Optimality Theory: Universal Grammar, Learning and Parsing Algorithms, and Connectionist Foundations
(Abstract)

Paul Smolensky and Bruce Tesar
Department of Computer Science and Institute of Cognitive Science
University of Colorado, Boulder USA

We present a recently proposed theory of grammar, Optimality Theory (OT; Prince & Smolensky 1991, 1993). The principles of OT derive in large part from the high-level principles governing computation in connectionist networks. The talk proceeds as follows: (1) we summarize OT and its applications to UG. The we present (2) learning and (3) parsing algorithms for OT. Finally, (4) we show how crucial elements of OT emerge from connectionism, and discuss the one central feature of OT which so far eludes connectionist explanation.

(1) In OT, UG provides a set of highly general universal constraints which apply in parallel to assess the well-formedness of possible structural descriptions of linguistic inputs. The constraints may conflict, and for most inputs no structural description meets them all. The grammatical structure is the one that optimally meets the conflicting constraint sets. Optimality is defined on a language-particular basis: each language's grammar ranks the universal constraints in a dominance hierarchy such that each constraint has absolute priority over all lower-ranked constraints. Given knowledge of UG, the job of the learner is to determine the constraint ranking which is particular to his or her language. [The explanatory power of OT as a theory of UG has now been attested for phonology in over two dozen papers and books (e.g., McCarthy & Prince 1993; Rutgers Optimality Workshop, 1993); applications of OT to syntax are now being explored (e.g. Legendre, Raymond, & Smolensky 1993; Grimshaw 1993).]

(2) Learnability of OT (Tesar & Smolensky, 1993). Theories of UG can be used to address questions of learnability via the formal universal principles they provide, or via their substantive universals. We will show that OT endows UG with sufficiently tight formal structure to yield a number of strong learnability results at the formal level. We will present a family of closely related algorithms for learning, from positive examples only, language-particular grammars on the basis of prior knowledge of the universal principles. We will sketch our proof of the correctness of these algorithms and demonstrate their low computational complexity. (More precisely, the learning time in the worst case, measured in terms of 'informative examples', grows only as n^2, where n is the number of constraints in UG, even though the number of possible grammars grows as $n!$, i.e., faster than exponentially.) Because these results depend only on the formal universals of OT, and not on the content of the universal constraints which provide the substantive universals of the theory, the conclusion that OT grammars are highly learnable applies equally to OT grammars in phonology, syntax, or any other grammar component.

(3) Parsing in OT is assumed by many to be problematic. For OT is often described as follows: take an input form, generate all possible parses of it (generally, infinite in number), evaluate all the constraints against all the parses, filter the parses by descending the constraints in the dominance hierarchy. While this correctly characterizes the input/output function which is an OT grammar, it hardly provides an efficient parsing procedure. We will show, however, that efficient, provably correct parsing by dynamic programming is possible, at least when the set of candidate parses is sufficiently simple (Tesar, 1994).

(4) OT is built from a set of principles, most of which derive from high-level principles of connectionist computation. The most central of these assert that, given an input representation, connectionist networks tend to compute an output representation which best satisfies a set of conflicting soft constraints, with constraint conflicts handled via a notion of differential strength. Formalized through Harmony Theory (Smolensky, 1986) and Harmonic Grammar (Legendre, Miyata, & Smolensky 1990), this conception of computation yields a theory of grammar based on optimization. Optimality Theory introduces to a non-numerical form of optimization, made possible by a property as yet unexplained from the connectionist perspective: in grammars, constraints fall into strict domination hierarchies.