smaller number of bits than are in the data that it explains", or generates. "The greater the degree of compression, the better the law, the more you understand the data. But if the experimental data cannot be compressed, if the smallest program for calculating it is just as large as it is [...], then the data is lawless, unstructured, patternless, not amenable to scientific study, incomprehensible. In a word, random, irreducible". In the terms of generative grammar (Chomsky & Miller 1963: 285):

> As a matter of principle, a grammar must be finite. If we permit ourselves grammars with an unspecifiable set of rules[,] we can simply adopt an infinite sentence dictionary. But that would be a completely meaningless proposal. Clearly, a grammar must have the status of a theory about those regularities that we call the syntactic structure of the language.

To have the status of a theory, the grammar must be compressed, generating – and thereby explaining – the regularities in syntactic structures.

This idea is appreciated surprisingly seldom today: many computational cognitive scientists and machine learning theorists (and hence virtually all "artificial intelligence" (AI) labs in academia and industry) have perversely redefined a successful theory or computer program to be one that merely approximates or classifies unanalyzed data. This contrasts dramatically with the Enlightenment definition in which data are selectively analyzed as evidence for/against conjectured explanations (see Popper 1963; Chomsky 2000; Deutsch 2011). The machine learning systems (e.g., deep learning neural nets, reinforcement learning techniques, etc.) so popular in the current "AI spring" are *weak AI*: brute-force systems laboriously trained to "unthinkingly" associate patterns in the input data to produce outputs that approximate those data in a process with no resemblance to human cognition (thus betraying Turing's original vision for AI). These systems will never be genuinely intelligent, and are to be contrasted with the *strong – anthronoetic – AI* Turing envisioned: a program designed to attain human-level competence with a *human-style* typified by *syntactic generativity* and *semantic fluidity* – to think *the way* a human thinks. Today such programs, based on generative grammars, are finally being built.[1]

The early discussions on simplicity were addressing the logic of theory construction by the scientist, but later (Chomsky 1965: 4) this logic was analogized to the learning of language by children: "The problem for the linguist, as well as for the child learning the language, is to determine from the data of performance the underlying system of rules that has been mastered by the speaker-hearer". To determine the grammar (qua "theory" *in* the mind of the learner and qua theory *of* the mind by the linguist), some procedure to evaluate candidate grammars

[1]https://www.oceanit.com/science-technology/artificial-intelligence/

is necessary. Specifically, a format-evaluation framework: "(v) specification of a function *m* such that *m*(*i*) is an integer associated with the grammar G_i as its value (with, let us say, lower value indicated by higher number)" (Chomsky 1965: 31). Naturally, "simpler" grammars are more highly valued, but, then as now, "simplicity" is complex: "In the context of this discussion, 'simplicity' (that is, the evaluation measure *m* of (v)) is a notion to be defined within linguistic theory along with "grammar", "phoneme", etc. Choice of simplicity measure is rather like determination of the value of a physical constant" (Chomsky 1965: 37–38). Goodman (1943: 107–108) too was cognizant of the complexity of simplicity, observing that "the mere counting of primitives is no satisfactory measure" because "by the purely mechanical application of certain logical devices, we can readily reduce all the primitives of any system to one". Thus while Goodman searched for a general notion of simplicity applicable to all systems, a specific notion applicable to language was sought in generative linguistics, and both ultimately "failed" (i.e., superseded by better notions – characteristic of a healthy science): the former for technical reasons, the latter because of the success of the principles-and-parameters (P&P) framework (Chomsky 1981), which obviated the need for any simplicity measure of the type envisioned for the format-evaluation framework.

4 The principles-and-parameters mission

In P&P, language acquisition is the process of setting the values for the finitely many universal parameters of the initial state of the language faculty (UG). The apparent complexity and diversity of linguistic phenomena is illusory and epiphenomenal, emerging from the interaction of invariant principles under varying conditions. This was a radical shift from the early work in generative linguistics, which sought only an evaluation measure that would select among alternative theories of a language (grammars) – the simplest congruent with the format encoded in UG and consistent with the primary linguistic data. But with the P&P shift in perspective, simplicity can be rethought, though this was not initially appreciated. As discussed in the earliest work in generative linguistics, notions of simplicity assume two distinct forms: the imprecise but profound notion of simplicity that enters into rational inquiry generally, and the theory-internal measure of simplicity that selects among I-languages. The former notion of simplicity is language-independent, but the theory-internal notion is a component of UG, a subcomponent of the procedure for determining the relation between experience and I-language (again, something like a physical constant). In early work, the internal notion was implemented in the form of the evaluation procedure to select among proposed grammars/I-languages consistent with the UG format for rule systems. But, as Ian Roberts (2012) and others (e.g., Sheehan et al. 2017) discovered, the P&P approach transcends that limited, parochial conception of simplicity: with no evaluation procedure, there is no internal notion of simplicity in the earlier sense. There remains only the universal notion of simplicity.

In P&P, grammars – I-languages – are simple, but, as evidenced in Roberts' work (e.g., Roberts & Holmberg 2010), they are so by virtue of third-factor principles of computational efficiency (Chomsky 2005), not by analogy to theory-construction or by stipulation in UG. In fact, rather than "simple", we propose to define P&P-style acquisition as "economical", which, in the Leibnizian spirit, we understand to subsume simplicity:

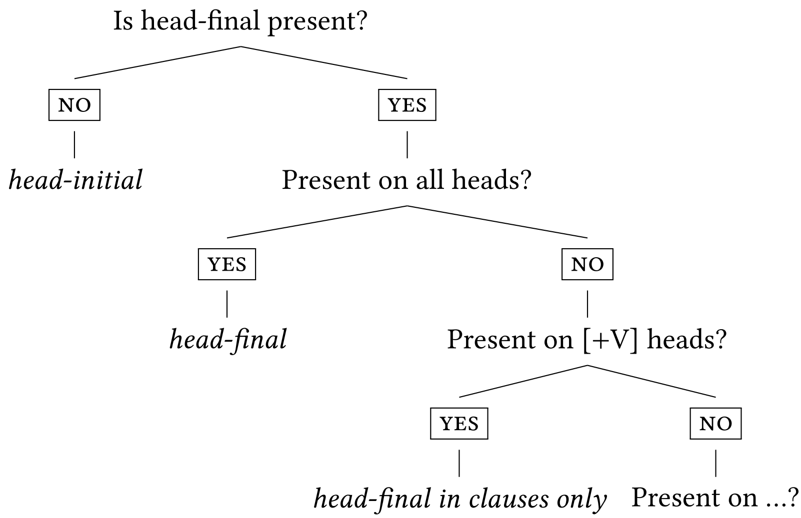
> The most economical idea, like the most economical engine, is the one that accomplishes most by using least. Simplicity – or fuel consumption – is a different factor from power [i.e., generative capacity, empirical coverage, etc.] but has to be taken equally into consideration [...]. The economy of a basis may be said to be the ratio of its *strength* to its simplicity. But superfluous power is also a waste. Adequacy for a given system is the only relevant factor in the power of a basis; and where we are comparing several alternative bases for some one system, as is normally the case, that factor is a constant. Thus in practice the simplest basis is the most economical.
>
> (Goodman 1943: 111)

Economy, in other words, is a *minimax* notion. In Leibniz's words (see Roberts & Watumull 2015): "the simplicity of the means counterbalances the richness of the effects" so that in nature "the maximum effect [is] produced by the simplest means". This notion is enshrined in the Galilean ideal (see Chomsky 2002).

One economical form of P&P-style learning explicable in terms of third-factors is the traversal of a parameter hierarchy (see Roberts 2012; Biberauer 2016) – parameter specification. In such a system, the child is not unthinkingly enumerating and evaluating grammars.[2] Instead, the I-language matures to a steady state in a relatively deterministic process of "answering questions" that *emerge naturally and necessarily* in the sense that there exist "choices" in acquisition that logically must be "made" for the system to function at all; none of the parameters need be encoded in the genetic endowment (see Obata et al. 2015 for similar ideas). This is the ideal, of course. Like SMT generally, how closely it can be approximated is an empirical matter, and there remain many challenges.

[2] Such an inefficient and unintelligent technique is the modus operandi of many machine learning (weak AI) systems.

Parameter specification – i.e., the P&P-conception of "learning" as the specification of values for the variables in I-language – can be schematized as a decision tree (parameter hierarchy) which, as Roberts has shown, is governed by minimax economy: minimizing formal features (feature-economy) coupled with maximizing accessible features (input-generalization). Traversal of a hierarchy – a conditional-branching Turing machine program – is inevitably economical in that the shortest (in binary) and most general parameter settings are necessarily "preferred" in the sense that the faster the computation halts, the shorter the parameter settings. For instance, to specify word-order, a series of binary queries with answers of increasing length and decreasing generality (microparameters) is structured thus:



For compatibility with computability theory and Boolean logic, the parameter hierarchy can be translated as follows:

(1) Hierarchy: *H*
State *T*: Decision problem
Yes: 0/1 (0 = transition to state *T*+1) (1 = halt and output parameter specification for *H*)
No: 0/1 (0 = transition to state *T*+1) (1 = halt and output parameter specification for *H*)

(2) Hierarchy: Word order
State 1: Is head-final present?
Yes: Output 0 (transition to State 2)
No: Output 1 (halt and output "head-initial")

State 2: Present on all heads?
Yes: Output 1 (halt and output "head-final")
No: Output 0 (transition to State 3)

State 3: Present on [+V] heads?
Yes: Output 1 (halt and output "head-final in clause only")
No: Output 0 (transition to State 4)

…

So in P&P, the logic is not "enumerate and evaluate" with stipulative (theory-internal) simplicity measures: it is "compute all and only what is necessary", which implies the language-independent reality of economy in that, as with the parameter hierarchies, the process answers all and only the questions it needs to. It is not that there is any explicit instruction in the genetic endowment to prefer simple answers: it is simply otiose and meaningless to answer unasked questions (i.e., once the parameters are set, the computation halts).[3]

Moreover the "answers" to "questions" can be represented in binary. Indeed binary is a *notation-independent* notion necessary and sufficient to *maximize* computation with *minimal* complexity: functions of arbitrarily many arguments can be realized by the composition of binary (but not unary) functions – a truth of minimax logic with "far-reaching significance for our understanding of the functional architecture of the brain" (Gallistel & King 2010: x). The mathematical and computational import of binary was rendered explicit in the theories of Turing (1937) and Shannon (1948), the former demonstrating the necessarily digital – hence ultimately binary – nature of *universal computation* (a universal Turing machine being the most general mathematical characterization of computation); the latter formalizing *information* in terms of *bits* (binary digits). The consilience of these ideas is our economy thesis: human language is based on simple representations (i.e., bits) and strong computations (i.e., the binary functions of Turing machines) – and "economy of a basis may be said to be the ratio of its *strength* to its simplicity" (Goodman 1943: 111).

[3]In this way it is trivial to derive Ockham's razor from virtual conceptual necessity. If the law of parsimony is not to multiple entities beyond necessity, and language conforms to conceptual necessity, then ergo it is maximally parsimonious. As Wittgenstein (1922) observed: "Ockham's maxim is, of course, not an arbitrary rule, nor one that is justified by its success in practice: its point is that unnecessary units in a sign-language mean nothing" (5.47321); "If a sign is *useless*, it is meaningless. That is the point of Ockham's maxim" (3.328).

5 Universal economy

As one of the "general considerations of conceptual naturalness that have some independent plausibility", economy would be a factor that obtains of any optimally "designed" (natural or artificial) computational system. So, rethinking universality, if the Martian language were optimal in the sense of conforming to virtual conceptual necessity, then it might be surprisingly similar to human language. In point of fact, we ought not to be too surprised. It is now well established by biologists that *convergence* is a common theme in any evolutionary process:

> the number of evolutionary end-points is limited: by no means is everything possible. [Because of evolutionary convergence,] what is possible usually has been arrived at multiple times, meaning that the emergence of the various biological properties is effectively inevitable.
>
> (Conway Morris 2013: xii–xiii)

Indeed, the paleontologist Simon Conway Morris argues that human-style intelligence was effectively inevitable given the initial conditions of evolution on Earth. And there is no reason a priori to assume that the principle of evolutionary convergence is unique to the biology of a particular planet. Quite the contrary, if we accept the rational form of inquiry in which the principle is understood abstractly in a computational framework. The idea is that *any* computational system *anywhere* made of *anything* is governed by *laws* of computation. As the cognitive scientist C.R. Gallistel and computer scientist Adam King argue persuasively (Gallistel & King 2010: 167):

> The functional structure of modern computers is sometimes discussed by neuroscientists as if it were an accidental consequence of the fact that computing circuits are constructed on a silicon substrate and communicate by means of pulses of electrical current sent over wires. Brains are not computers, it is argued, because computers are made of silicon and wire, while brains are made of neurons. We argue that, on the contrary, several of the most fundamental aspects of the functional structure of a computer are dictated by the logic of computation itself and that, therefore, they will be observed in any powerful computational device, no matter what stuff it is made of. In common with most contemporary neuroscientists, we believe that brains are powerful computational devices. We argue, therefore, that those aspects of the functional structure of a modern computer that are dictated by the logic of computation must be critical parts of the functional structure of brains. (Gallistel & King 2010: 167)

This argument simply reiterates Turing's (1950: 446) thesis that "[i]f we wish to find such similarities [as may exist between minds and machines] we should look [not at their substrates, but] rather for mathematical analogies of function". And given this universality of the functional, mathematical architecture of computation, it is possible that we may need to rethink how uniquely human or even uniquely biological our modes of mental computation really are. One interesting implication is that we must rethink any presumptions that extraterrestrial intelligence or artificial intelligence would really be all that different from human intelligence.

So we assume that human language is a computational process that can be characterized by a Turing machine (see Watumull 2015). It is possible to explore the space of all possible Turing machines (i.e., the space of all possible computer programs), not exhaustively of course, but with sufficient breadth and depth to make some profound discoveries. The late Marvin Minsky, founder of the artificial intelligence laboratory at MIT, and his student Daniel Bobrow, once enumerated and ran some thousands of the simplest Turing machines (computer programs with minimal numbers of rules). Intriguingly, out of the infinity of possible behaviors, only a surprisingly small subset emerged. These divided into the trivial and the nontrivial. The boring programs either halted immediately or erased the input data or looped indefinitely or engaged in some similar silliness. The remainder, however, were singularly interesting: *all* of these programs executed an effectively *identical* counting function – a primitive of elementary arithmetic. In fact, this operation reduces to a form of Merge (see Chomsky 2008). More generally, these "A-machines" (*A* for *arithmetic*) prove a point:

> [I]t seems inevitable that, somewhere, in a growing mind some A-machines must come to be. Now, possibly, there are other, really different ways to count. So there may appear, much, much later, some of what we represent as 'B-machines' – which are processes that act in ways which are similar, but not identical to, how the A-machines behave. But, our experiment hints that even the very simplest possible B-machine will be so much more complicated that it is unlikely that any brain would discover one before it first found many A-machines. (Minsky 1985: 121)

> Let us think of this exploration as exposing parts of some infinite 'universe of possible computational structures'. Then this tiny fragment of evidence suggests that such a universe may look something like [Figure 1.1]. (Minsky 1985: 120)

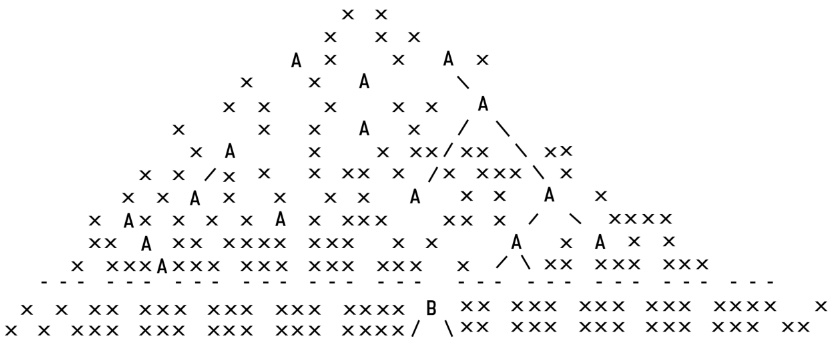


Figure 1.1: Representation of a universe with “A” and “B-machines” (Minsky 1985: 120)

This is evidence that arithmetic – the foundation of any mathematical/computational system – as represented in an A-machine – reducible to Merge – is technically an *attractor* in the *phase space* of possible mathematical structures:

> any entity who searches through the simplest processes will soon find fragments which do not merely resemble arithmetic but *are* arithmetic. It is not a matter of inventiveness or imagination, only a fact about the geography of the universe of computation. (Minsky 1985: 122)

Curiously, some physicists have argued that human mathematics is contingent: “the next batch of aliens might turn out to be different” (Alford 2006: 774), with no recognizable rules or systems. This objection echoes once regnant dogma in linguistics that “[human] languages could differ from each other without limit and in unpredictable ways” such that linguists ought to proceed “without any preexistent scheme of what a language must be” (Joos 1957: 96, v), implying that any two human languages could be as different from each other as any one could be from an alien language. But this dogma could not withstand critical scrutiny, and was dispelled with the advent of generative linguistics and its formulation of universal grammar – the theory of the abstract grammatical system encoded genetically in *Homo sapiens sapiens* – and crucially by the deeper empirical inquiries into the languages of the world undertaken within the framework of generative grammar (e.g., the spectacular demonstration that Warlpiri, contrary to all appearances, has the standard hierarchical structures universal to natural languages (see Hale 1976; Legate 2001). To the extent that SMT is true, general properties derivative of this formal system define the properties universal to particular languages. Therefore we should indeed study these particular languages with a "preexistent scheme of what a language must be" because UG and general principles of computation constrain the space of possible linguistic properties. And thus languages could not "differ from each other without limit", but only in "[predictable] ways".

The thesis that arithmetic is an *attractor* in the *phase space* of possible mathematical structures obviously generalizes beyond arithmetic to all simple computations (see Wolfram 2002 for countless examples). "Because of this, we can expect certain 'a priori' structures to appear, almost always, whenever a computational system evolves by selection from a universe of possible processes" (Minsky 1985: 119). Analogously, we submit that it is not implausible that an evolutionary search through the simplest computations will soon find something like Merge. Merge is an operation so elementary as to be subsumed somehow in every more complex computational procedure: take two objects X and Y already constructed and form the object Z without either modifying X or Y, or imposing any additional structure on them: thus Merge(X, Y) = {X, Y}.[4] This simple assumption suffices to derive in a principled (necessary) way a complex array of otherwise arbitrary (contingent) phenomena such as the asymmetry of the conceptual-intentional and sensory-motor interfaces (entailing the locus of surface complexity and variety), the ubiquity of dislocation, structure-dependence, minimal structural distance for anaphoric and other construals, the difference between what reaches the mind for semantic interpretation and what reaches the apparatus of articulation and perception (see Chomsky 2017).

6 The dawn of language

As we discussed in terms of our economy thesis, simplicity can be defined in algorithmic information theory (or the theory of program-size complexity): the complexity of a program is measured by its maximally compressed length in bits so that the simplest program is that with the shortest description. A search of the phase space of possible programs, whether conducted consciously (e.g., by us, extraterrestrials, etc.) or unconsciously (e.g., by modern computers, evolution, etc.) automatically proceeds in size order from the shortest and increasing to programs no shorter than their outputs (these incompressible programs are effectively lists); many complex programs would subsume simpler programs as the real numbers subsume the natural numbers. And, as demonstrated logically and empirically, "any evolutionary process must first consider relatively simple

[4] This formulation of Merge requires some rethinking in ways that we can put aside here (see Watumull et al. in press for discussion).

systems, and thus discover the same, isolated, islands of efficiency" (Minsky 1985: 122). Why are the simple systems (e.g., Merge) so sparsely distributed in the phase space of possible processes? (Why are they "islands" in the computational universe?) Why are there no "similar" processes in the neighborhood? (There is not something "like" arithmetic out there: there is just arithmetic, "cold and austere, […] yet sublimely pure, and capable of a stern perfection such as only the greatest art can show" in Bertrand Russell's words.) The answer must be that small sets of rules (e.g., Merge) can generate unbounded complexity, but the converse is not in general true: it is simply a mathematical fact (a tautology) that there is only a small set of small sets of rules, and thus not all complex phenomena can be generated by small sets of rules (there is simply not a sufficient number of small sets of rules "to go around"). This explains why, for instance, one cannot fiddle with arithmetic: one cannot posit its simple rules, generate a universe of consequences, and then make changes to that universe and expect the simple rules to cover the "revised" universe (e.g., one cannot remove a number or change a sum, product, etc.). Analogously, having posited Merge and executed it to generate the discrete infinity of syntactic structures, one cannot modify the logic (e.g., structure dependence) that obtains of those structures by dint of their having been generated by Merge and still expect Merge to generate new structures that conform to the modified logic, for the modified system is now "miraculous" in the technical sense of possessing properties that did not emerge from the rules themselves (or nonarbitrary third factors, i.e., laws of nature). And there cannot be infinitely many sets of small rules in the neighborhood of Merge to produce the effect of continuity. Thus there can only be *islands* of computation, not *continents*.

Thus it may well be that, given the universal and invariant laws of evolution, convergence on systems – Turing machines – virtually identical to those "discovered" in our evolutionary history is inevitable.[5] Hence our rethinking the proposition "Martian could be different".

The fact that simple computations are attractors in the phase space of possible computations goes some way to explaining why language should be optimally designed (insofar as SMT holds) in that an evolutionary search is likely to converge on it, which leads us to consideration of the origin of language. Convergence is a consequence of constraints. As with intelligence, evolution and development are possible only by coupling scope with constraints. Stated generally: the scope

[5]Indeed we might speculate that were we to "wind the tape of life back" and play it again, in Stephen Jay Gould's phrasing, not only would something like Merge reemerge, but something like humans could well be "inevitable", as some biologists have suggested (see Conway Morris 2013).

of any creative process is a function of its operating within limits. In the context of evolution, for instance, Stuart Kauffman (1993: 118) observes,

> Adaptive evolution is a search process – driven by mutation, recombination, and selection – on fixed or deforming fitness landscapes. An adapting population flows over the landscape under these forces. The structure of such landscapes, smooth or rugged, governs both the evolvability of populations and the sustained fitness of their members. The structure of fitness landscapes inevitably imposes limitations on adaptive search.

The analogy to mind is deeply nontrivial, for "intellectual activity consists mainly of various kinds of search" (Turing 1948: 431).

The evolution of language is mysterious (see Hauser et al. 2014), but SMT is consistent with the limited archeological evidence that does exist on the emergence of language, evidently quite recently and suddenly in the evolutionary time frame (see Tattersall 2012).[6] Furthermore there is compelling evidence for SMT in the design of language itself. For instance, it is a universal truth of natural language that the rules of syntax-semantics are structure-dependent (see Berwick et al. 2011): hierarchy, not linearity, is determinative in the application of rules and interpretation of expressions. This implies a far-reaching thesis with many consequences: linear order is a peripheral property of language, emerging only in externalization at the sensory-motor interface (where serial ordering is necessary). If this thesis holds generally, then Aristotle's dictum that language is "sound with meaning" should be revised: language is not sound with meaning, but rather meaning with sound (or some other modality of externalization), a very different concept, reflecting a different traditional idea: that language is fundamentally an instrument of thought – "audible thinking", "the spoken instrumentality of thought", as William Dwight Whitney expressed the traditional conception (see Chomsky 2013), consistent with the Cartesian idea that language is a central component of our mind as a "universal instrument", endowing us with general intelligence. As François Jacob suggested (see Berwick & Chomsky 2011), plausibly, "the role of language as a communication system between individuals would have come about only secondarily" to the emergence of generative syntax (Merge, we would now say) and its mapping of structures to the conceptual-intentional system for semantic interpretation. "The quality of language that makes it unique does not seem to be so much its role in communicating directives for action" or other typical features of animal communication, but rather

[6] There is quite compelling evidence that since the trek of our ancestors from Africa some 50,000 years ago, the language faculty has undergone no significant change, and not very long before (in evolutionary time) there is no evidence that it existed at all.

"its role in symbolizing, in evoking cognitive images", in molding our notion of reality and yielding our capacity for thought and planning, through its unique property of allowing "infinite combinations of symbols" and therefore "mental creation of possible worlds". Thus the most reasonable speculation today – and one that opens productive lines of research – is that from some simple rewiring of the brain, Merge emerged, naturally in its simplest form, providing the basis for unbounded and creative thought – the "great leap forward" evidenced in the archeological record and in the remarkable differences distinguishing modern humans from their predecessors and the rest of the animal kingdom (see Huybregts 2017; Berwick & Chomsky 2016 for in-depth discussion of these topics).

If this conjecture can be sustained, we could answer the question why language should be optimally designed: optimality would be expected under the postulated conditions, with no selectional or other pressures operating; the emerging system should just follow the laws of nature such as minimal computation and more "general considerations of conceptual naturalness that have some independent plausibility, namely, simplicity, economy, symmetry, nonredundancy, and the like" – rather the way a snowflake forms. If this is correct, then, contrary to what was once presumed, there *would* be a priori reasons to expect any language anywhere in the universe would resemble human language; the "principles, conditions, and rules that are elements or properties of all human languages" *would* be *logically* necessary, deriving from laws of nature. And so, just as physicists seek "an idea so simple, so beautiful, that […] we will all say to each other, how could it have been otherwise?", in the study of language we search for – and are discovering – objects of great beauty and simplicity.

7 The wonders of language

> It is […] quite possible that we, as a species, have crossed a cognitive threshold. Our capacity to express anything, through the recursive syntax and compositional semantics of natural language, might have taken us into a cognitive realm where anything, everything, is possible. Effectively, having language has made us the equal of any extraterrestrial.
>
> (Roberts 2017: 181–182)

Notwithstanding the universal logic of computation, it is obviously necessary that there exist *constraints* on the mind if it is to have any *scope* at all, and these constraints may very well be uniquely human. Taking the extreme case, suppose that the human mind is a universal Turing machine (see Watumull 2015).

Such a mind could be a *universal explainer*. The argument is simple: a universal Turing machine can emulate any other Turing machine (i.e., a universal computer can run any program); a program is a kind of theory (written to be readable/executable by a computer); thus a universal Turing machine can compute any theory; and thus, assuming that everything in the universe could in principle be explained by and understood within some theory or other (in other words, assuming no magic, miracles, etc.), a universal Turing machine – a Turing-universal mind – could explain and understand everything. It is an intriguing conclusion, and not obviously false, but numerous objections could be posed. For instance,

> an arbitrary Turing machine, or an unrestricted rewriting system, is too unstructured to serve as a grammar [...]. Obviously, a computer program that succeeded in generating sentences of a language would be, in itself, of no scientific interest unless it also shed some light on the kinds of structural features that distinguish languages from arbitrary, recursively enumerable sets. (Chomsky 1963: 360)

Beyond language, if a Turing-universal mind is to be a universal explainer, it should not generate all possible explanations, true and false, because that would be merely to restate the problem of explaining nature: deciding which in an infinite set of explanations are the true (or best) explanations is as difficult as constructing the best explanations in the first place. There must be "limits on admissible hypotheses", in the words of Charles Sanders Peirce (see Chomsky 2006). This interdependence of scope and limits has been expounded by many creative thinkers and analyzed by (creative) philosophers of esthetics: the beauty of jazz emerges not by "playing anything", but only when the improvisation is structured, canalized; the beauty of a poem is a function of its having to satisfy the constraints of its form, as the mathematician Stanislaw Ulam (1976: 180) observed,

> When I was a boy I felt that the role of rhyme in poetry was to compel one to find the unobvious because of the necessity of finding a word which rhymes. This forces novel associations and almost guarantees deviations from routine chains or trains of thought. It becomes paradoxically a sort of automatic mechanism of originality.

Thus from science to art, we see that the (hypothesized) infinite creativity of the Turing-universal human mind is non-vacuous and useful – and beautiful – only if it operates within constraints – constraints that appear to be uniquely human.

> So understanding language means understanding a very big part of what it is to be human, what it is to be you. And that is perhaps the greatest wonder of language of all. (Roberts 2017: 182)

The wonders of language Ian Roberts has illuminated are beyond counting; we have surveyed but a twinkling here. Indeed, of his work we might say, in closing, "my God! – *it's full of stars*!" (Clarke 1968: 202).

Abbreviations

SMT	strong Minimalist thesis	UG	Universal Grammar

References

Alford, Mark. 2006. On math, matter, and mind. *Foundations of Physics* 36(6). 765–794. DOI: 10.1007/s10701-006-9048-x.

Berwick, Robert C. & Noam Chomsky. 2011. The biolinguistic program: The current state of its evolution. In Anna Maria Di Sciullo & Cedric Boeckx (eds.), *The biolinguistic enterprise: New perspectives on the evolution and nature of the human language faculty*, 19–41. Oxford: Oxford University Press.

Berwick, Robert C. & Noam Chomsky. 2016. *Why only us: Language and evolution*. Cambridge, MA: MIT Press.

Berwick, Robert C., Paul Pietroski, Beracah Yankama & Noam Chomsky. 2011. Poverty of the stimulus revisited. *Cognitive Science* 35(7). 1207–1242. DOI: 10.1111/j.1551-6709.2011.01189.x.

Biberauer, Theresa. 2016. Going beyond the input (and UG): An emergentist generative perspective on syntactic variation, stability and change. Paper presented at The Emergence of Modern Hebrew Workshop, Hebrew University of Jerusalem, 6 July 2016.

Chaitin, Gregory. 2005. *Meta math: The quest for omega*. New York: Vintage Books.

Chomsky, Noam. 1951. *The morphophonemics of modern Hebrew*. University of Pennsylvania. (MA thesis).

Chomsky, Noam. 1963. Formal properties of grammars. In R. Duncan Luce, Robert R. Bush & Eugene Galanter (eds.), *Handbook of mathematical psychology*, vol. II, 323–418. New York: Wiley & Sons.

Chomsky, Noam. 1965. *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.

Chomsky, Noam. 1975. *Reflections on language*. New York: Pantheon.

Chomsky, Noam. 1981. *Lectures on government and binding*. Dordrecht: Foris.

Chomsky, Noam. 1995. *The Minimalist program*. Cambridge, MA: MIT Press.

Chomsky, Noam. 2000. Minimalist inquiries: The framework. In Roger Martin, David Michaels & Juan Uriagereka (eds.), *Step by step: Essays on minimalist syntax in honor of Howard Lasnik*, 89–155. Cambridge, MA: MIT Press.

Chomsky, Noam. 2002. *On nature and language*. Cambridge: Cambridge University Press.

Chomsky, Noam. 2005. Three factors in language design. *Linguistic Inquiry* 36(1). 1–22. DOI: 10.1162/0024389052993655.

Chomsky, Noam. 2006. *Language and mind*. Cambridge: Cambridge University Press.

Chomsky, Noam. 2008. On phases. In Robert Freidin, Carlos P. Otero & Maria Luisa Zubizarreta (eds.), *Foundational issues in linguistic theory: Essays in honor of Jean-Roger Vergnaud*, 133–166. Cambridge, MA: MIT Press.

Chomsky, Noam. 2013. Problems of projection. *Lingua* 130. 33–49. DOI: 10.1016/j.lingua.2012.12.003.

Chomsky, Noam. 2016. *What kind of creatures are we?* New York: Columbia University Press.

Chomsky, Noam. 2017. The language capacity: Architecture and evolution. *Psychonomic Bulletin & Review* 24(1). 200–203. DOI: 10.3758/s13423-016-1078-6.

Chomsky, Noam, Ángel J. Gallego & Dennis Ott. 2019. Generative grammar and the faculty of language: Insights, questions and challenges. *Catalan Journal of Linguistics*. DOI: 10.5565/rev/catjl.288.

Chomsky, Noam & George Miller. 1963. Introduction to the formal analysis of natural languages. In R. Duncan Luce, Robert R. Bush & Eugene Galanter (eds.), *Handbook of mathematical psychology*, vol. II, 269–321. New York: Wiley & Sons.

Clarke, Arthur C. 1968. *2001: A space odyssey*. New York: Penguin.

Conway Morris, Simon. 2013. *Inevitable humans in a lonely universe*. Cambridge: Cambridge University Press.

Deutsch, David. 2011. *The beginning of infinity: Explanations that transform the world*. New York: Viking.

Gallistel, Charles Randy & Adam Philip King. 2010. *Memory and the computational brain: Why cognitive science will revolutionize neuroscience*. New York: Wiley–Blackwell.

Goodman, Nelson. 1943. On the simplicity of ideas. *Journal of Symbolic Logic* 8(4). 107–121. DOI: 10.2307/2271052.

Hale, Kenneth L. 1976. The adjoined relative clause in Australia. In R.M.W. Dixon (ed.), *Grammatical categories in Australian languages*, 78–105. Canberra: Australian Institute of Aboriginal Studies.

Hauser, Marc D., Charles D. Yang, Robert C. Berwick, Ian Tattersall, Michael J. Ryan, Jeffrey Watumull, Noam Chomsky & Richard C. Lewontin. 2014. The mystery of language evolution. *Frontiers in Psychology* 5. DOI: 10.3389/fpsyg.2014.00401.

Huybregts, Riny. 2017. Phonemic clicks and the mapping asymmetry: How language emerged and speech developed. *Neuroscience and Behavioral Reviews* 81(B). 279–294. DOI: 10.1016/j.neubiorev.2017.01.041.

Joos, Martin. 1957. *Readings in linguistics: The development of descriptive linguistics in America since 1925.* Washington, DC: American Council of Learned Societies.

Kauffman, Stuart. 1993. *Self-organization and selection in evolution.* Oxford: Oxford University Press.

Legate, Julie Anne. 2001. The configurational structure of a nonfigurational language. *Linguistic Variation Yearbook* 1(1). 61–104. DOI: 10.1075/livy.1.05leg.

Minsky, Marvin. 1963. Steps towards artificial intelligence. In Edward A. Feigenbaum & Julian Feldman (eds.), *Computers and thought*, 406–450. New York: McGraw–Hill.

Minsky, Marvin. 1985. Why intelligent aliens will be intelligible. In Edward Regis (ed.), *Extraterrestrials: Science and alien intelligence*, 117–128. Cambridge, MA: MIT Press.

Obata, Miki, Samuel Epstein & Marlyse Baptista. 2015. Can crosslinguistically variant grammars be formally identical? Third factor underspecification and the possible elimination of parameters of UG. *Lingua* 156. 1–16. DOI: 10.1016/j.lingua.2014.12.003.

Popper, Karl. 1963. *Conjectures and refutations.* New York: Routledge.

Riskin, Jessica. 2017. *The restless clock: A history of the centuries-long argument over what makes living things tick.* Chicago: University of Chicago Press.

Roberts, Ian. 2012. Macroparameters and minimalism: A programme for comparative research. In Charlotte Galves, Sonia Cyrino, Ruth Lopes, Filomena Sandalo & Juanito Avelar (eds.), *Parameter theory and linguistic change*, 320–335. Oxford: Oxford University Press.

Roberts, Ian. 2017. *The wonders of language or how to make noises and influence people.* Cambridge: Cambridge University Press.

Roberts, Ian & Anders Holmberg. 2010. Introduction: Parameters in minimalist theory. In Theresa Biberauer, Anders Holmberg, Ian Roberts & Michelle Sheehan (eds.), *Parametric variation: Null subjects in minimalist theory*, 1–57. Cambridge: Cambridge University Press.

Roberts, Ian & Jeffrey Watumull. 2015. Leibnizian linguistics. In Ángel J. Gallego & Dennis Ott (eds.), *50 years later: Reflections on Chomsky's* Aspects, 211–222. Cambridge, MA: MIT Press.

Shannon, C.E. 1948. A mathematical theory of communication. *Bell System Technical Journal* 27(3). 379–423. DOI: 10.1002/j.1538-7305.1948.tb01338.x.

Sheehan, Michelle, Theresa Biberauer, Ian Roberts & Anders Holmberg. 2017. *The Final-over-Final Condition: A syntactic universal*. Cambridge, MA: MIT Press.

Tattersall, Ian. 2012. *Masters of the planet: The search for our human origins*. New York: Palgrave Macmillan.

Turing, Alan M. 1937. On computable numbers, with an application to the Entscheidungsproblem. *Proceedings of the London Mathematical Society* s2-42(1). 230–265. DOI: 10.1112/plms/s2-42.1.230.

Turing, Alan M. 1950. Computing machinery and intelligence. In Jack B. Copeland (ed.), *The essential Turing*, 433–464. Oxford: Clarendon Press.

Turing, Alan M. 1948. Intelligent machinery. In Jack B. Copeland (ed.), *The essential Turing*, 395–432. Oxford: Clarendon Press.

Ulam, Stanislaw. 1976. *Adventures of a mathematician*. New York: Scribner's.

Watumull, Jeffrey. 2015. *The linguistic Turing Machine*. University of Cambridge. (Doctoral dissertation).

Watumull, Jeffrey, Noam Chomsky & Ian Roberts. 2017. Economy in grammar learning. Paper presented at the workshop *Simplicity in Grammar Learning*, 23 September 2017.

Watumull, Jeffrey, Ian G. Roberts & Noam Chomsky. In press. Universal Grammar. In Douglas Vakoch (ed.), *Xenolinguistics: Toward a science of extraterrestrial language*. Oxford: Oxford University Press.

Wheeler, John Archibald. 1986. How come the quantum? *Annals of the New York Academy of Sciences* 480(1). 304–316. DOI: 10.1111/j.1749-6632.1986.tb12434.x.

Wittgenstein, Ludwig. 1922. *Tractatus logico-philosophicus*. London: Routledge.

Wolfram, Stephen. 2002. *A new kind of science*. Champagne, IL: Wolfram Media.