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Introducing Information Gradient Theory

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Much of modern science and technology relies on the notion of taxonomy (e.g., conceptual hierarchy, set theory). In a typical taxonomy, information is organized based on set/super/subset relationship from most specific to most generic (see Fig. 1a). Set theoretic or hierarchical organization of information is common in mathematics, logic, computing and information sciences (e.g., ontologies, conceptual modeling, and information retrieval). Taxonomic organization of knowledge counts as a theoretical contribution in natural and social sciences, including design science research [1, 2].

While there are advantages to set theoretic/taxonomic organization of information, we identify four important limitations, including (a) ***ontic rigidity*** (e.g., adjacent nodes in a taxonomy must belong to the same ontological kind – concepts and concepts but not concepts and attributes; individuals, when included must be at terminal nodes), (b) ***authoritative origin*** (e.g., taxonomies are typically created by experts and often do not reflect intuitive knowledge) (c) ***linearity*** (e.g., taxonomies are inflexible for depicting non-monotonic, analog structures), (d) bias toward ***property inheritance*** (which is one of many potentially useful ways to organize knowledge).

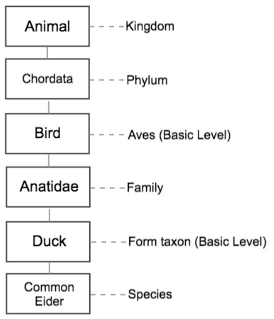

Fig 1a: Established Biol Hierarchy

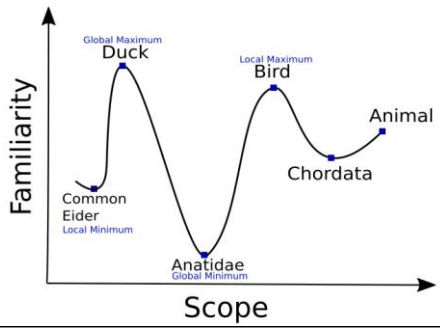

Fig 1b: Information gradient for Fig 1a

Recent developments in psychology suggest a variety of alternative structures for organizing information, including semantic networks, analog and non-discrete representational forms, and prototypical concepts [3, 4]. Research on semantic networks, for example, demonstrates that people form complex relationships between non-adjacent hierarchical nodes defying strict taxonomic arrangements [3]. Research on basic level categories, including in neuroscience, suggests that people privilege (in thinking, communication, action) middle levels (e.g., *bird* and *duck* in Fig 1a) implying that innate organization for humans may break strict traditional taxonomies [4, 5].

Informed by recent developments in psychology, to overcome limitations of set theory (above), we propose **information gradient theory (IGT).** According to IGT, domains can be represented as non-monotonic gradients consisting of continuous or discrete informational units, which may have *any ontic* status (including universals or classes, attributes or features and particulars or individuals) following a chosen organizing criteria (i.e., purpose or goal) that form two or more dimensions. For example, focusing on *familiarity* and *scope*, one can turn the taxonomy in Fig. 1a into an Information Gradient (IG) shown in Fig. 1b by taking each information unit and plotting it based on the organizing criteria (i.e., familiarity, scope) and then fitting a curve to the resulting points. The IG may be different based on another organizing criterion such as perceptual salience, frequency of encounter, ability to visualize, or any other goal. In each case we expect the IG to defy traditional taxonomic organization. Information gradients can be obtained by eliciting concepts from stakeholders or referencing existing information sources. Gradients may differ between individuals, between collectives, and within individuals, depending on the organizing criteria. IGT provides additional information not found in the hierarchical organization of knowledge. In Fig 1b IGT reflects the tradeoff between cognitive capacity (familiarity) and inferential utility (scope) of objects. The average individual may refer to a *Common Eider* as *bird* or *duck* - a tendency not evident in Fig 1 a.

As taxonomies underlie much of modern science and technology, we believe IGT has the potential for a broad contribution. Information gradients become a novel form of knowledge organization. They can be used to compare common knowledge with expert hierarchies, identify inconsistencies between intuitive and expert knowledge, suggest potential conflicts, and uncover conceptual gaps and opportunities. Information gradients can become valuable input for information technology design (e.g., by suggesting which concepts among many are more and less salient for people during data collection, search, and retrieval). Gradients may naturally differ in their shapes (e.g., some may have multiple minima and maxima, sharp vertical distances between nodes) reflecting and representing different in how people relate to the world. We hope that future studies will provide a formal definition of IG, describe its properties, suggest outcomes and explore specific applications of IGT in science and practice.

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