AUTOBIOGRAPHICAL RETROSPECTIVES

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KEY INFLUENCES

1. Antonín Svoboda

2. W. Ross Ashby

3. Lotfi A. Zadeh

Antonín (Tony) Svoboda (1907–1980)

- **He was one of the very best computer architects and designers. As his assistant for several years, I learned from him all stages of designing complex computer systems.**
- **He possessed incredibly deep knowledge in many areas outside engineering, and this became a role model for me.**
- **His remarkable creativity (98 patents!), holistic systems thinking, deep mathematical knowledge, and overall intellectual integrity have made a lasting influence on me throughout my whole professional career.**

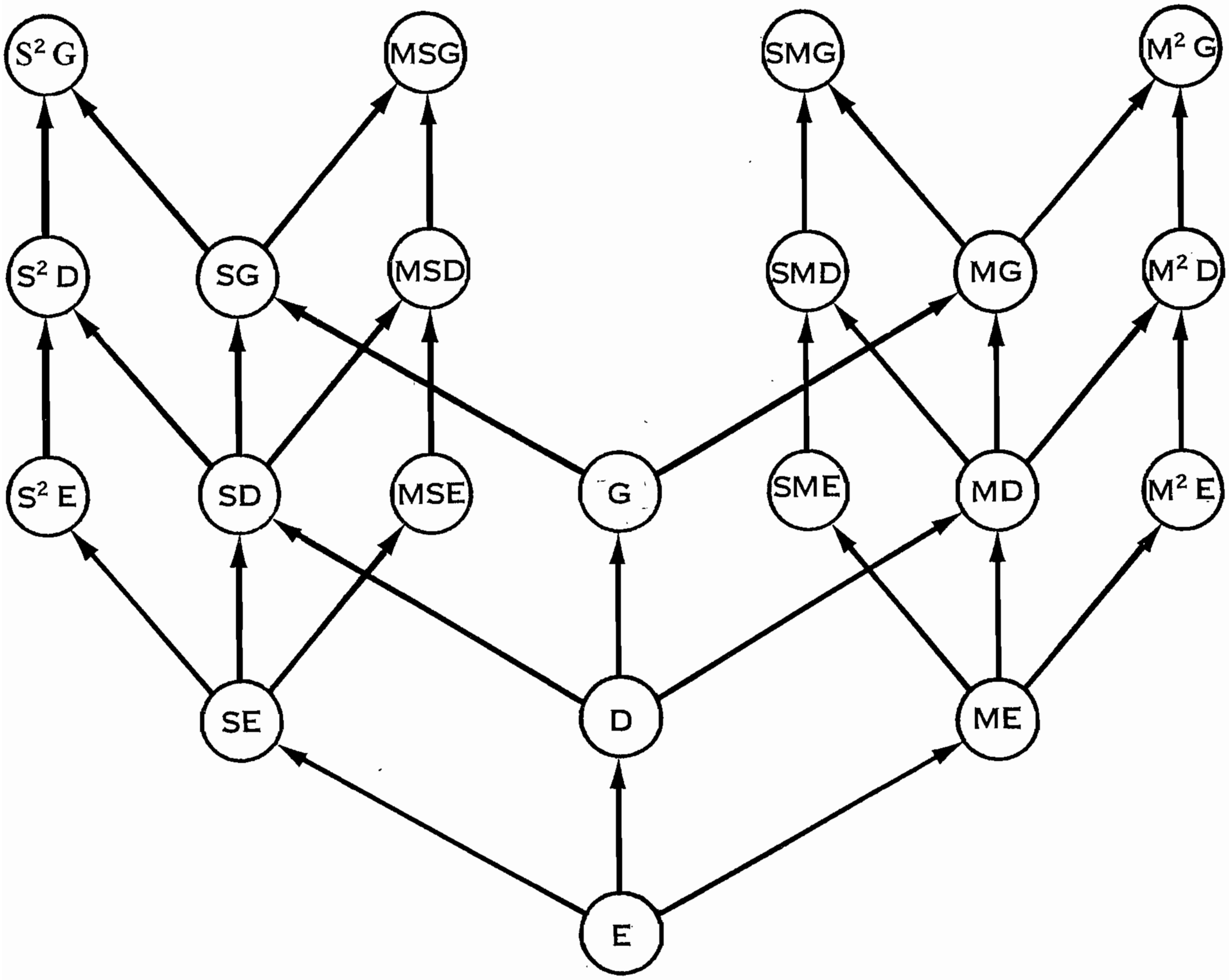
W. Ross Ashby
(1903–1972)

- **He made the concept of a system clear, highly general, and practical. His writings devoted to this issue confirmed to me that I was on the right track and encouraged me to pursue research that led eventually to my epistemological hierarchy of systems categories.**

- **He established the role of the computer as the laboratory of systems science.**

- **He was a pioneer in recognizing the value of information theory in studying systems, and he influenced me greatly in this regard.**

EPISTEMOLOGICAL HIERARCHY OF SYSTEMS CATEGORIES



UNCERTAINTY↔ INFORMATION

↑

CONSTRAINT

- **Experimental frame (EF_S) of a given system (S) is S without the constraint among its variables.**

- **The difference in uncertainty,**

  Uncertainty(EF_S|q) – Uncertainty(S|q),

  for each given question q results from the constraint among variables of system S.

- **Since this difference is equal to the amount of information furnished by system S with respect to question q, the constraint among variables of S is a source of this information for any given question q.**

Ashby's views about systems

At this point we must be clear about how a "system" is to be defined. Our first impulse is to point at the pendulum and to say "the system is that thing there". This method, however, has a fundamental disadvantage: every material object contains no less than an infinity of variables and therefore of possible systems. The real pendulum, for instance, has not only length and position; it has also mass, temperature, electric conductivity, crystalline structure, chemical impurities, some radio-activity, velocity, reflecting power, tensile strength, a surface film of moisture, bacterial contamination, and optical absorption, elasticity, shape, specific gravity, and so on and on. Any suggestion that we should study "all" the facts is unrealistic and actually the attempt is never made. What is necessary is that we should pick out and study the facts that are relevant to some main interest that is already given. …

… The system now means, not a thing, but a list of variables.

(*An Introduction to Cybernetics*, John Wiley, 1957, pp.39-40)

Ashby's Views About Systems Complexity

The word "complex," as it may be applied to systems, has many possible meanings, and I must first make my use clear. There is no obvious or preeminent meaning, for although all would agree that the brain is complex and the bicycle simple, one has also to remember that to a butcher the brain of a sheep is simple while a bicycle, if studied exhaustively (as the only clue to a crime) may present a very great quantity of significant detail.

Without further justification, I shall follow, in this paper, an interpretation of "complexity" that I have used and found suitable for about ten years. I shall measure the degree of "*complexity*" by a *quantity of information required to describe the vital system.* To the neurophysiologist the brain, as a feltwork of fibers and a soup of enzymes, is certainly complex; and equally the transmission of a detailed description of it would require much time. To the butcher the brain is simple, for he has to distinguish it from only about thirty other "meats," so no more than $\log_2 30$, i.e. about 5 bits, are involved. This method admittedly makes a system's complexity purely <u>relative to a given observer</u>; it rejects the attempt to measure an absolute, or intrinsic, complexity; but this acceptance of complexity as something in the eye of the beholder is, in my opinion, the only workable way of measuring complexity. ["Some peculiarities of complex systems." <u>Cybernetic Medicine</u>, IX(2), 1972, pp. 1-8.]

Lotfi A. Zadeh

- **His revolutionary idea of fuzzy sets, published in 1965, has tremendously expanded my way of thinking about systems.**

- **His many seminal ideas connected with fuzzy set theory, which have been emerging since 1965, have been an ongoing inspiration for my own research. This is perhaps most visible in my work on generalized information theory.**

- **His generalized theory of uncertainty (GTU), the latest of his seminal ideas, is a research program that is in some sense complementary to the one known as generalized information theory (GIT). While the goal of both GIT and GTU is to conceptualize and formalize uncertainty in all its manifestations, GIT follows a bottom-up approach to achieve this goal, while GTU follows a top-down approach.**

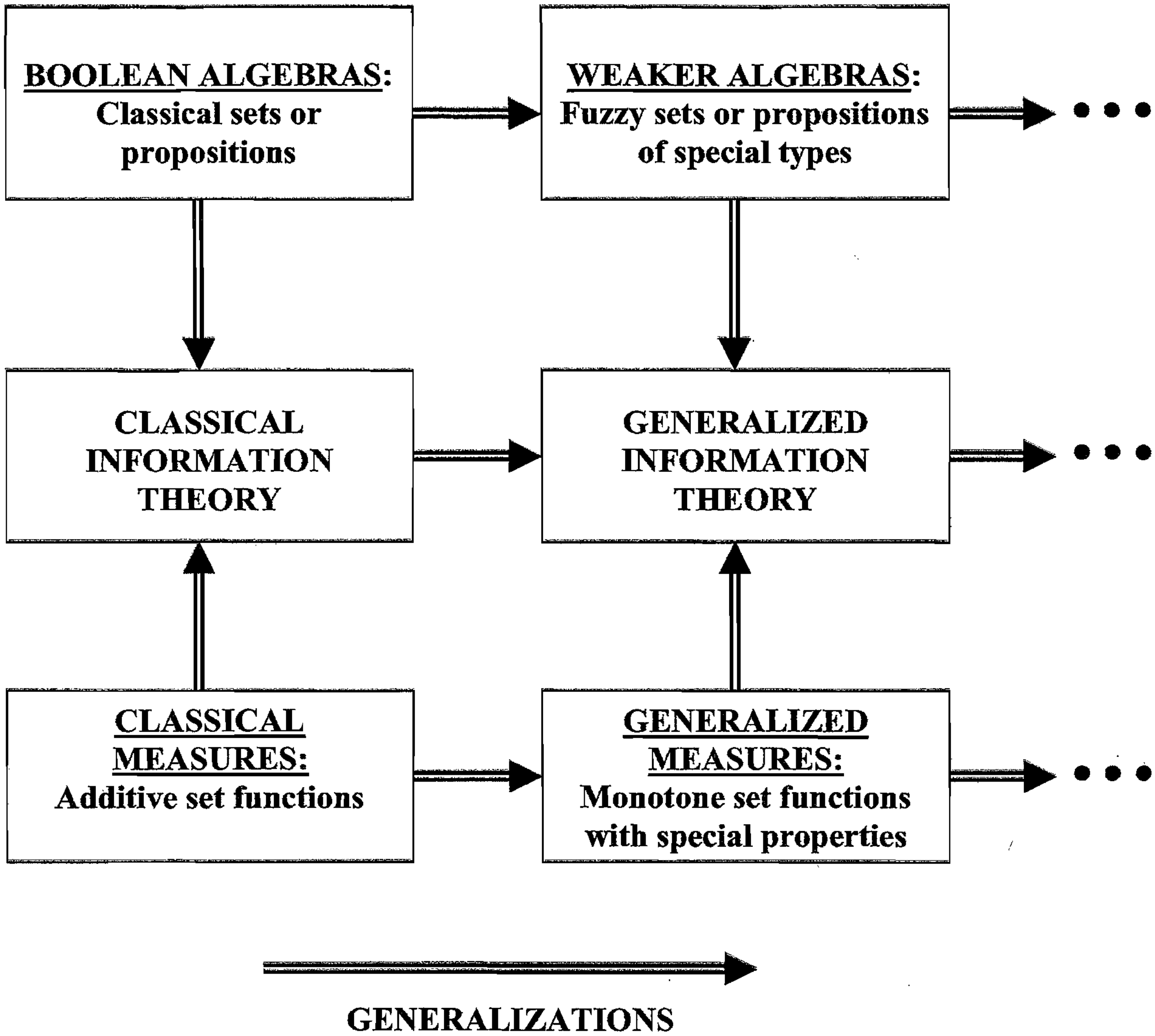
GENERALIZED INFORMATION THEORY (GIT)

- **GIT is a <u>research program</u> whose objective is to develop a formal treatment of the interrelated concepts of <u>uncertainty</u> and <u>information</u> in all their varieties; it is a generalization of two distinct branches of classical information theory, which are based, respectively, on the notions of <u>possibility</u> (crisp) and <u>probability</u>.**

- **In GIT, as in classical information theory, uncertainty (predictive, retrodictive, diagnostic, prescriptive, etc.) is viewed as a manifestation of some information deficiency, while information is viewed as the capacity to reduce uncertainty. That is, GIT deals with <u>information-based uncertainty</u> and <u>uncertainty-based information</u>.**

- **The aims of GIT were <u>introduced in 1991</u> in my paper "Generalized Information Theory" [*Fuzzy Sets and Systems*, 40(1), pp. 127-142].**

- **Comprehensive and up-to date coverage of results obtained by research within GIT is contained in the text <u>Uncertainty and Information</u> [John Wiley, Hoboken, NJ, 2006].**


BOOLEAN ALGEBRAS: Classical sets or propositions
WEAKER ALGEBRAS: Fuzzy sets or propositions of special types
CLASSICAL INFORMATION THEORY
GENERALIZED INFORMATION THEORY
CLASSICAL MEASURES: Additive set functions
GENERALIZED MEASURES: Monotone set functions with special properties
GENERALIZATIONS

UNCERTAINTY THEORIES			FORMALIZED LANGUAGES						
			CLASSICAL SETS	NONCLASSICAL SETS					
				STANDARD FUZZY SETS	NONSTANDARD FUZZY SETS				
					INTERVAL VALUED	TYPE 2	LEVEL 2	LATTICE BASED	• • •
MONOTONE MEASURES	ADDITIVE	CLASSICAL NUMERICAL PROBABILITY							
	NONADDITIVE	POSSIBILITY/ NECESSITY							
		SUGENO λ-MEASURES							
		BELIEF/ PLAUSIBILITY (CAPACITIES OF ORDER ∞)							
		CAPACITIES OF VARIOUS FINITE ORDERS							
		INTERVAL-VALUED PROBABILITY DISTRIBUTIONS							
		• • •							
		GENERAL LOWER AND UPPER PROBABILITIES							

THEORIES OF UNCERTAINTY

In order to develop a fully operational theory, T, for dealing with uncertainty of some conceived type requires that a host of issues be addressed at the following four levels:

- **LEVEL 1 --- we need to find an appropriate mathematical representation of the conceived type of uncertainty, which is achieved by characterizing, via appropriate axioms, a class of uncertainty functions, say functions u, that represent uncertainty in theory T.**

- **LEVEL 2 --- we need to develop operating rules (calculus) for manipulating the uncertainty functions u in theory T.**

- **LEVEL 3 --- we need to find a meaningful way of measuring the amount of relevant uncertainty in any situation formalizable in theory T, which is achieved by finding a justifiable functional, U, which for each uncertainty function u in theory T measures the amount of uncertainty associated with it.**

- **LEVEL 4 --- we need to develop methodological aspects of theory T by utilizing functional U as an abstract measuring instrument.**

The mathematical theory of information had come into being when it was realized that the flow of information can be represented numerically in the same way as distance, mass, temperature, etc.

(Alfréd Rényi)

UNCERTAINTY MEASURES: Key Requirements

1. **<u>Subadditivity</u>: The amount of uncertainty in a joint representation of evidence cannot be greater than the sum of the amounts of uncertainty in the associated marginal representations of uncertainty.**

2. **<u>Additivity</u>: The two amounts of uncertainty considered under subadditivity become equal when the marginal representations of evidence are noninteractive according to the rules of the uncertainty calculus involved.**

3. **<u>Range</u>: The range of uncertainty is [0, M], where 0 must be assigned to the unique uncertainty function that describes full certainty and M depends on the cardinality of the universal set involved and on the chosen unit of measurement.**

4. **<u>Continuity</u>: Any measure of uncertainty must be continuous.**

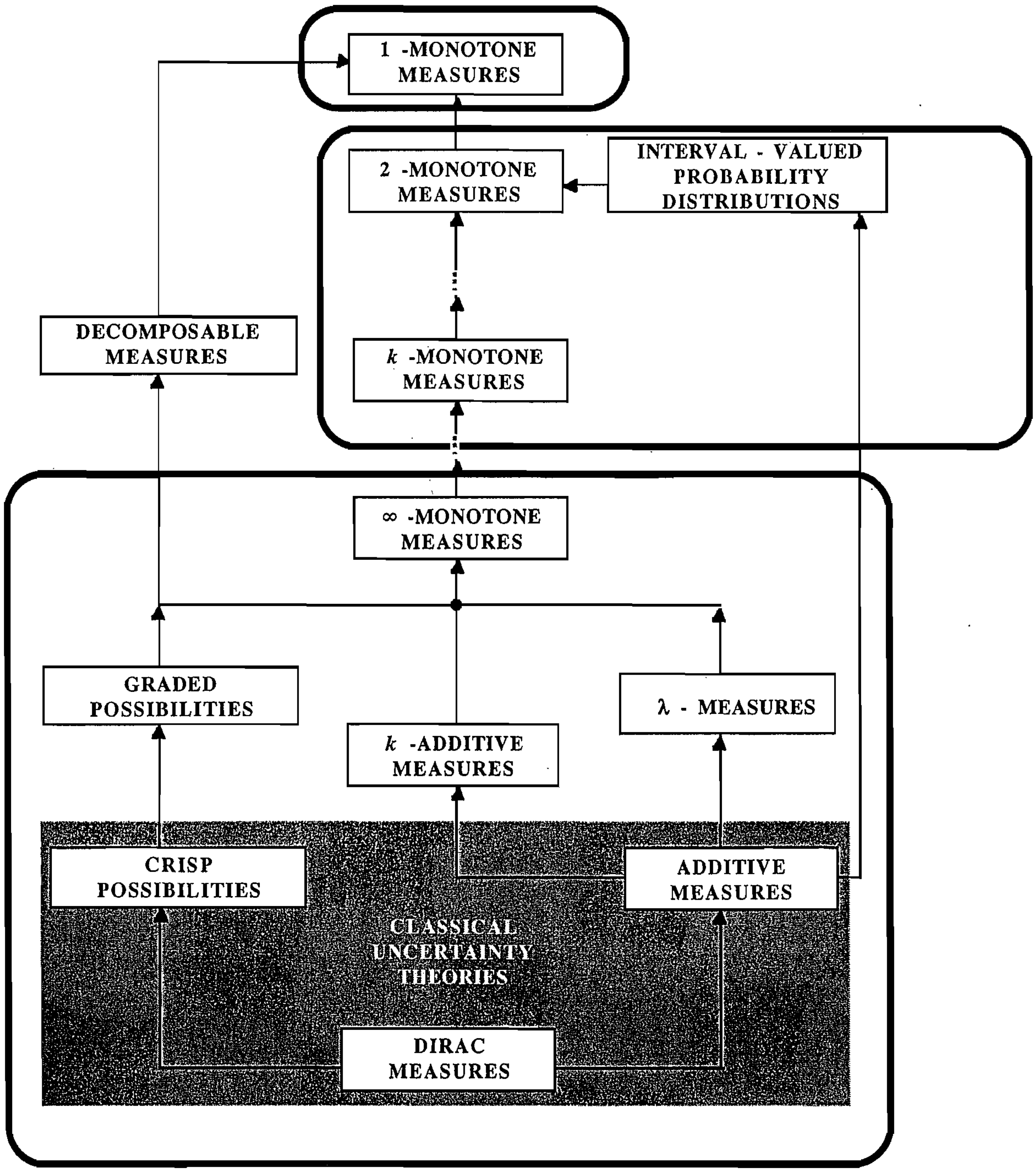
5. **<u>Expansibility</u>: Expanding the universal set by alternatives that are not supported by evidence must not affect the amount of uncertainty.**

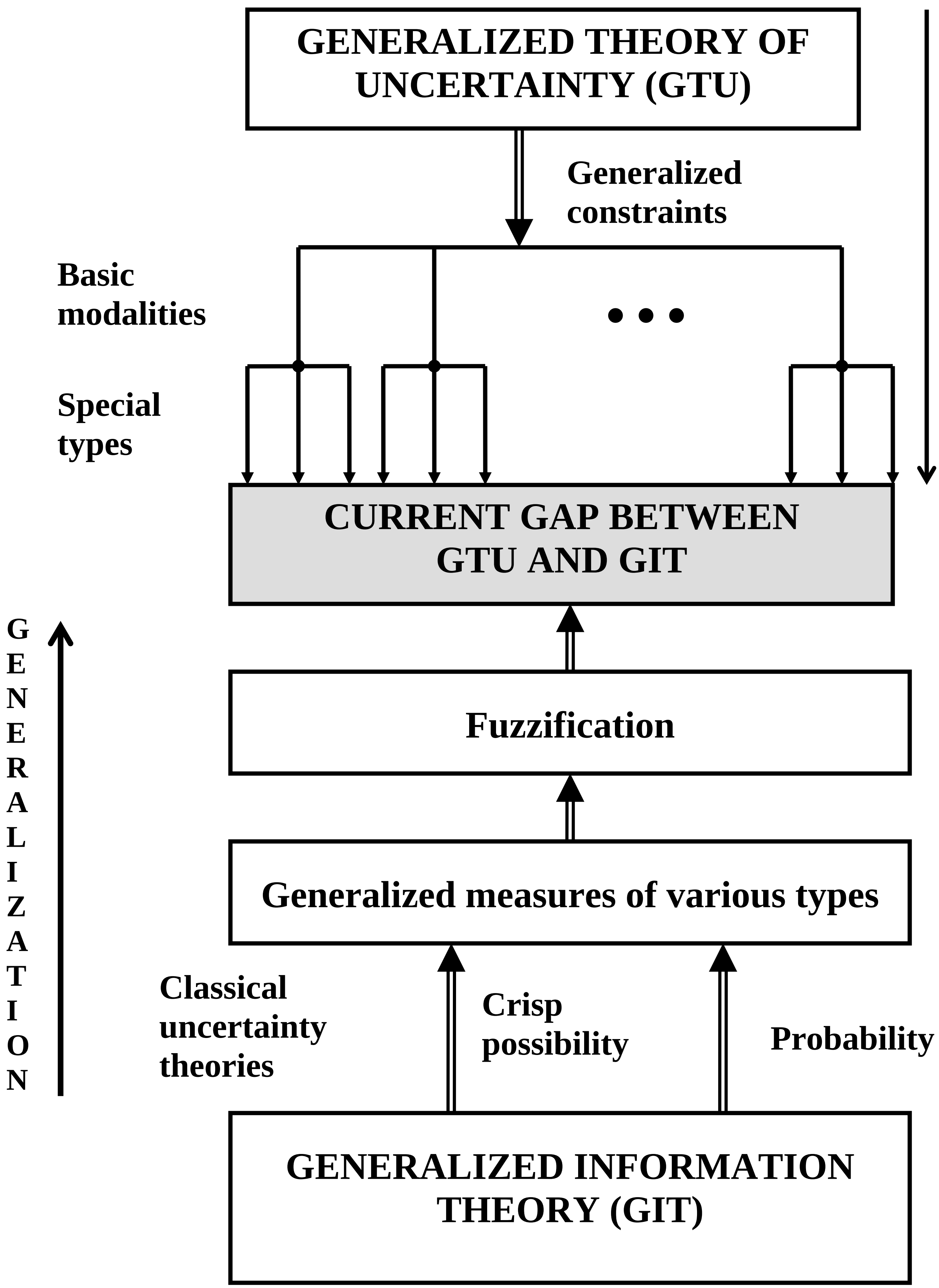
6. **<u>Branching/Consistency</u>: When uncertainty can be computed in several distinct ways, each conforming to the calculus of the theory, the results must be the same (consistent).**

7. **<u>Monotonicity</u>: When evidence can be ordered in the theory, the measure of uncertainty must preserve this ordering.**

8. **<u>Coordinate invariance</u>: When evidence is expressed within some Euclidean space, uncertainty must not change under isometric transformation of coordinates.**

Uncertainty Theories





GENERALIZED THEORY OF UNCERTAINTY (GTU)
Generalized constraints
Basic modalities
Special types
SPECIALIZATION
CURRENT GAP BETWEEN GTU AND GIT
GENERALIZATION
Fuzzification
Generalized measures of various types
Classical uncertainty theories
Crisp possibility
Probability
GENERALIZED INFORMATION THEORY (GIT)

**To be uncertain is uncomfortable,
but to be certain is ridiculous.**

(CHINESE PROVERB)