Toward a Systems Perspective on Information

Resources, Processes, and Capabilities in Context

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Abstract

Systems may make effective use of observations, diagnoses, representations, procedures and expertise; in other situations, these resources may be only partly exploited or remain unused when a response is needed. Another system may receive data correctly while misunderstanding what they refer to. This essay relates informational resources, capabilities, and processes within interacting systems. It examines how signs and representations make selected aspects of reality accessible, how knowledge and capabilities are mobilized under contextual and temporal constraints, and how present activities can change future possibilities. An illustrative industrial-valve case connects a missed deterioration trend with a semantic error at an interface. The article distinguishes retained results from learning and effects on the acting system from effects on other systems. Four complementary figures and five questions for prospective design make the proposed synthesis tangible. Its immediate aim is to identify informational possibilities that could be better used; its wider research context concerns representation, knowledge, intelligence, organization and control.

Keywords: information; systems; representation; sign; knowledge; capability; process; interpretation; accessibility; temporality; industrial control.

1. Information is available. Why is it not used?

Consider a motor-operated valve on a manufacturing line. Its controller records the interval between an opening request and confirmation of the open position. A protective rule signals a discrepancy if confirmation has not arrived within five seconds. Successive opening times slowly increase, and the values are retained in a historian. Experienced technicians know that such a trend may precede mechanical sticking. Yet the first warning may be issued only when the protective limit is reached.

This fictional case describes no particular installation. Diagnostic and prognostic engineering already offers methods for detecting such deterioration (Jardine, Lin, and Banjevic, 2006). The puzzle is more general. **Measurements, a rule, and experience can all be present without jointly providing a usable capability to anticipate the fault.** Information available somewhere in an organization is not necessarily accessible to the participant who needs it, correctly interpreted, or mobilized soon enough to matter.

The same valve exposes a second problem. Suppose its controller distinguishes:

OpenRequest = TRUE — a request has been issued;

OpenConfirmed = FALSE — the open position has not yet been confirmed.

An integration interface publishes the request as ValveOpen = TRUE. A receiving application treats that field as confirmation of the physical state. No bit needs to have been corrupted: the mapping has obscured **what the value refers to**. A technically successful transfer can therefore enable an incorrect conclusion. Industrial information-modelling standards, including OPC UA, offer

mechanisms for representing structures and relationships more explicitly, but the conventions and referents still have to be selected and used appropriately (OPC Foundation, 2025).

The first difficulty concerns the mobilization of available resources; the second concerns the adequacy of a representation. Both also concern time. An interpretation that arrives after the intervention opportunity has closed may be well justified yet operationally useless. The central question of this article is therefore:

How can we examine the information-related resources, capabilities, and processes of interacting systems in order to recognize underused possibilities and consider improvements in their ability to observe, understand, decide, and act?

The answer requires more than a ladder from data to information to knowledge. Such hierarchies can be useful for particular explanatory purposes, but their diverse versions do not establish a compulsory sequence of transformations (Ackoff, 1989; Rowley, 2007). A controller can apply a rule without learning. A person can exercise a skilled capability without expressing every intermediate meaning. A new diagnosis can be recorded without changing the knowledge or rule that produced it. The perspective developed below keeps these possibilities distinct while showing how they are connected. It also establishes an initial vocabulary for a broader investigation of information, systems, and intelligence—without asking this first article to resolve every question about meaning, learning, or intelligence.

2. Representations, knowledge, and the boundaries of systems

Equipment, humans, computers, documents, and representations all participate in the same reality. A stored temperature value is real, although it is not the temperature it represents. In this article, a **system** is understood as an organized set of elements and interactions considered for a particular analytical purpose. Its boundary depends in part on the question being investigated. Within an industrial system, operations and control can be distinguished as interacting subsystems, even when their functions are closely integrated. This decomposition allows us to examine informational interactions within a system, as well as direct and information-mediated interactions between systems.

That choice of boundary affects what it means for a resource to be *available*. The maintenance technician's experience can be internal to an installation-wide system while remaining unavailable to the controller's diagnostic logic. An externally hosted rules service might provide an explicit procedure; an external person might contribute an experienced judgment. Inclusion within a larger organizational boundary does not by itself make the participants' knowledge mutually accessible. The study of distributed cognition has examined related interactions among people, instruments, and representations (Hutchins, 1995).

Three terms describe overlapping aspects of such interactions. A **representation** makes selected aspects of something available according to a viewpoint, purpose, and set of conventions. A **sign** is considered in the role it plays in referring to, indicating, or contributing to the interpretation of something else. **Data** are conventionally expressed representations available for recording, processing, or exchange. The value OpenConfirmed = FALSE can simultaneously be data, a representation of a reported state, and a sign for a technician. They are not three successive levels or exclusive kinds of objects.

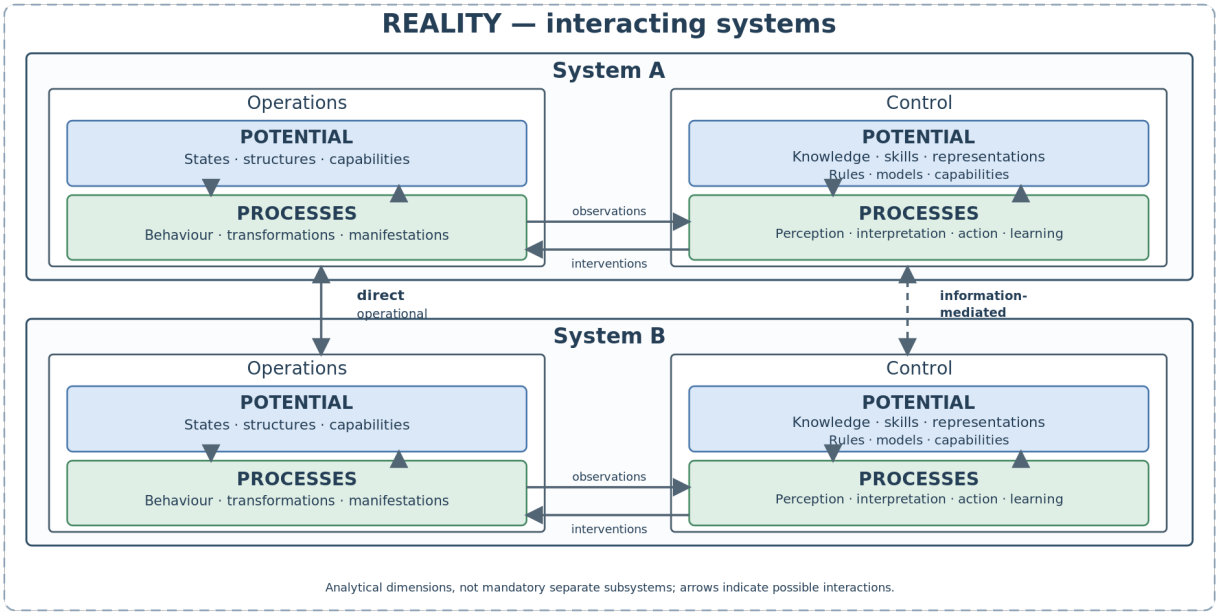

Figure 1. Operational and information-mediated interactions within and between systems. Systems A and B are analyzed as wholes, with operational and control-related dimensions, each involving potential and processes. Direct and mediated links illustrate different inter-system interactions; the decomposition is analytical, not a universal architecture.

These distinctions have established intellectual relatives. Peirce's account of signs, objects, and interpretants directs attention to relations of reference and interpretation; it also reminds us that the represented object must not be identified with its representation (Peirce, 1868; Atkin, 2023). Davis, Shrobe, and Szolovits (1993) examine representations as surrogates that impose commitments and enable particular forms of reasoning and computation. Their analysis helps explain why a representation is evaluated by what it makes possible and what it leaves aside, not just by its syntactic correctness.

Meaning is relational and contextual. A convention can make meaning available; interpretation establishes, actualizes, or uses it in a particular situation. Interpretation can also generate a conclusion or hypothesis and contribute to the development or revision of knowledge when its result is connected with evidence and subsequent experience. Such outcomes may be represented and retained, without implying that every interpretation immediately changes a learned capability. A message provides signs or representations for a recipient to interpret; the ValveOpen example shows why meaning cannot be treated as a guaranteed property of a transmitted string.

A system's **knowledge** can concern itself, other systems, or the correspondences between them. An industrial controller may rely on representations of a manufacturing line, of its own database structure, and of the relationships between physical equipment and stored information. These representations differ in their purposes, referents, and criteria of adequacy. A representation of the line selectively describes an independently existing, changing operational reality; a database schema may formally specify a designed logical structure. Both depend on conventions. Models, descriptions and schemas are forms or uses of representations here, rather than additional foundational categories. Formal precision does not by itself establish what a field refers to in the physical installation.

Knowledge also differs in its form of realization. Rules and models may express it explicitly. Acquired human skills or capabilities of a trained neural model may rely on organized dispositions that lack a complete human-readable symbolic account. Polanyi's work on tacit knowing (1966) is

pertinent here. A pianist can perform a learned passage without reconstructing each written note; an industrial expert can recognize a pattern without being able to state a full diagnostic algorithm. Rasmussen (1983) likewise distinguishes skill-, rule-, and knowledge-based modes of human performance. These are useful comparisons for understanding how existing abilities may be mobilized differently in different situations.

The information available to a recipient is therefore different from the knowledge or competence of the system supplying it. A representation is selective; access is conditional; interpretation is situated. This is the setting in which resources may—or may not—contribute to activity.

3. Available resources, capabilities, and processes

The central proposal of this article is to examine resources, capabilities, and processes together in their information-related roles, rather than treating information only as recorded objects or messages in transit. These three notions are general to systems: our specific concern is how they participate in observing, representing, interpreting, communicating, deciding, learning and acting.

An **informational resource** is something available to a system that can contribute to an information-related task: a measurement, a diagnostic result, a model, a rule, or the service of a participant possessing relevant expertise. A **capability** is an ability grounded in a system's organization and resources to perform a class of activities or produce effects under stated conditions. An **process** is an activity or interaction that occurs in a particular situation: sensing, interpreting, communicating, applying a rule, deciding, learning, intervening, or some combination of these. The distinction depends on the chosen system boundary: a technician's expertise is a capability of that person and may become a resource for an industrial organization or another participating system.

These are overlapping analytical descriptions, not disjoint inventories. A stored model may be a resource; a system may have the capability to evaluate it; and evaluation is a process. A process can also be represented or specified before it takes place; its occurrence is an activity in a particular situation.

Potential is used here as an analytical perspective on the organization, states, knowledge and capabilities of a system, considered in relation to possible future activity. It does not imply that an observer can identify every possibility the system offers. More specifically, informational potential concerns the possibilities offered by relevant resources, representations, knowledge and capabilities to a particular system, task, context and time horizon. Some possibilities may remain unused or become usable only through further processes. The broader question of informational possibilities independent of current observers remains open for later research.

An activity can have several distinguishable consequences:

A rule produces a result. When opening takes longer than five seconds, the controller's existing timeout rule triggers an alarm. The rule itself remains unchanged.

A result made available for later use. After detecting a timeout, the controller records the event and its diagnostic result. These representations may support later interpretation or comparison, while the rule that detected the fault remains unchanged.

A revised knowledge base or capability. Interpreted observations, comparison with outcomes, and validation revise a prediction model, diagnostic rule, or acquired skill. The system can respond differently to later situations.

A change in another system. An authorized intervention adjusts, repairs, or stops the valve. The most important outcome may occur in the controlled equipment rather than in the controller's knowledge.

These outcomes can coexist. The controller may record an event while issuing a command; later evaluation may use the record to revise a model. **Keeping a result and changing a capability are different outcomes.** Nor does possessing a model guarantee that it can be understood or used within the required time. An activity may leave changes in several systems at once.

Figure 2 enlarges one possible arrangement of processes. A perception can contribute directly to action; interpretation can produce a result available for later use; perception, interpretation, and action can contribute to learning. No single path is prescribed for all systems. The arrows describe possible functional or causal dependencies; some, but not all, need be semiotic relations.

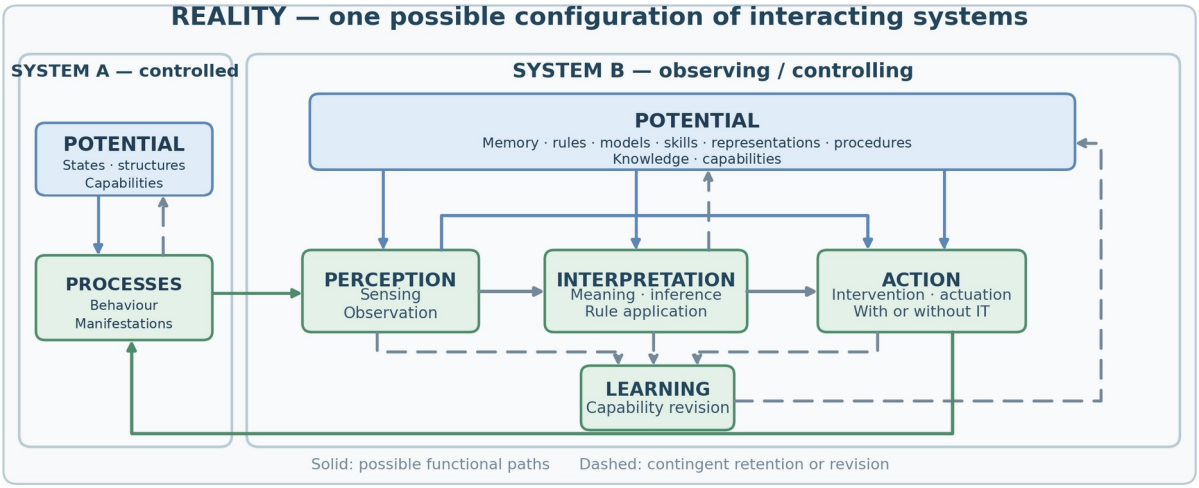

Figure 2. Potential and possible processes in an observing or controlling system. The blue boxes show selected aspects of potential; the green boxes show processes. Solid arrows indicate possible functional pathways; dashed arrows indicate contingent retention, learning or revision. The figure does not prescribe one compulsory sequence.

The contrast between capacity and its exercise has long been recognized—for example in Aristotle's distinction between potentiality and actuality (Metaphysics, Book Θ [IX]), Buckland's (1991) analysis of informative things, knowledge and processes, and Ashby's (1956) analysis of states and regulation. What concerns us is how these distinctions intersect when systems exchange representations, mobilize capabilities, undertake processes, and change the conditions of future activity.

4. Access, interpretation, and time to act

A capability contributes to an objective under conditions in which it can be exercised. These conditions include **access**, **relevance**, **adequacy of interpretation**, **authority**, and **time**. Each can limit what a system or participant can do, even when relevant resources exist elsewhere.

Figure 3 makes this problem concrete. The observed equipment, controller, records, and human or AI participants offer different resources. Access to each can be direct, mediated, delayed, partial, or unavailable. The processes that mobilize them can change both the controlled system and the knowledge, models, or skills available for later use.

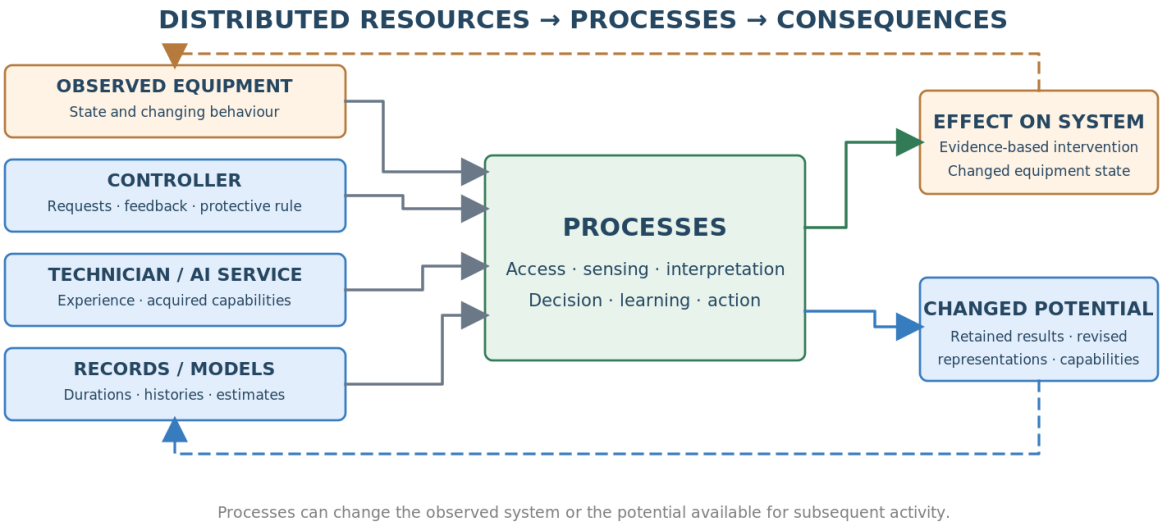

Figure 3. Distributed resources, conditional access, processes, and consequences. Interventions may change the observed system, while retained results or revised representations and capabilities may change the potential available for subsequent activity.

An accessible value is not necessarily an adequate representation. In our interface example, the receiving application can read ValveOpen = TRUE, but cannot safely infer an opened valve when the value encodes only an opening request. The required correction is to distinguish the command, the reported state, the conditions of observation, and the origin of the claim. A diagnostic assertion needs appropriate evidence and justification; a prediction needs stated conditions and uncertainty; a command needs an identified recipient and proper authority. These are different criteria of adequacy, not a single scalar *validity score*.

Recognition of **relevance** is also a capability. Two technicians may hear the same unfamiliar noise, yet only one associates it with a previous failure. The significance of the observation depends on experience, task, expectations, and current objectives. Situation-awareness research treats perception, comprehension, projection, goals, and attention as interacting concerns in dynamic tasks (Endsley, 1995). Such recognition can motivate further interpretation, a familiar rule-based response, or exploration of a novel possibility. Not all capable action needs a separate, explicitly recorded meaning between observation and intervention.

Time makes these distinctions operational. An event occurs; it may be sensed later, transmitted or retained later still, interpreted after further processing, and followed by a decision and an intervention. Learning a missing capability introduces another timescale. Processes may overlap, so response latency depends on the **critical dependencies between activities**, not necessarily on the sum of all their isolated durations. A justified conclusion delivered after the intervention opportunity has closed cannot avert the event it was intended to prevent.

Figure 4 contrasts three possible timelines. An available capability can support intervention within the useful window. Developing or validating the capability during the event may take too long; delayed observation or deliberation may also lead to the same missed opportunity without involving learning at all. These are illustrative timing scenarios rather than measured durations or universal sequences.

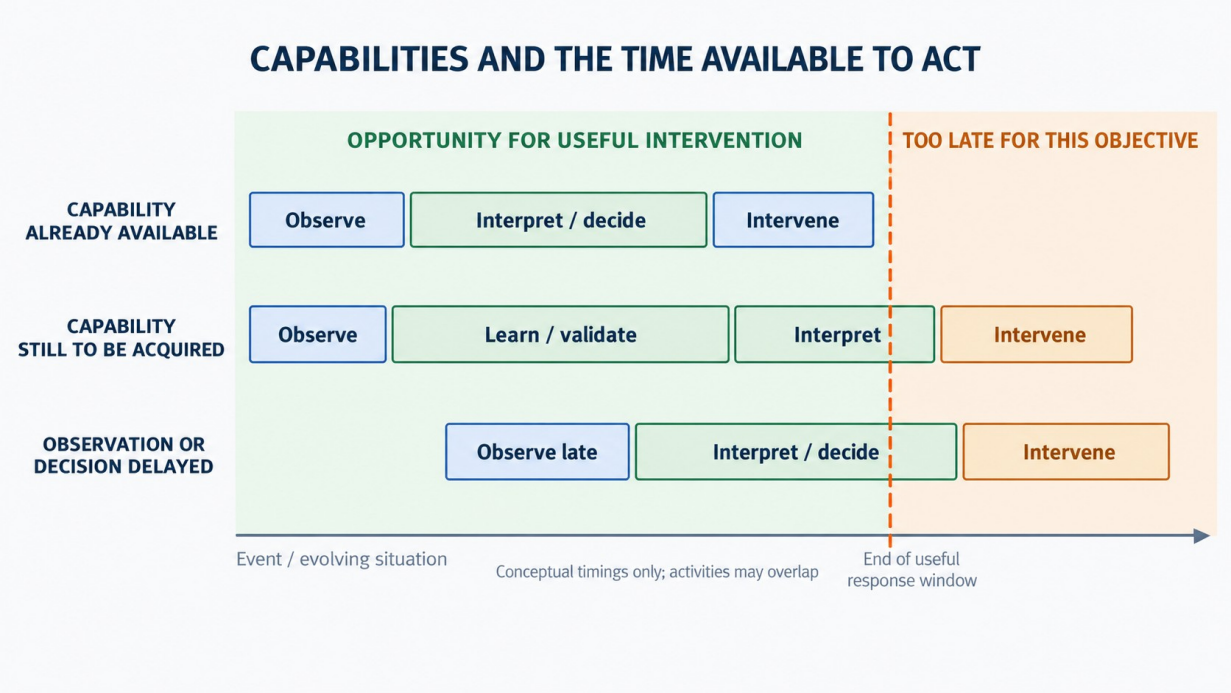

Figure 4. Capabilities and the opportunity window. The first scenario intervenes in time; the other two illustrate late intervention caused by capability acquisition or by observation and interpretation extending beyond the useful window.

For control engineers, **observability and controllability** are relevant formal precedents. Under the assumptions of a specified dynamical model, they address whether internal state can be inferred from system outputs and whether a system state can be driven through admissible inputs (Kalman, 1960). Questions about access, meaning, authority, and time also concern socio-technical conditions beyond those model-based properties. For action, an inferred state must also be accessible, adequately interpreted, and available in time to a participant with the authority and means to intervene.

A capability that can be acquired tomorrow is not equivalent to one that can be exercised today. Conversely, high processing speed alone does not ensure a sound interpretation or a justified intervention. This relation between availability, preparation, and the time needed to respond is one reason to study information within actual systems and their activities rather than as detached data alone.

5. From a conceptual distinction to a design inquiry

A practical use of this perspective is **prospective**: begin with the capability that a system needs, then examine which resources and processes can provide it. The objective is not simply to accumulate data or prescribe a new application, but to recognize possible improvements that serve specified purposes under real constraints.

For the valve, a useful requirement might be: *provide a justified warning of developing blockage sufficiently early for an authorized participant to assess the evidence and intervene safely*. This is different from the existing requirement to detect failure to open within five seconds. The protective limit must remain independent of any adaptive warning criterion.

Five questions organize the inquiry. Their application illustrates different kinds of possible design decisions; they are offered as a scaffold for reflection, not as a validated engineering method.

1. Required capability — What must be recognized or achieved, and by when? The controller currently detects a timeout, not a developing blockage. A prospective requirement should specify an early warning, the supporting evidence, an acceptable rate of false alarms, the required lead time, and the participant authorized to intervene.

2. Available resources — What observations, knowledge, and skills already exist? Opening durations, operating context, asset records, and technicians' experience may be held in different places. The design task is to identify which conditions make past cycles comparable and how maintenance findings can be associated with the relevant observations.

3. Access and meaning — What must reach whom, and with which referents? The OpenRequest / OpenConfirmed distinction must survive interfaces. A diagnosis needs provenance, timing, and applicability information; useful technical experience may have to be elicited or brought into the review process rather than assumed to exist in the application.

4. Processes and timing — What must happen while intervention is still useful? Interpreting a trend is only part of the response. Review, authorization, and maintenance scheduling may dominate the critical path. The design must therefore locate the analysis appropriately and budget the complete route to action.

5. Adaptation and learning — How should informational and control capabilities evolve as the system and its operating context change? Equipment ages or is replaced, processes and products change, and operational objectives or constraints evolve. The representations, rules, knowledge and capabilities supporting control may therefore need to be revised. The design should establish how relevant changes are recognized, how their consequences are assessed, and how appropriate adaptations are implemented and validated. Learning from recorded outcomes is one possible mechanism, but it does not cover every form of necessary adaptation.

The resulting interventions differ in nature: some concern representations and interfaces, others the processes of trend surveillance, diagnostic review, authorization, and maintenance planning; still others concern knowledge acquisition, human responsibility, or equipment. A predictive algorithm may be part of the solution, but it is not necessarily the first or most urgent design decision. Even if an algorithm predicts the trend accurately, the capability remains ineffective when the maintenance process cannot act in time.

A digital twin can participate in such an arrangement. ISO 23247-1:2021 (ISO, 2021) sets out general principles for digital twins in manufacturing. A purpose-specific digital representation may combine measurements, estimates, retained history, and predictive models. Yet its synchronization does not make it identical to the physical installation, establish the correctness of its interpretation, or guarantee effective intervention. The twin's role must be determined by the capability it supports, the limits of its representation, and the processes that use it.

The five questions are intended as a **cross-disciplinary checklist for reflection**, not as a competitor to established requirements engineering, reliability engineering, or control design. They may be particularly useful for readers learning to diagnose information-related gaps and for teams that must coordinate industrial operations, IT, maintenance, and human judgment. Whether such use improves outcomes or reduces missed requirements remains an empirical question.

6. What this synthesis can contribute—and what remains to be tested

This synthesis proposes a common perspective on how systems acquire, represent, make accessible and mobilize informational resources, and how their processes may transform their own knowledge and capabilities or other systems. Its contribution lies in making the relationships among these dimensions explicit across disciplines and system boundaries.

Those relationships are already addressed, from different angles, in established research. Buckland (1991) distinguishes informative things, knowledge, and processes; Peirce's semiotics investigates reference and interpretation (Peirce, 1868; Atkin, 2023); Davis, Shrobe, and Szolovits (1993) examine the roles and commitments of knowledge representations. Rasmussen (1983) studies modes of skilled and rule-guided human performance. Hutchins (1995) and Star and Griesemer (1989) study coordination across people and artefacts; Ashby (1956) and Kalman (1960) address specified dimensions of regulation. Gibson's (1979) account of affordances provides another comparison for possibilities relative to an agent's capabilities and environment. Our synthesis brings these viewpoints into conversation without equating their theoretical objects or importing their formal claims outside their conditions of applicability.

The wider ambition is to support a sustained investigation into **how representations, meaning, knowledge, processes, and capacities contribute to intelligence and to the evolution of systems**. In this first article, that ambition is made tractable by focusing on what is available to a given system, what becomes accessible and intelligible across boundaries, which activities actually take place, and what their outcomes make possible next. A representation can enable an interpretation yet remain partial; a capability can exist without being mobilized; a completed activity can change another system while leaving the original rule intact. Bringing these cases into one view offers a basis for subsequent conceptual analysis rather than an all-encompassing theory.

One immediate application is prospective design. The five questions can help a reader or multidisciplinary team move from a desired ability to relevant observations, accessible knowledge, meaningful interfaces, authorized processes, timely action, and controlled revision. The valve example shows possible outcomes of that inquiry, not evidence that it outperforms competent established engineering. Such a practical claim would require independent cases and comparisons using predefined criteria, including the quality of decisions, effort, and reproducibility.

Several deeper questions remain open: where physical indication becomes semiosis; when interpretation develops knowledge; how attention, initiative, and creativity shape the selection of actions; and what informational possibilities reality may offer independently of current observers. These questions belong to a broader programme on information, systems, and intelligence, including later studies of representation, complexity, cognition, organization, control, and performance.

7. Conclusion — What can a system do with what it has?

The valve's increasing opening times, the technician's experience, and the ambiguous ValveOpen field illustrate three different conditions: a resource may be present but unused; knowledge may reside where another participant cannot access it; and an exchanged representation may support an invalid interpretation. Even when these gaps are addressed, the time available to act may determine whether a response is useful.

A systems perspective brings together resources, capabilities and processes to examine what an organization or participant possesses, what can be accessed and interpreted in context, and which

capabilities can be mobilized under actual constraints. The capability of one participant may become a resource for another. The central issue is whether available knowledge, representations and abilities can support a pertinent response in the time allowed—and how such responses may change the potential available for subsequent activity.

Its practical purpose is to identify informational possibilities that remain underused and examine how changes in observation, representations, relationships, skills, processes, or responsibilities could better serve defined goals and constraints. Its intellectual purpose is to connect these practical distinctions to the wider study of information, knowledge, intelligence, and systemic development. This does not require all knowledge to be encoded or every action to follow a symbolic interpretation. It requires asking whether the right capabilities can be brought to bear, appropriately and in time.

The question is not only what information a system possesses or records, but what that information makes possible, for whom, under which conditions, and within what time—and how present activity can change those possibilities for the future.

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Editorial Note

This standalone conceptual article presents the author's synthesis, developed from earlier exploratory work and refined through research and critical editorial exchanges involving AI assistance. It forms part of a broader, ongoing inquiry. The author retains responsibility for the arguments, references, and conclusions.