

INFORMATION: THEORIES AND TECHNOLOGIES

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Abstract: *The study of information has evolved into a multifaceted scientific field that brings together a wide range of theoretical and technological directions. This work explores the interdisciplinary nature of information studies, highlighting the key theoretical and technological contributions that shape our understanding of information in various contexts. This paper offers a general overview of this field, systematizing the directions discussed at the Summits of the International Society for the Study of Information (IS4SI) and ITHEA International Scientific Society (ITHEA ISS), complemented by directions that were not the subject of these Summits but remain essential for information science. The paper presents nineteen theoretical and eleven technological directions, providing for each a substantive characterization of its subject matter, core concepts, historical development, and representative sources. The aim is to offer a relatively complete and structured account of the directions, capable of serving as a reference point for further discussion.*

Keywords: *studies of information, directions in information science, theoretical directions, technological directions, IS4SI, ITHEA.*

ITHEA Keywords: *A.1 Introductory, Survey, and Overview*

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1. Introduction

The study of information is an exceptionally broad and multifaceted field that draws on achievements from practically every branch of science and technology. It encompasses both theoretical and technological directions, each contributing to a deeper understanding of how information is created, processed, and used. Theoretical studies address fundamental concepts and philosophical questions concerning the nature of information, while

technological achievements drive the practical applications and innovations that increasingly define everyday life. This paper presents the key theoretical frameworks and technological directions that shape the contemporary study of information, outlining the diversity of areas of interest and their significance in an increasingly digitized world.

The presentation is built upon a systematized review of the topics discussed at the Summits of the International Society for the Study of Information (IS4SI, <https://is4si.org>) and ITHEA International Scientific Society (ITHEA ISS, <http://ithea.org>). In addition, several areas that were not a direct subject of these Summits but remain essential for information science are included. The main goal is to provide a relatively complete list of directions that can serve as reference material and as a foundation for further discussion. Without claiming exhaustiveness, the paper outlines nineteen theoretical and eleven technological directions, each presented below in a self-contained section.

2. Theoretical Directions in the Study of Information

Theoretical studies of information are the cornerstone of our understanding of how information is conceptualized, structured, and interpreted across disciplines. These directions delve into the fundamental principles and abstract frameworks underlying the vast and multifaceted domain of information science. At the heart of theoretical research lies the effort to define and quantify information — an effort that has produced influential theories and models, including Claude Shannon's mathematical theory of information, the General Information Theory developed by Krassimir Markov (Markov, 1988, Markov, Ivanova, & Mitov, 1993, 2007), the Chinese Philosophy of Information by Kun Wu (Wu, 2012; Wu & Da, 2021), and the General Theory of Information proposed by Mark Burgin (Burgin, 2003, 2010). Beyond these foundational theories, theoretical directions encompass the study of information structures, formal systems, and cognitive processes, with results that carry profound practical implications, guiding the design of information systems, algorithms, and communication networks.

The Theoretical Directions of Studies of Information include basic and new knowledge from practically all branches of science. The nineteen theoretical directions outlined below do not exhaust the possible scope of the field; rather, they illustrate its breadth and indicate avenues for further, more detailed treatment. We will mention information theories in:

- Philosophy - Explores the nature, ontology, and epistemology of information.
- Mathematics - Studies formal models and quantitative aspects of information.
- Methodology - Focuses on research methods and frameworks for studying information.
- Logic - Investigates formal logic systems and reasoning structures.
- Psychology - Examines how information is perceived and processed by the human mind.
- Cognition, Epistemology and Semiotics - Combines studies of cognition, knowledge, and sign systems.
- Theoretical Informational Modeling - Involve creating representations of systems to understand and predict their behavior.
- Linguistics - Analyzes language structures and semantics in information.
- Biology - Studies information in biological systems like genetics and neural networks.
- Humanitarian studies - Connects information to humanities such as history, philosophy, and culture.
- Sociology - Investigates the role of information in social systems and communication.
- Pedagogics - Explores information in education, learning processes, and didactics.
- Ethics - Addresses moral issues in the creation and use of information.
- Ecology - Studies the relationship between information and environmental systems.
- Noosphere - Relates to the concept of a global information field of humanity.

- Infonomics - Theoretical study of the value and governance of information.
- Economics - Information analyzes as an economic asset and market factor.
- Legal and Regulatory Domain - Examines legal frameworks and standards governing information.
- Culture and Media - Studies how information is shaped and shared in cultural and media contexts.

2.1. Philosophy

The philosophical approach to information studies treats information as a fundamental concept whose nature, origin, and ontological status remain deeply contested. Two broad orientations dominate the field: information as a subjective, cognitive phenomenon grounded in consciousness, and information as an objective, mind-independent reality embedded in the structure of the world. These two orientations frame much of the contemporary debate in the philosophy of information.

The subjective perspective holds that information depends inherently on interpretation and meaning-making and does not exist independently of a cognitive agent. This view finds a classic formulation in Gregory Bateson's definition of information as "a difference that makes a difference" (Bateson, 1972), tying information directly to its effect on a perceiving system. Krassimir Markov's General Information Theory emphasizes the role of the human brain and cognitive structures in information generation and interpretation (Markov, Ivanova, & Mitov, 2007).

A significant extension of this subjective tradition comes from the Chinese philosophy of information developed by Kun Wu over more than four decades, which treats information as a relational, dynamic, and meaning-centered phenomenon mediating between existence, cognition, and value (Wu, 2012; Li, 2011). Wu and Da (2021) identify three core dimensions of this framework — the ontological, epistemological, and axiological — and argue that it offers a

non-Western yet theoretically rigorous foundation for subjective conceptions of information, enriching the global discourse in information studies.

According to the objective perspective, information exists independently of human cognition and functions as a basic explanatory principle alongside matter and energy. A systematic articulation of this position is provided by Mark Burgin's General Theory of Information (GTI), which defines information relative to so-called infological systems — parameters that distinguish kinds of information (cognitive, social, biological, chemical) while unifying them within a single coherent framework (Burgin, 2003, 2010). This ontological interpretation resonates with the cybernetic tradition of Norbert Wiener, who insisted that information is irreducible to matter or energy (Wiener, 1950).

Let note that the GIT and GTI are not contradict but complementary theories. GTI practically renew and further develop the Theory of reflections which is the starting point of GIT. So, they are two parts of the same theory. To understand this idea it is needed to replace in GTI the word "information" with word "reflection". In addition, the GTI in some sense is an extension of GIT because Markov and Burgin in early 1990-s work together on GIT and a common publication had been published (Burgin & Markov, 1991).

Luciano Floridi's Philosophy of Information plays a mediating role between these orientations, framing information as a foundational philosophical concept that bridges metaphysics, epistemology, and ethics through his method of levels of abstraction and his defense of informational structural realism (Floridi, 2011). This broader philosophical context shows that the tension between objective and subjective conceptions reflects a deeper divide between ontology and epistemology, one that contemporary philosophy of information increasingly seeks to address by examining both dimensions together rather than in isolation.

2.2. Mathematics

Mathematical approaches provide the rigorous formal backbone of information studies, offering precise tools for quantifying uncertainty, complexity, and communication. Claude Shannon's landmark paper "A Mathematical Theory of

Communication" (1948) established the probabilistic foundations of information theory, introducing the concepts of entropy, redundancy, and channel capacity that remain central to digital communication systems today (Shannon, 1948; Cover & Thomas, 2006). Algorithmic information theory, developed by Kolmogorov, Chaitin, and Solomonoff, reframed information content in terms of the shortest possible description of a string or system, linking information directly to computation and complexity (Chaitin, 1977).

An important complementary strand is the Theory of Strongly Semantic Information, which introduces veridicality — truthfulness — as a necessary condition for genuine informativeness, building on the earlier logical-probabilistic framework of Carnap and Bar-Hillel (1952) and offering a resolution of the well-known Bar-Hillel–Carnap paradox, whereby a logical contradiction would otherwise carry maximal informational content. A related semantic approach was independently developed by Shreider (1965), who treated information as a transformation of a receiver's thesaurus rather than a purely syntactic quantity.

A distinct mathematical line of development underlies Krassimir Markov's General Information Theory (GIT), which seeks to ground the philosophical notion of information, introduced in Section 2.1, in a precise set and categorical theoretic apparatus (Markov, Ivanova, Mitov, and Velikova-Bandova, 2003, 2004, Markov, 2024)

Modern mathematical Information Theories extend these classical and GIT-related foundations considerably. Topological Data Analysis (TDA), popularized by Carlsson (2009), applies tools from algebraic topology, most notably persistent homology, to uncover the qualitative "shape" of high-dimensional data sets, with applications spanning neuroscience, materials science, and biology. Categorical Informatics, exemplified by Spivak's (2012) functorial approach to database schemas, treats a database schema as a small mathematical category and a database instance as a set-valued functor on it, providing a rigorous bridge for data integration across heterogeneous systems. Differential Privacy, introduced by Dwork, McSherry, Nissim, and Smith (2006), offers a mathematically calibrated method for adding noise to data queries so as to guarantee rigorous, provable bounds on the privacy of individuals within a

data set. Finally, Algorithmic Game Theory models strategic interactions and information cascades within networked systems, formalizing how individuals update beliefs from observing others' actions (Bikhchandani, Hirshleifer, & Welch, 1992; Kleinberg, 2007; Easley & Kleinberg, 2010). Together, these Information Theories extend mathematics into coding theory, quantum information (Nielsen & Chuang, 2010), and network science, forming a new theoretical paradigm for managing complexity in the digital age.

2.3. Methodology

Methodological directions in information theories address the frameworks, strategies, and integrative approaches used to study information across diverse domains. Early systems theorists such as von Bertalanffy (1968) emphasized holistic, interdisciplinary methods for understanding complex systems, laying the groundwork for the methodologies of contemporary information science. Today, methodological research incorporates empirical, formal, computational, and interpretive approaches, reflecting the inherently cross-disciplinary nature of information studies.

Scholars such as Burgin (2010) and Bawden and Robinson (2022) argue for unified or integrative methodologies capable of bridging natural, cognitive, and social perspectives, rather than treating each disciplinary approach in isolation. Methodological research in information theories also examines questions of model validity, conceptual clarity, and the appropriate interplay between qualitative and quantitative evidence — questions that become especially pressing as information science incorporates ever larger volumes of heterogeneous data drawn from disparate sources and disciplines.

A central methodological tension concerns the relationship between reductionist approaches, which seek to explain informational phenomena through their constituent mechanisms, and holistic approaches, which insist that certain properties of information — meaning, context, relevance — emerge only at the level of the system as a whole. By providing robust tools for structuring inquiry and integrating diverse forms of knowledge, methodological studies help ensure that information science remains coherent, rigorous, and capable of addressing

the multifaceted challenges posed by the rapid expansion of digital data and computational power.

Methodological information theories also address the practical question of how findings from disparate disciplinary traditions, each with its own standards of evidence, its own vocabulary, and often its own implicit ontology, can be compared, combined, or arbitrated when they appear to conflict. This concern has grown increasingly salient as information science has come to depend on mixed-methods research designs that combine large-scale computational analysis with qualitative interviews, ethnographic observation, or experimental psychology. Bawden and Robinson (2022) argue that information science's traditional position at the intersection of the humanities, the social sciences, and computing gives it a distinctive methodological responsibility: rather than importing the methods of any single parent discipline wholesale, the field must continually develop and refine integrative methodologies suited to objects of study (documents, data, conversations, algorithms) that resist neat disciplinary categorization. Methodological self-reflection of this kind remains essential precisely because the tools used to study information inevitably shape the conclusions that can be drawn about it.

2.4. Logic

Logical information theories investigate the formal structures that govern reasoning, inference, and the transformation of information. The roots of this field lie in the pioneering work of Gottlob Frege, who established the foundations of modern logic and formal semantics by distinguishing sense from reference (Frege, 1892). Charles Sanders Peirce expanded this tradition by integrating logic with semiotics, showing how signs participate in inferential processes through the interaction of icon, index, and symbol (Peirce, 1931–1958).

In contemporary information science, logic extends far beyond classical propositional and predicate systems. Modal logics capture notions of possibility, necessity, and knowledge; temporal logics model change over time; dynamic logics describe how actions update informational states; and non-monotonic

logics reflect the defeasible, revisable character of real-world reasoning, where conclusions drawn from incomplete information must be retracted in light of new evidence (Gabbay & Woods, 2003). These logical frameworks underpin knowledge representation, database theory, semantic technologies, and reasoning systems in artificial intelligence.

A further important strand concerns relevance logic and the broader question of epistemic relevance — how a logical system can capture not merely formal validity but the informativeness of an inference for a particular cognitive agent (Mizzaro, 1997). Logical Information Theories thus provide the rigorous scaffolding that allows both humans and machines to manipulate information coherently, consistently, and meaningfully, and they remain indispensable for the design of formally verifiable software, ontologies, and automated reasoning systems used throughout contemporary information technology.

The practical stakes of logical Information Theories have grown considerably with the deployment of automated systems whose decisions affect human welfare directly, from medical diagnosis support to autonomous navigation. Description logics, which underlie modern ontology languages such as OWL, allow knowledge engineers to specify class hierarchies and relationships with a level of formal precision that supports automated consistency checking and classification, while paraconsistent logics tolerate localized contradictions without permitting them to trivialize an entire reasoning system — an increasingly important property as large knowledge bases assembled from heterogeneous, sometimes conflicting sources become commonplace. The interaction between symbolic logical systems and the statistical, sub-symbolic methods that dominate contemporary machine learning constitutes one of the most actively debated questions at the boundary of logic and artificial intelligence, with neuro-symbolic approaches attempting to combine the interpretability and provable guarantees of formal logic with the pattern-recognition capacity of learned statistical models.

2.5. Psychology

Psychological information theories explore how humans perceive, interpret, store, and act upon information. Early cognitive psychology revealed fundamental constraints on human information processing — most famously Miller's (1956) discovery that working memory can hold only a limited number of discrete items, a finding that continues to inform interface and instructional design. Gibson's ecological theory of perception (1979) reframed perception not as passive reception of sensory data but as an active engagement with informational structures available directly in the environment, emphasizing the concept of affordances.

Contemporary research integrates cognitive psychology with neuroscience, showing how neural circuits encode information, how emotions shape interpretation, and how systematic biases influence judgment and decision-making under uncertainty (Kahneman, 2011). Baddeley's (2012) extensive body of work on the structure and working memory limits, in turn, become foundational for understanding cognitive load in both educational and technological contexts.

Psychological Information Theories also inform human–computer interaction, examining how interface design, cognitive load, and multimodal communication affect user experience and error rates. By revealing the mechanisms through which humans make sense of information, this direction bridges internal cognition with external informational environments, and it provides essential empirical grounding for designing information systems, educational technologies, and decision-support tools that operate within, rather than against, the known limits and biases of human cognition.

A particularly consequential strand of psychological research concerns the systematic heuristics and biases that govern judgment under uncertainty, including the availability heuristic, anchoring effects, and loss aversion. All of them Kahneman (2011) situates within a broader dual-process account distinguishing fast, intuitive judgment from slower, deliberate reasoning. These findings carry direct implications for the design of information systems intended to support, rather than exploit, human decision-making: interfaces that present

information in ways that trigger predictable biases can mislead users even when every individual fact displayed is accurate. As digital environments increasingly mediate consequential decisions (financial, medical, civic). Psychological Information Theories thus intersect closely with the ethical Information Theories discussed in Section 2.13, raising the question of what obligations designers bear when the cognitive vulnerabilities they exploit are well documented in the scientific literature.

2.6. Cognition, Epistemology & Semiotics

These directions unite three deeply interconnected domains: cognition, knowledge, and meaning. Semiotics, grounded in the work of Peirce (1931–1958) and later systematized by Eco (1976), studies how signs and symbols convey information and how interpretation unfolds through dynamic processes of inference, in which a sign stands for an object to an interpreting mind by virtue of some ground or convention.

Epistemology examines how knowledge is formed, justified, and validated, with Dretske (1981) influentially framing knowledge itself as an informational state — a belief caused by, and reliably correlated with, the fact that makes it true. Cognitive science, in turn, integrates symbolic, embodied, and computational models to explain how minds, whether human or artificial, process information, with Clark's (2016) work on predictive processing suggesting that the brain continuously generates and updates internal models to minimize prediction error rather than passively registering external stimuli.

These directions are especially relevant today, as artificial intelligence systems increasingly participate in processes of interpretation, classification, and reasoning that were once considered exclusively human. The convergence of semiotic, epistemological, and cognitive perspectives raises profound questions about the nature of understanding, intentionality, and the limits of machine cognition - questions that have only grown sharper with the advent of large language models capable of producing fluent, contextually appropriate text without any straightforward analogue of human understanding (Floridi & Chiriatti, 2020).

These questions connect directly to long-standing philosophical debates over the symbol grounding problem. The question of how abstract symbols manipulated by a formal system come to be meaningfully connected to the objects and situations they purport to represent, rather than remaining purely syntactic tokens. Where human cognition appears to ground symbolic meaning in embodied sensorimotor experience, contemporary statistical language models derive their behavior instead from patterns of co-occurrence across enormous text corpora, achieving a form of competence that is functionally impressive yet conceptually distinct from human understanding in ways that remain only partially understood. This unresolved tension gives the cognitive, epistemological, and semiotic direction renewed urgency, since the practical deployment of such systems in education, law, and journalism depends critically on a clear-eyed assessment of what kind of "knowing" they actually instantiate.

2.7. Theoretical Informational Modeling

Theoretical informational modeling develops abstract representations of systems in order to understand, predict, and explain their behavior. Inspired by early cybernetics (Ashby, 1956) and general systems theory (von Bertalanffy, 1968), this direction seeks to capture the informational dynamics that govern natural, social, and artificial systems through models that may take the form of mathematical equations, conceptual diagrams, agent-based simulations, or cognitive architectures.

Modern approaches emphasize:

- complexity, emergence, and non-linear interaction, drawing on fields such as system dynamics (Sterman, 2000), which represents systems through stocks, flows, and feedback loops to reveal counterintuitive long-term behavior;
- agent-based modeling (Epstein, 2006), which generates macro-level social phenomena from simple rules governing the interactions of autonomous micro-level agents;

- computational cognitive modeling (Sun, 2016), which constructs detailed architectures, such as the Clarion framework, to simulate the interplay of implicit and explicit cognitive processes.

Informational modeling provides a crucial bridge between abstract theory and empirical observation, enabling researchers to test hypotheses, explore counterfactual scenarios, and reveal hidden structural relationships within complex systems before committing to costly real-world interventions. It is a foundational tool for interdisciplinary research across information science, supporting both theoretical insight into the general principles governing informational systems and practical decision-making in domains ranging from epidemiology to organizational design.

A persistent methodological challenge within theoretical informational modeling concerns the appropriate level of abstraction at which a model should be constructed: overly detailed models risk becoming as difficult to analyze as the original system, while overly simplified models risk omitting the very interactions responsible for the emergent behavior under study. Floridi's (2011) method of levels of abstraction offers one influential framework for making this trade-off explicit, treating a model not as a single privileged representation of reality but as one of many possible "observations" of a system, each adequate for some purposes and inadequate for others. This perspective has proven especially valuable in informational modeling, where the same underlying system (a social network, an ecosystem, a financial market) may need to be represented at radically different levels of granularity depending on whether the research question concerns individual behavior, aggregate statistical regularities, or long-term structural evolution.

2.8. Linguistics

Linguistic information theories examine how the language encodes, structures, and transmit information. From Saussure's structural linguistics, which introduced the foundational distinction between *langue* and *parole* and treated linguistic signs as arbitrary pairings of signifier and signified (Saussure, 2011 [1916]), to Chomsky's generative grammar, which proposed an innate, universal

syntactic structure underlying all human languages (Chomsky, 1957), linguistic theory has sought to uncover the deep rules that govern human communication.

Modern linguistic research expands this foundation through semantics, pragmatics, discourse analysis, and computational linguistics (Jackendoff, 2002; Jurafsky & Martin, 2023). Language is not merely a vehicle for information but a system that actively shapes thought, culture, and social interaction; the precise mechanisms by which linguistic context resolves ambiguity and determines pragmatic meaning remain an active area of theoretical and computational research.

In the digital age, linguistic studies have become central to a wide range of technological applications: natural language processing, machine translation, and conversational artificial intelligence all rely directly on insights from formal and computational linguistics. The recent success of transformer-based architectures (Vaswani et al., 2017) in capturing long-range syntactic and semantic dependencies illustrates how theoretical advances in the study of language structure can translate, often unexpectedly, into transformative technological capability, making linguistic Information Theories central to both humanistic inquiry and contemporary information technology.

At the same time, the gap between formal linguistic theory and the statistical methods underlying contemporary language technology has prompted renewed debate over how much of human linguistic competence can be captured by exposure to large quantities of text alone, without the kind of innate structural endowment that Chomsky's framework presupposes. Distributional semantics, which represents word meaning through patterns of co-occurrence across large corpora rather than through explicit definitional structure, has proven surprisingly effective at capturing many aspects of lexical meaning, yet continues to struggle with the kind of compositional, rule-governed generalization that formal syntactic theories were designed to explain. This unresolved tension between distributional and structural approaches to meaning remains one of the most productive open questions linking theoretical linguistics to the practical engineering of contemporary language technologies.

2.9. Biology

Information theories in biology explore how information operates within living systems, from molecular genetics to neural networks and ecological interactions. The recognition of DNA as an informational molecule (Crick, 1958) revolutionized biology, framing life itself as a system of encoded instructions that are transcribed, translated, and ultimately expressed as observable traits. Neural information processing, grounded in Hebb's (1949) theory of synaptic learning (the principle that neurons which fire together strengthen their connections) provides foundational insight into perception, memory, and cognition.

Modern systems biology views organisms as complex informational networks, integrating genomics, proteomics, and metabolic pathways to explain how robust biological function emerges from the coordinated interaction of vast numbers of molecular components, often described through the lens of self-organized criticality and the edge of chaos (Kauffman, 1993). Biosemiotics, developed by Hoffmeyer (2008) and others, extends this perspective by examining how organisms use signs and signals to coordinate behavior, adapt to their environments, and maintain ecological relationships, treating semiosis as a process that pervades the living world and is not restricted to human cognition.

Biological information theories reveal how information drives adaptation, development, and evolution, offering profound parallels with artificial information systems and inspiring computational paradigms such as artificial neural networks, evolutionary algorithms, and DNA-based computation. As molecular biology becomes increasingly data-intensive, this direction also intersects directly with bioinformatics and the broader challenge of extracting biologically meaningful patterns from vast genomic and proteomic data sets.

The informational framing of biology has deepened considerably with the recognition that genetic information is neither static nor purely linear: epigenetic mechanisms allow environmental conditions to modulate gene expression across generations without altering the underlying DNA sequence, complicating any simple picture of biological information flowing unidirectionally from

genotype to phenotype. Likewise, the immune system has increasingly been analyzed as an adaptive information-processing network capable of distinguishing self from non-self and of "remembering" past pathogenic encounters, a perspective that has informed both immunological research and the design of artificial immune systems in computer science. These developments illustrate how biological Information Theories continue to generate genuinely novel informational concepts, distinct from those originating in physics or engineering, that subsequently migrate into computational and technological domains, reversing the more familiar direction of inspiration from technology to biology.

2.10. Humanitarian Studies

Information theories in humanitarian studies explore the cultural, ethical, historical, and human-centered dimensions of information, emphasizing that information is never merely a technical artifact but a deeply social and interpretive phenomenon. Scholars such as Capurro and Hjørland (2003) argue that information must be understood within the contexts of human meaning-making, cultural tradition, and interpretive framework, challenging purely formal or quantitative definitions of the concept.

Frohmann (2004) further demonstrates how information practices are shaped by power, discourse, and institutional structure, drawing on the broader tradition of discourse analysis to show that what counts as legitimate or authoritative information is itself a historically contingent social construction rather than a neutral given. Contemporary humanitarian perspectives examine how digital technologies influence identity, memory, cultural heritage, and human relationships, raising urgent questions about authenticity, representation, and the preservation of cultural knowledge in an age of rapid technological change.

Ess (2020) extends this analysis directly into digital media ethics, addressing how online communication reshapes notions of privacy, selfhood, and moral responsibility across different cultural contexts, and cautioning against assuming that ethical frameworks developed in one cultural setting transfer unproblematically to global digital platforms. By foregrounding human

experience, humanitarian information theories ensure that information science remains grounded in the values, needs, and aspirations of individuals and communities, rather than being driven solely by technical or economic considerations.

Humanitarian information theories also engage critically with questions of digital heritage and collective memory: as an increasing share of cultural production, correspondence, and historical record exists only in digital form, questions of long-term preservation, format obsolescence, and institutional custodianship take on significance unanticipated by earlier archival traditions built around physical media. The risk of a "digital dark age," in which vast quantities of culturally significant material become inaccessible owing to obsolete formats or failed storage infrastructure, has prompted renewed scholarly attention to digital curation as a humanitarian, not merely technical, undertaking. This concern intersects closely with debates over algorithmic curation and the digital divide, since unequal access to the technical means of preservation risks systematically privileging the cultural record of already well-resourced institutions and communities over those with fewer resources to invest in long-term digital stewardship.

2.11. Sociology

Social information theories investigate how information circulates within societies, how it shapes collective behavior, and how social structures influence the production and interpretation of information. Classical sociological thinkers such as Weber (1922) and Habermas (1984) laid the groundwork for understanding communication, rationality, and social action, with Habermas's theory of communicative action distinguishing strategic from genuinely communicative uses of language oriented toward mutual understanding.

In the contemporary era, Manuel Castells's theory of the network society (2009) has become foundational, showing how digital networks transform power, identity, and social organization by enabling new forms of decentralized coordination that bypass traditional hierarchical institutions. Social information studies also examine phenomena such as misinformation, social media

dynamics, and the formation of online communities, with Sunstein (2017) warning that personalized information environments can fragment shared public discourse into mutually isolated echo chambers.

A particularly active area within this direction concerns information cascades — situations in which individuals, observing the actions of others, rationally discount their own private information and conform to an emerging consensus, sometimes propagating widely incorrect beliefs through an otherwise rational population (Bikhchandani, Hirshleifer, & Welch, 1992; Easley & Kleinberg, 2010). By analyzing the interplay between information and society, this direction provides essential insight into the challenges and opportunities of the information age, from the dynamics of collective intelligence to the structural vulnerabilities of networked public discourse.

Social information theories also increasingly examine the structural properties of online networks themselves, their degree distributions, clustering patterns, and propensity for rapid, large-scale cascades, as objects of study in their own right, distinct from the specific content that happens to circulate through them. Research on network topology shows that certain structural configurations make a network systematically more vulnerable to misinformation cascades or coordinated manipulation, regardless of the particular claims being spread, suggesting that interventions aimed purely at content moderation may address only part of the underlying problem. This structural perspective has become increasingly important for policymakers and platform designers seeking to understand why certain categories of false or misleading information propagate so much more readily than corrective or nuanced information, a phenomenon that appears to depend as much on network architecture and incentive structure as on the persuasive content of any individual message.

2.12. Pedagogics

Pedagogical information theories focus on the role of information in learning, teaching, and educational systems. Foundational theories developed by Vygotsky (1978) and Bruner (1966) emphasized the social and cognitive dimensions of learning, highlighting how information is internalized through

social interaction, scaffolding, and progressive conceptual development, most notably through Vygotsky's concept of the zone of proximal development.

In the digital era, pedagogical research explores how online platforms, multimedia resources, and adaptive learning systems reshape educational practice (Laurillard, 2012), with Laurillard's conversational framework explicitly modeling teaching as an iterative dialogue between teacher and learner conceptions which digital tools can support but not replace. The rise of connectivism, articulated by Siemens (2005), reframed learning as a process of navigating and constructing networks of information and social connections, particularly relevant in an era when knowledge is distributed across vast, rapidly changing digital networks rather than concentrated in static, authoritative texts.

Pedagogical information theories also address digital literacy, critical thinking, and the ethical use of information in educational contexts, including the difficult question of how learners can be taught to evaluate the reliability of information sources within environments engineered to maximize engagement rather than comprehension. By examining how information supports knowledge acquisition and intellectual growth, this direction contributes directly to the design of effective, inclusive, and future-oriented learning environments capable of preparing learners for an information landscape that continues to change at an accelerating pace.

The growing availability of generative artificial intelligence tools in educational settings has introduced a further pedagogical challenge: distinguishing between uses of such tools that genuinely support learning (by providing tailored feedback, generating practice material, or scaffolding the development of a learner's own reasoning) and uses that substitute for the cognitive effort on which durable learning actually depends. Educational researchers increasingly emphasize that the pedagogical value of any information technology depends less on its raw capability than on how its use is integrated into broader instructional design, assessment practice, and learner motivation, echoing Laurillard's (2012) insistence that technology should be evaluated in terms of the conversational and reflective processes it enables rather than treated as a self-sufficient educational solution.

2.13. Ethics

Ethical information theories address the moral challenges associated with the creation, use, and governance of information. Norbert Wiener (1950) was among the first to articulate the ethical implications of information technologies, warning that automation and communication systems would reshape human agency and responsibility in ways that demanded urgent moral reflection well before such consequences became fully visible.

Contemporary information ethics, advanced by scholars such as Floridi and Taddeo (2016), examines issues including privacy, autonomy; fairness, transparency, and the moral status of artificial agents, proposing frameworks for "data ethics" that go beyond traditional computer ethics to address the full lifecycle of data generation, curation, and use. The rise of artificial intelligence and big data has intensified concerns about algorithmic bias, surveillance, digital manipulation, and the erosion of trust in information systems, with Mittelstadt and colleagues (2016) cataloguing the specific epistemic, normative, and traceability challenges that automated decision-making poses for ethical accountability.

Ethical information theories also explore the responsibilities of designers, policymakers, and users in shaping the informational environment, including debates over whether moral responsibility for algorithmic harm can meaningfully be distributed across the long causal chains connecting data collectors, model developers, and deploying organizations. By providing normative frameworks for evaluating technological and informational practices, this direction helps ensure that information science contributes to a just and humane society rather than merely to technical efficiency.

A distinctive ethical challenge raised by contemporary information systems concerns the opacity of many high-performing machine learning models, whose internal decision processes resist straightforward human interpretation even when their outputs can be empirically validated. This opacity complicates the traditional ethical requirement that morally significant decisions be justifiable through reasons that affected parties can scrutinize and contest, giving rise to an active research program on explainable artificial intelligence that seeks to

render automated decisions intelligible without sacrificing predictive performance. Ethical information theories increasingly treat such interpretability not as a narrowly technical feature but as a precondition for meaningful accountability, due process, and trust in any information system whose decisions materially affect human lives.

2.14. Ecology

Ecological information theories explore how information flows within natural systems and how environmental processes encode, transmit, and transform information. Systems ecologists such as Odum (1983) demonstrated that ecosystems can be understood as complex networks of energy and information exchange, in which nutrient cycles and trophic relationships function analogously to communication channels carrying signals between organisms and their environment.

Biosemiotics, developed by Hoffmeyer (2008) and others, extends this perspective by examining how organisms use signs and signals to coordinate behavior, adapt to environments, and maintain ecological relationships, treating the exchange of chemical, visual, and behavioral signals throughout an ecosystem as a genuinely semiotic process rather than a merely mechanical one. Contemporary ecological information studies also address environmental monitoring, sustainability, and the use of large-scale sensor and satellite data to understand climate change and biodiversity loss, drawing on remote sensing, citizen science platforms, and increasingly sophisticated ecological modeling.

This direction highlights deep parallels between natural and artificial information systems (for instance, between the resilience strategies of biological ecosystems and the fault-tolerance mechanisms of distributed computing networks) and emphasizes the importance of informational perspectives for addressing pressing global ecological challenges, including the design of early-warning systems for ecological collapse and the informational dimensions of sustainable resource management.

The growing computational and energy footprint of digital infrastructure itself has, in turn, become a subject of ecological information studies: training and

operating large-scale machine learning models, maintaining global data centers, and manufacturing the hardware that underpins contemporary information technology all carry environmental costs that must be weighed against the considerable informational and economic benefits these systems provide. This has prompted a parallel research agenda on "green computing" and information-system sustainability, seeking to quantify and reduce the ecological cost of information processing itself, treating computational infrastructure not merely as a tool for monitoring environmental change but as an environmentally consequential system in its own right that warrants the same ecological scrutiny applied to other large-scale industrial activities.

2.15. Noosphere

Noospheric information studies investigate the informational dimension of the noosphere — the sphere of human thought, collective intelligence, and planetary cognition. The concept originates with Vernadsky (1944/1997) and Teilhard de Chardin (1955/2008), who, working independently yet in dialogue, envisioned the noosphere as a new evolutionary stage shaped by the growth of knowledge, communication, and collective human reason, succeeding the geosphere and the biosphere as the dominant organizing layer of planetary development.

Modern scholars such as Heylighen (2016) reinterpret the noosphere through the lens of global information networks, artificial intelligence, and distributed cognition, proposing the metaphor of a "global brain" in which the internet and its users together constitute an emergent, planet-spanning cognitive system exhibiting properties: self-organization, adaptive learning, and problem-solving, that exceed those of any individual human participant. Gorokhov (2020) extends this analysis by examining the noosphere as a global superorganism, situating contemporary discussions of collective intelligence within a longer philosophical lineage connecting Vernadsky's biogeochemistry to present-day theories of planetary-scale computation.

This direction explores how humanity's informational activities contribute to the emergence of large-scale cognitive structures, how digital technologies amplify

collective intelligence, and how global information flows shape cultural evolution. Noospheric studies offer a genuinely visionary perspective on the future of information, emphasizing the deep interconnectedness of human minds, technologies, and planetary systems, while also raising difficult questions about the governance and resilience of a cognitive infrastructure on which an increasing share of human decision-making now depends.

A recurring theme within noospheric studies is the question of whether the emergent global cognitive layer described by Vernadsky, Teilhard de Chardin, and their successors should be understood primarily as a beneficial evolutionary advance, a planetary nervous system capable of solving problems beyond the reach of any individual mind, or whether it equally creates new forms of fragility, including susceptibility to coordinated manipulation, cascading misinformation, and a loss of the cognitive diversity that historically allowed isolated human communities to arrive at solutions independently. Heylighen's (2016) global brain framework explicitly engages this tension, arguing that the same network properties that enable rapid collective problem-solving also require deliberate institutional and technical safeguards if the noosphere is to develop in a genuinely adaptive, rather than merely volatile, direction. As planetary-scale computational infrastructure continues to expand, noospheric information theories increasingly intersect with the social, ethical, and ecological ones discussed elsewhere in this paper, suggesting that the future trajectory of the noosphere will depend as much on deliberate governance choices as on the underlying technological capacity for global information exchange.

2.16. Infonomics

Infonomics examines the economic value, governance, and management of information as a strategic asset in its own right, distinct from the physical media or computing infrastructure that carries it. Early work in information economics, such as Arrow's (1962) analysis of information asymmetry and the peculiar economics of invention, laid the foundation for understanding information as a unique economic good - one that, unlike conventional goods, can be copied at negligible marginal cost and shared without depletion.

Contemporary infonomics, led by scholars such as Laney (2018), focuses on data valuation, information governance, and the monetization of digital assets, proposing formal methods for placing information on an organization's balance sheet alongside more conventional assets and thereby making its economic contribution explicit to decision-makers. This direction also explores the dynamics of knowledge markets, digital platforms, and the role of information in organizational decision-making, distinguishing, as the field has increasingly done, between *macro-infonomics* (the study of information as a factor shaping entire economies and industries) and *micro-infonomics* (the practical valuation and management of specific information assets within individual organizations).

As economies become increasingly data-driven, infonomics provides essential frameworks for understanding how information creates economic value, how it should be governed and protected, and how it transforms business models and competitive dynamics across virtually every economic sector, from the platform economy to traditional manufacturing increasingly augmented by data-driven services.

A distinctive feature of information as an economic asset, central to infonomics, is its capacity for non-rivalrous use: unlike physical capital, the same data set or piece of information can in principle be employed simultaneously by multiple parties without depleting its usefulness to any one of them, though its economic value may nonetheless depend critically on exclusivity, timeliness, or the surrounding analytical capability needed to extract insight from it. This distinctive economic character complicates conventional accounting and valuation practices, which were developed primarily for tangible and rivalrous assets, and has motivated infonomics researchers to propose alternative valuation methodologies (ranging from cost-based and market-based approaches to more speculative "economic value of use" models) that attempt to capture how much a given information asset actually contributes to organizational decision-making and competitive advantage, even where no established market price exists for that asset in isolation.

2.17. Economics

Economic information theories analyze how information influences markets, decision-making, and economic behavior, departing from the classical assumption of perfect information that long characterized neoclassical economic theory. Seminal contributions by Akerlof (1970) demonstrated how information asymmetry between buyers and sellers can cause markets to collapse or systematically favor low-quality goods, using the now-classic example of the used-car market, while Spence (1973) showed how agents possessing private information can credibly signal their quality to less-informed parties through costly, otherwise wasteful actions, such as acquiring formal education.

Modern economic research explores how digital technologies alter competition, pricing, labor markets, and consumer behavior (Goldfarb & Tucker, 2019), examining, for instance, how algorithmic pricing and platform-mediated matching change the strategic calculations available to firms and consumers alike. This direction also examines the role of information in game theory, behavioral economics, and organizational strategy, including the persistent gap between the idealized, fully rational agents of classical economic models and the systematically biased, cognitively constrained decision-makers documented by behavioral economics.

By revealing how information structures economic interactions, determining who can credibly commit to an action, who can verify a claim, and who bears the cost of uncertainty, economic information theories provide critical insight into the functioning of modern digital economies, where information itself has become both a primary input to production and an increasingly important commodity traded directly between firms.

Economic information theories also engage closely with mechanism design, the branch of game theory concerned with constructing institutions and incentive structures that elicit truthful or otherwise socially desirable behavior from self-interested agents who possess private information unavailable to a central designer. Auction theory, a leading application of mechanism design, has acquired considerable practical importance through its use in allocating online

advertising space and wireless spectrum, illustrating how abstract theoretical results concerning information and incentives can be translated directly into the design of real-world digital marketplaces. This close connection between theoretical economic analysis and the concrete architecture of digital platforms exemplifies a broader pattern within information economics, in which formal results about information asymmetry and strategic behavior increasingly inform the literal engineering of markets rather than remaining purely descriptive.

2.18. Legal & Regulatory domain

Legal and regulatory information theories examine the frameworks that govern information rights, privacy, intellectual property, and data protection. Foundational work by Lessig (1999) argued that "code is law," highlighting how the technical architecture of software and networks shapes legal and social norms every bit as effectively as formal legislation, often without the deliberative legitimacy that accompanies conventional lawmaking.

Contemporary legal scholarship addresses the challenges posed by digital surveillance, algorithmic decision-making, and cross-border data flows, with Solove (2021) critically examining the so-called "privacy paradox" (the apparent contradiction between individuals' stated concern for privacy and their continued willingness to share personal data) and arguing that this paradox largely dissolves once the structural constraints individuals face are properly taken into account.

Major regulatory frameworks such as the European Union's General Data Protection Regulation (Regulation (EU) 2016/679) have transformed global approaches to data governance, establishing comprehensive rules on lawful processing, purpose limitation, and data subject rights that have influenced legislation well beyond the European Union itself (European Parliament and Council of the European Union, 2016; Tikkinen-Piri, Rohunen, & Markkula, 2018). This direction provides essential conceptual and practical tools for understanding how societies regulate information and how legal structures continue to adapt, often imperfectly and unevenly across jurisdictions, to rapid technological change.

Legal and regulatory theory in this direction also grapples with the difficulty of applying jurisdictionally bounded legal frameworks to information flows that are inherently transnational, since data generated in one country may be stored on servers in a second, processed by an organization headquartered in a third, and ultimately affect individuals residing in a fourth. This jurisdictional fragmentation generates persistent conflicts between national legal traditions (some emphasizing individual privacy as a fundamental right, others prioritizing free data flow for commercial or security purposes) and has prompted ongoing scholarly debate over whether meaningful global harmonization of information law is achievable, or whether the field is better understood as a continually negotiated patchwork of overlapping, sometimes conflicting, regional regimes.

2.19. Culture & Media

Cultural and media information theories explore how information is produced, mediated, and interpreted within cultural systems. Marshall McLuhan's famous dictum that "the medium is the message" (1964) remains foundational, emphasizing that the formal properties of a communication medium, not merely its explicit content, shape perception, cognition, and social organization in ways that often go unnoticed by the very societies transformed by them.

Contemporary scholars such as Jenkins (2006) examine participatory culture, documenting how digital technologies have blurred the boundary between media producers and consumers, enabling audiences to actively reshape, remix, and redistribute cultural content rather than merely receiving it passively. Manovich (2020) extends this analysis into cultural analytics and algorithmic media, applying quantitative, data-driven methods to the study of cultural production at a scale previously accessible only to qualitative humanistic inquiry.

This direction investigates how information circulates through media ecosystems, how cultural identities are constructed and contested within them, and how digital platforms transform artistic and communicative practice, often through algorithmic curation mechanisms that themselves become powerful, largely opaque arbiters of cultural visibility. By integrating cultural theory with

information science, this direction illuminates the symbolic, aesthetic, and social dimensions of information that purely technical or economic analyses tend to overlook.

A further theoretical concern within this direction is the changing status of authorship and originality in cultural production once digital reproduction and remixing become trivially easy, a question McLuhan's framework anticipated by suggesting that each new medium does not simply transmit existing cultural content but actively reorganizes the sensory and cognitive relationships through which that content is experienced. Contemporary cultural and media theory must therefore account not only for the explicit messages carried by digital platforms but for the deeper structural effects of algorithmic recommendation, infinite scroll, and platform-specific affordances on attention, narrative form, and collective memory — effects that, in McLuhan's spirit, often prove considerably more consequential than the particular pieces of content that happen to circulate through them at any given moment.

A complementary, more formally grounded perspective on the cultural dimension of information is offered by the Theory of Inforaction, a branch of Krassimir Markov's General Information Theory. Markov, Poryazov, Ivanova, Mitov, and Markova (2008) analyze how cultural environment shapes the way information models — the structures through which one entity comes to represent another for a given subject — are perceived, verified, and either accepted or contested by an Infos. Drawing on Leslie White's and Julian Huxley's classic three-part division of culture into mentifacts (beliefs, mythologies, and bodies of knowledge), artifacts (tools and the technical information models needed to use them), and sociofacts (patterns of interpersonal and institutional relations), the authors argue that culture itself can be understood as an evolving collection of shared information models, continuously built, transmitted, and revised through repeated information interaction, or "inforaction", among the members of a society.

Central to this analysis is the distinction between a scientific and a non-scientific orientation toward incoming information models, captured in the contrasting medieval mottos "Credo, ut intelligam" (I believe in order to understand) and

"Intelligo, ut credam" (I understand in order to believe). Markov and colleagues (2008) contend that every receiving Infos requires a kind of "information immune system" to decide which incoming information models warrant verification and which may be accepted on trust, a decision shaped as much by prevailing cultural norms as by the formal properties of the information itself; they illustrate the resulting risks with documented cases in which scientifically generated claims were nonetheless propagated and accepted in a essentially non-scientific, dogmatic manner. The paper further extends this analysis to artificially generated information objects, including those produced by automated administrative and AI systems, arguing that culturally embedded habits of trust formed around human and institutional sources of information transfer, often uncritically, to algorithmically generated content as well — a concern that anticipates, within an explicitly GIT-based framework, many of the issues subsequently raised about algorithmic curation and trust discussed earlier in this section.

3. Technological Directions in the Study of Information

In our rapidly advancing digital age, the technological dimensions of information studies have become increasingly vital. These directions explore how information is generated, processed, and used through technological means, driving innovation and transforming nearly every aspect of modern life. The intersection of technology and information spans computer science, data science, cybersecurity, and information systems, fields that focus not only on the practical application of technology but also on the theoretical underpinnings that guide technological advancement.

Technological studies of information are not limited to purely technical concerns; they also address the broader societal implications of technological innovation, including data privacy, security, and the digital divide. The eleven technological directions outlined below illustrate this breadth without claiming to exhaust the field's full possible scope:

- Basic Information Technologies - Technologies for storing, processing, and transmitting data.

- Intelligent Information Technologies and Applications - AI-driven systems and smart applications.
- Natural Information Technologies and Applications - Applications inspired by natural information processes.
- Informational Modeling Technologies - Modeling and simulation of informational systems.
- Computing Technologies - Computational methods and digital processing of information.
- Information-based Societies - Studies the societal impact of information as a key resource.
- Modern (e-) Learning Information Technologies - Digital tools and platforms for education and learning.
- Computational and Algorithmic Technologies - Development of algorithms and computational models.
- Information Technologies in Economics - Practical use of information in economic analysis and digital markets.
- Applied Legal and Regulatory Information Technologies - Implementation of laws and standards in information governance.
- Applied Cultural and Media Information Technologies - Use of information in media production, digital culture, and communication.

3.1. Basic Information Technologies

Basic information technologies encompass the vast ecosystem of tools, infrastructures, and systems that enable the storage, processing, transmission, and retrieval of data. Their theoretical foundations lie in the pioneering work of Turing (1936) on the limits and nature of computation, and the later development of digital packet-switched networks by Cerf and Kahn (1974), whose protocol design made global, interoperable data exchange possible across heterogeneous physical networks for the first time.

Today, information technologies include big data platforms capable of processing volumes of data that would have been entirely intractable a generation ago (Zikopoulos & Eaton, 2011), cloud computing infrastructures that decouple computational capacity from physical hardware ownership, and

cybersecurity systems designed to defend increasingly interconnected infrastructures against a correspondingly expanding range of threats. Blockchain architectures, introduced through Nakamoto's (2008) proposal for a peer-to-peer electronic cash system, demonstrate how cryptographic techniques and distributed consensus can establish trust and verifiable transaction history without reliance on any centralized authority.

The Internet of Things (IoT), a term coined by Ashton (2009) to describe a network of interconnected physical devices that sense, communicate, and act on data largely without direct human intervention, has extended information technologies into the physical environment at an unprecedented scale. The Semantic Web, envisioned by Berners-Lee, Hendler, and Lassila (2001), adds a layer of machine-interpretable meaning to online information, enabling more intelligent and interoperable systems that can reason about, rather than merely retrieve, the data they exchange. These technologies not only support modern communication and commerce but actively reshape social structures, governance, and cultural practice, continuing to evolve rapidly and to drive innovation across all other technological directions.

3.2. Intelligent Information Technologies

Intelligent information technologies enhance decision-making and data-processing capabilities through advanced systems such as machine learning and artificial neural networks. The field traces its origins to the Dartmouth Summer Research Project proposal (McCarthy, Minsky, Rochester, & Shannon, 1956), which formally launched artificial intelligence as a distinct scientific discipline with the explicit conjecture that every aspect of learning or intelligence could in principle be simulated by a machine.

Over the following decades, advances in machine learning, neural networks, and statistical modeling transformed artificial intelligence from a largely theoretical pursuit into a practical force shaping everyday life. Deep learning breakthroughs (LeCun, Bengio, & Hinton, 2015) enabled machines to recognize images, understand speech, and generate natural language with previously unattainable accuracy, while the introduction of the transformer architecture

(Vaswani et al., 2017) made it computationally feasible to train language models on web-scale text corpora by replacing sequential recurrent processing with parallelizable attention mechanisms.

Large language models and generative artificial intelligence systems, exemplified by the GPT family of models (Brown et al., 2020), now create text, images, and simulations of striking fluency, prompting renewed philosophical and technical debate over the nature, scope, and genuine limits of the resulting capabilities (Floridi & Chiriatti, 2020). Intelligent information technologies today power applications ranging from medical diagnostics to autonomous vehicles, making this direction one of the most rapidly transformative within contemporary information science, even as questions of reliability, interpretability, and safety remain the subject of active research.

The rapid scaling of intelligent information technologies has also exposed a distinctive engineering challenge: as models grow in size and training data volume, they exhibit emergent capabilities — abilities such as multi-step reasoning or in-context learning that were not explicitly designed into the system and are not straightforwardly predictable from the performance of smaller models. This pattern has shifted considerable research attention toward understanding scaling laws, toward developing more efficient architectures capable of delivering comparable capability at lower computational cost, and toward techniques for aligning model behavior with human intentions and values, since increasingly capable systems correspondingly raise the practical stakes of any remaining gap between intended and actual behavior.

3.3. Natural Information Technologies

Natural information technologies draw inspiration from biological, physical, and chemical processes to develop genuinely new computational paradigms that depart from the conventional digital, silicon-based architecture. Quantum computing, first conceptualized by Feynman (1982, 1985), proposes harnessing quantum superposition and entanglement to simulate physical systems and perform certain classes of computation far beyond the reach of classical

machines, a vision later given rigorous mathematical foundation by Nielsen and Chuang (2010).

DNA computing, introduced by Adleman (1994), uses biological molecules to encode and manipulate information, demonstrating concretely how nature's own molecular mechanisms (hybridization, ligation, and selective amplification) can be repurposed to solve combinatorial optimization problems that classical algorithms handle only with great difficulty. This approach exploits the extraordinary parallelism inherent in molecular chemistry, in which an enormous number of candidate solutions can be tested simultaneously within a single test tube.

Cellular automata, neural computation, and swarm intelligence further illustrate how natural systems process information through distributed, adaptive, and emergent behavior, in which sophisticated global outcomes arise from the interaction of many simple, locally acting components rather than from centralized control. As research progresses, natural information technologies continue to promise breakthroughs in cryptography, optimization, simulation, and bioengineering, even as significant engineering challenges, from quantum error correction to the reliable readout of DNA-based computation, remain to be resolved before many of these approaches reach practical maturity.

Recent progress in natural information technologies has increasingly focused on hybrid architectures that combine biologically or physically inspired computation with conventional digital processing, rather than seeking to replace classical computing wholesale. Quantum-classical hybrid algorithms, for instance, delegate the portions of a computation best suited to quantum hardware while retaining classical processing for the remainder, reflecting a pragmatic recognition that near-term quantum devices remain limited in qubit count and susceptible to decoherence (Feynman, 1985; Nielsen & Chuang, 2010). Similarly, neuromorphic computing architectures draw inspiration from the structure and energy efficiency of biological neural tissue without attempting to replicate its full biochemical complexity, illustrating how natural information technologies often proceed by selectively abstracting specific principles from nature rather than by direct, literal imitation of biological systems.

3.4. Informational Modeling Technologies

Technological informational modeling focuses on computational simulations and digital representations of complex systems, building directly on the theoretical modeling traditions discussed in Section 2.7 while emphasizing concrete implementation and deployment. This direction employs tools such as agent-based models, system dynamics simulations, digital twins, and cognitive simulations to analyze and predict system behavior under realistic operating conditions.

Digital twins — dynamic virtual replicas of physical systems, continuously updated through sensor data and historical records — originated in Grieves's (2014) work on product lifecycle management and were subsequently formalized for aerospace applications, where Tuegel, Ingrassia, Eason, and Spottswood (2011) demonstrated how a digital twin could re-engineer structural life prediction for aircraft by integrating physical models with continuously updated sensor data, and where NASA further extended the concept to multi-physics, multi-scale, probabilistic simulation of entire vehicle fleets.

Agent-based modeling allows researchers to explore emergent phenomena arising from the interaction of autonomous agents under realistic computational constraints (Epstein, 2006), supporting decision-making, optimization, and scenario analysis across domains as varied as climate science, economics, healthcare, and logistics. By enabling the systematic exploration of "what-if" scenarios at a level of fidelity that purely analytical models cannot match, technological informational modeling provides powerful, practically actionable insight into the dynamics of complex informational environments, from individual manufacturing plants to entire urban transportation networks.

The practical value of technological informational modeling depends critically on the continuous flow of high-quality sensor and operational data needed to keep a digital twin or simulation faithful to the physical or social system it represents, a dependency that links this direction closely to the broader information technology infrastructure discussed in Section 3.1. As digital twins extend beyond individual machines or vehicles toward entire factories, supply chains, and even cities, the technical challenge shifts from modeling any single

component to integrating heterogeneous data streams, maintaining consistency across multiple interacting models operating at different scales, and ensuring that the resulting composite simulation remains computationally tractable despite the combinatorial growth in complexity that such integration entails.

3.5. Computing technologies

Computing technologies encompass the architectures, algorithms, and infrastructures that enable digital information processing. From von Neumann's (1945/1993) foundational stored-program architecture, which established the basic logical organization of virtually all subsequent general-purpose computers, to modern high-performance computing (HPC) systems capable of exascale calculation, computing has evolved into an extraordinarily diverse and rapidly advancing field.

Cloud computing provides scalable, on-demand computational resources that decouple processing capacity from any specific physical location; parallel and distributed computing, increasingly reliant on graphics processing units originally designed for rendering but now repurposed for general-purpose numerical computation, enable the massive data processing that underlies contemporary scientific simulation and machine learning (Dongarra, Gates, Haidar, & Kurzak, 2020); and cognitive computing systems attempt to emulate selected aspects of human reasoning within otherwise conventional computational architectures.

Quantum computing represents a genuine paradigm shift, offering exponential speedups for specific, carefully identified classes of problems by exploiting quantum mechanical phenomena that have no classical analogue (Nielsen & Chuang, 2010; Feynman, 1985). These technologies collectively underpin scientific research, industrial automation, financial systems, and everyday digital services, and as computing continues to advance along multiple, only partially convergent technological trajectories (classical, quantum, and neuromorphic) it continues to drive innovation across every other technological direction surveyed in this paper, expanding the practical horizon of what information systems can be made to achieve.

A persistent challenge throughout the history of computing has been the widening gap between the rate at which processing power increases and the rate at which memory and interconnect bandwidth can keep pace, a constraint that increasingly determines the practical performance of large-scale scientific and machine learning workloads regardless of how many processing cores are made available. The growing use of graphics processing units and other specialized accelerators for general-purpose numerical computation reflects a broader architectural shift away from a single dominant processor design toward heterogeneous systems that combine multiple specialized computing elements, each optimized for a particular class of workload (Dongarra, Gates, Haidar, & Kurzak, 2020). This architectural diversification, in turn, places growing demands on software systems and programming models capable of allocating computation efficiently across fundamentally different types of hardware within a single application.

3.6. Information-Based Societies

A set of agents is called "Society", iff there exists agreement for information interaction between them, by means of which they could communicate. An important element of this agreement is the availability of a common information base. In other words, every group of agents, people in particular, is a society if any agreement for information interaction between them exists (Markov, Poryazov, Ivanova, Mitov, and Markova, 2008).

This definition is in accordance with usual understanding of the concept "society". The sociologist Richard Jenkins remarked that the term addresses a number of important existential issues facing people (Jenkins, 2002):

1. How humans think and exchange information – the sensory world makes up only a fraction of human experience. In order to understand the world, we have to conceive of human interaction in the abstract (i.e., society).
2. Many phenomena cannot be reduced to individual behavior – to explain certain conditions, a view of something "greater than the sum of its parts" is needed.

3. Collectives often endure beyond the lifespan of individual members.
4. The human condition has always meant going beyond the evidence of our senses; every aspect of our lives is tied to the collective.

We shouldn't picture the information base like a number of drives with a certain data recorded, although it's the way it's been since the beginning – it was recorded on clay plates, papyrus, paper. The ability for digital storage of the data lays the beginnings of the genesis of the "Information Societies". It's obvious that, there are many societies with correspondent information bases, and a person could belong to more than one society. Thus we could talk about "information societies" which exist in a certain way with or without a particular correlation between them. And it's not very likely for the humanity to reach such state of integrity so we could use this term in singular when speaking about the population of the whole planet. Nevertheless the concept "global information society" is very popular. This is a general concept which means the hypothetical digitally based integrated humanity (Markov, Poryazov, Ivanova, Mitov, and Markova, 2008).

The concept of an information-based society highlights how digital technologies transform social structures, institutions, and everyday life at a pace that has historically outstripped the capacity of existing institutions to adapt. Early theorists such as Bell (1973) described the broader shift from industrial to post-industrial society, a transition driven primarily by knowledge and information rather than by the production of physical goods, with theoretical and technical occupations displacing manufacturing as the principal source of economic value.

Castells (2009) later articulated the influential concept of the "network society," in which digital networks reshape power, identity, and social organization by privileging those nodes and actors best positioned within increasingly important informational networks, often independently of their formal institutional standing. Today, information-based societies rely extensively on e-governance, digital healthcare, online education, and data-driven decision-making across virtually every domain of public administration and private enterprise.

These transformations raise pressing questions about digital inclusion, algorithmic governance, and the broader social implications of ubiquitous data collection, with Kitchin (2014) examining how the unprecedented volume, velocity, and variety of contemporary data generation (the so-called "data revolution") reshapes scientific method, public administration, and the texture of everyday life itself. Information-based society studies thus explore how technology reshapes citizenship, culture, labor, and public life, offering critical insight into both the considerable opportunities and the significant risks of accelerating digital transformation.

A defining feature of the information-based society is the increasing reliance of public institutions on algorithmic systems for tasks ranging from resource allocation to risk assessment, a development that promises efficiency gains while simultaneously raising difficult questions about due process, contestability, and the appropriate role of human judgment in decisions that were traditionally made by accountable public officials. The concept of e-governance captures this shift toward digitally mediated interaction between citizens and the state, encompassing not only the digitization of existing administrative procedures but the more fundamental redesign of public services around the availability of real-time data and automated processing. As information-based societies continue to mature, the central governance challenge increasingly concerns how to preserve democratic accountability and citizen trust while institutions become ever more dependent on data infrastructures and algorithmic decision-making processes that are not always fully transparent even to the officials who rely upon them.

3.7. Modern (e-)Learning Information Technologies

Modern e-learning technologies integrate digital platforms, multimedia resources, and adaptive systems to support learning in flexible and increasingly personalized ways. Early work on computer-assisted instruction (Suppes, 1966) laid the conceptual foundation for today's online learning ecosystems, demonstrating already in the 1960s that carefully designed computer-based instruction could adapt systematically to individual student responses.

Massive Open Online Courses (MOOCs), learning analytics, and intelligent tutoring systems now enable learners to access high-quality educational content from virtually anywhere in the world, with Laurillard's (2012) conversational framework offering a principled account of how digital tools can support, rather than supplant, the iterative dialogue between teacher and learner conceptions that underlies effective instruction. Connectivist theories (Siemens, 2005) emphasize learning as a process of navigating and continuously reconfiguring networks of information and social connection, an emphasis that has only grown more relevant as educational content has become distributed across an ever-expanding array of platforms and formats.

Modern platforms increasingly incorporate AI-driven recommendation systems, interactive simulations, and collaborative tools that adapt dynamically to learner progress and preference. E-learning technologies also support lifelong learning, professional development, and inclusive education for learners facing geographic, financial, or physical barriers to traditional instruction; as digital learning environments continue to evolve, they reshape pedagogical practice and substantially expand global access to knowledge, even as questions of educational quality, completion rates, and digital equity remain unresolved.

The technological infrastructure underlying modern e-learning has shifted considerably from early, largely static online course materials toward systems capable of continuous, fine-grained learning analytics that track not only final assessment outcomes but the moment-by-moment patterns of engagement, hesitation, and error that characterize an individual learner's progress through course material. This analytic capability enables genuinely adaptive learning pathways, in which the sequence and difficulty of material presented to a given learner can be adjusted automatically in response to demonstrated mastery, though it simultaneously raises the same questions of data privacy and algorithmic transparency that arise throughout other technologically mediated domains of an information-based society, particularly where the learners generating such data are minors whose long-term educational and employment prospects may be shaped by automated assessments made early in their academic careers.

3.8. Computational & Algorithmic Technologies

Computational and algorithmic technologies focus on the design, analysis, and optimization of algorithms — the precise procedures that drive all information processing. Classical algorithm theory, developed comprehensively by Knuth (1968) in his multi-volume treatment of computer programming, established the rigorous foundations for analyzing computational efficiency and complexity that remain standard throughout computer science.

Modern algorithmic research spans machine learning, optimization, cryptography, data mining, and large-scale distributed computation (Goodfellow, Bengio, & Courville, 2016), extending classical algorithmic theory into domains where the relevant "problem" is often defined only implicitly, through a large training data set, rather than specified explicitly in advance. Algorithms determine how information is sorted, classified, compressed, encrypted, and interpreted at every stage of contemporary digital infrastructure.

Algorithms also shape social and economic systems directly, through recommendation engines that influence what content billions of people encounter daily, search algorithms that structure access to the entirety of publicly available online information, and automated decision-making systems increasingly deployed in lending, hiring, and criminal justice contexts. As algorithms become ever more deeply embedded in daily life, this direction examines not only their formal technical properties (correctness, efficiency, scalability) but also their fairness, transparency, and broader societal impact, questions that connect this technological direction directly to the ethical and legal technologies discussed in Sections 2.13 and 2.18.

Algorithmic research increasingly grapples with the gap between worst-case theoretical guarantees, which have traditionally dominated algorithm analysis, and the typical-case performance that determines practical usefulness on the specific kinds of data encountered in real applications, a gap that has motivated growing interest in data-dependent and average-case analysis frameworks. This shift is especially pronounced in machine learning, where algorithms are routinely deployed despite the absence of formal guarantees comparable to those available for classical sorting or searching procedures, relying instead on

extensive empirical validation across benchmark data sets whose representativeness of real-world deployment conditions cannot always be guaranteed in advance. The resulting tension between formal algorithmic rigor and empirically validated but theoretically less well-understood machine learning methods remains one of the most consequential open questions for the future development of computational and algorithmic technologies .

3.9. Information Technologies in Economics

Information technologies in economics reshape markets, industries, and economic behavior. Digital platforms, data-driven business models, and algorithmic marketplaces have transformed competition and value creation across virtually every industry (Brynjolfsson & McAfee, 2014), with the authors' concept of a "second machine age" emphasizing how digital technologies, unlike earlier mechanical innovations, directly augment cognitive rather than merely physical labor.

Information reduces transaction costs, enables highly personalized services tailored to individual consumer behavior, and supports real-time decision-making across supply chains, financial markets, and consumer-facing platforms alike. Applied economic information studies also examine the economics of data as a distinctive commodity, the conditions of digital labor in platform-mediated gig economies, the competitive dynamics of platform monopolies that benefit from strong network effects, and the expanding role of information in financial systems increasingly dominated by algorithmic trading (Goldfarb & Tucker, 2019).

As economics become increasingly digital, this direction provides essential insight into innovation, productivity measurement (a notoriously difficult task in sectors where much economic value is generated by free or near-free digital services) and the evolving structure of global markets shaped fundamentally by the economics of information rather than of physical goods alone.

Applied economic information research also examines the distinctive competitive dynamics that arise when digital platforms function simultaneously as marketplaces and as participants within those same marketplaces,

accumulating data advantages that can be difficult for new entrants to replicate regardless of the quality of their underlying products or services. This dynamic has prompted growing regulatory and academic attention to questions of platform power, interoperability, and data portability, as policymakers seek tools capable of preserving competitive markets in sectors where traditional antitrust frameworks, developed primarily with physical goods and conventional pricing in mind, do not always translate straightforwardly to markets where the most economically significant currency exchanged between consumers and platforms is personal data rather than money.

3.10. Applied Legal & Regulatory Information Technologies

Applied legal and regulatory information technologies focus on implementing laws, standards, and governance frameworks, which concretely regulate information practices within specific organizational and technical contexts. With the rise of digital technologies, issues such as data protection compliance, cybersecurity regulation, intellectual property enforcement, and algorithmic accountability have become central, practically pressing concerns for organizations of every size.

The General Data Protection Regulation represents a landmark in global data governance, establishing detailed, legally binding requirements around lawful processing, purpose limitation, data minimization, and individual rights such as access and erasure, and emphasizing transparency and accountability throughout the entire data lifecycle (European Parliament and Council of the European Union, 2016; Tikkinen-Piri, Rohunen, & Markkula, 2018). Its extraterritorial scope has, in practice, made it an influential reference point for data protection legislation well beyond the European Union's own borders.

Applied legal information studies also address regulatory compliance procedures, organizational risk management strategies, and the practical, often contested question of how to deploy artificial intelligence systems ethically and lawfully within existing regulatory frameworks not originally designed with such systems in mind. This direction thus ensures that information technologies operate within frameworks that concretely protect individuals, support

institutional trust, and promote responsible innovation, translating the theoretical concerns raised in Section 2.18 into specific operational requirements.

In practice, applied compliance work increasingly requires close collaboration between legal, technical, and organizational stakeholders, since requirements such as data minimization or the right to erasure cannot be satisfied merely through policy documentation but must be embedded directly into the design of databases, machine learning pipelines, and record-retention systems from the outset, an approach often described as "privacy by design." Organizations operating across multiple jurisdictions face the additional applied challenge of reconciling potentially conflicting regulatory requirements, for instance where one jurisdiction mandates data localization while another restricts cross-border transfer only under specific safeguards, requiring applied legal and regulatory expertise capable of translating abstract statutory language into concrete, auditable technical and organizational controls.

3.11. Applied Cultural & Media Information Technologies

Applied cultural and media information technologies examine how digital technologies concretely shape media production, cultural expression, and communication practice in present-day platforms and institutions. Social media platforms, digital storytelling tools, and multimedia production technologies have transformed how information is created, edited, and shared at a scale and speed unimaginable under earlier broadcast media models.

Jenkins's (2006) concept of participatory culture highlights how users actively contribute to media ecosystems through fan communities, remix practices, and grassroots content creation that often operates alongside, and sometimes in direct tension with, traditional commercial media production. Manovich (2020) extends this analysis through cultural analytics, applying large-scale, data-driven visualization techniques to reveal previously inaccessible patterns in cultural production, consumption, and stylistic evolution across vast digital archives.

Applied media information studies also address digital literacy, the construction and curation of online identity, and the considerable influence that

recommendation and ranking algorithms exert on cultural visibility, determining, in practice, which creators and works reach mass audiences and which remain largely invisible despite comparable artistic merit. This direction thus bridges information science directly with media studies and cultural production, offering practically grounded insight into the evolving landscape of digital culture and its institutional, economic, and aesthetic consequences.

The applied dimension of cultural and media information technology has been further reshaped by generative artificial intelligence tools capable of producing images, music, and text in a wide range of stylistic registers, raising practical questions about attribution, authenticity, and the economic position of human creators whose work may have been used, often without explicit consent, to train the very systems now competing with them in commercial markets. Cultural institutions (museums, broadcasters, publishers) must increasingly navigate these applied technological questions alongside their traditional curatorial and editorial responsibilities, developing policies for the disclosure and labeling of synthetically generated content that attempt to preserve public trust in cultural and informational institutions even as the line between human and machine-generated content grows increasingly difficult to discern through casual inspection alone.

4. Conclusion

The review of theoretical and technological directions in the study of information presented in this paper outlines the genuinely multifaceted character of the field. Theoretical studies provide the fundamental principles and abstract frameworks necessary for conceptualizing, structuring, and interpreting information, offering deep insight into its nature, transmission, and impact on cognition and societal dynamics. Technological information studies, in turn, emphasize the practical applications and innovations that drive our digital age, spanning a wide range of fields from computer science and data science to cybersecurity and information systems.

Through the systematic analysis of topics discussed at the IS4SI and ITHEA Summits and the inclusion of additional significant areas, this paper offers a

sample list of directions that can serve as valuable reference material and a foundation for further discussion in the field of information science. The interdisciplinary nature of information studies requires a holistic approach that integrates theoretical and technological perspectives, enabling effective navigation of the growing complexity of an increasingly digitized world.

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*Major Fields of Scientific Research: General theoretical information research, Intelligent natural and artificial systems
Multidimensional multi-layer structures and operations in self-structured systems*