NEXUS: A Synergistic Human-Service Ecosystems Approach

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***Abstract*—This paper presents a novel approach to organizational effectiveness that challenges the static hierarchies predominant in traditional institutional frameworks. Human-Service Ecosystems (HSEs) represent individuals and the technologies they use to achieve goals within an organization. However, in situations involving complex dynamics, such as emergency response, organizations are often ineffective at achieving these goals. This ineffectiveness has been attributed, among other things, to the organization's underlying structure, as static hierarchies are ill-suited to addressing the dynamics of an unfolding situation, and to individuals' cognitive limitations. By improving human-machine effectiveness, while simultaneously improving the interaction between individuals, operationally-networked organizations can synergistically emerge through dynamic social structures supported by dynamic information systems. This paper proposes a new approach, NEXUS, which leads to the design of such an information system (based on the concept of HSE), capable of supporting both the dynamics necessary to match situational complexity, and the formal and informal social structures present within organizations.**

I. Introduction

Organizational fitness refers to the ability of an organization to achieve its goals, and much research has gone into improving this characteristic [1-4]. Overwhelmingly, research posits that organizations are somehow less effective than they could be. The causes are myriad and include poor management strategies, misunderstanding of roles and responsibilities, mismatches between an organization's complexity and that of its environment, discrepancies between the top-down formal and bottom-up informal nature of organizations, and deficiencies resulting from the hierarchical form of governance.

Organizations are culturally complex systems composed of individuals and other resources, including technical resources [5]. Traditional organizations have established formal structures and policies that prescribe roles, functions, and appropriate practices for its members. These structures additionally serve to specify communication channels. However, informal structures often develop, causing the discrepancy between the prescriptive vision and descriptive reality of the organization.

The organization is fundamentally dependent on its human capital to achieve its goals, i.e., on the effectiveness of the individuals to perform their tasks, make timely, informed, and responsible decisions, and communicate effectively as needed. Moreover, these actions may require additional resources, besides the individual, including other individuals and technology. If these resources are used ineffectively, the organizational fitness of the system suffers; conversely, if the organization's resources are used more effectively, organizational fitness improves. Thus, an organization's fitness in achieving its goals is directly proportional to its ability to manage and allocate its resources.

In recent times, this resource allocation has been greatly advanced through the use of technology. For example, email, databases, and business software (e.g., word processing and inventory management software) have allowed for great increases in productivity. However, it is still challenging to design software to assist organizations with more complex tasks, such as linking the right person to the right information at the right time and in the right way. This is particularly relevant to emergency response where increased effectiveness can save not only money, but also lives.

As a running example, consider an Emergency Operations Centre (EOC) consisting of members from various organizations, including police, firefighters, hospitals, governmental departments, and volunteer organizations. Following an event, such as an earthquake, these individuals and their respective organizations must come together to make decisions about evacuations, shelters, and supply allocations to ultimately recover the system. Data is constantly being fed to the EOC, and members must make sense of a large volume of data to achieve different purposes (e.g., reunite families, rescue victims, and manage housing for volunteers).

The challenge of overcoming organizational limitations, while at the same time supporting complex tasks, demands a new framework in which both the social and technical views of the organization are considered. In this paper, the Human-Service Ecosystem (HSE) is presented as just such a framework and NEXUS as a proof-of-concept information-system implementation, in which organizational fitness is increased through a simultaneous, two-fold improvement of human-machine effectiveness and human-resource management.

Foundationally, organizations consist of groups of resources, both human and technological, used in concert to achieve goals and provide services and, as such, may be considered HSEs. These systems are socio-technical [6], multi-dimensional [5], and complex in nature [8], having both top-down policies and bottom-up practices, with properties specific to each level of organization. Complex systems have been defined in [8] as ensembles having key features, including elements, interaction, formation, and activity. They also exhibit specific properties, namely scale and emergence. In terms of scale, HSEs may be viewed from multiple levels: as a comprehensive unit (top-down); as individual actors (bottom-up); and as teams or groups (at some intermediary level of scale). These levels (or layers) act as both systems in their own right (e.g., individuals are biological systems and teams are systems of individuals) and parts of larger systems (e.g., individuals are part of teams and teams part of organizations).

To describe elements that participate in this kind of whole-part relationship, the term holon is used, which derives from a combination of the Greek word *holos*, meaning whole, with the suffix *–on*, meaning part [7]. This term, similar to the property of scale, highlights the emergent behaviour of systems, where the system as a whole is more than the net result of the behaviour of its constituent parts. This synergy—the whole achieving more than the sum of its parts—is precisely what organizations seek as the result of their resource management efforts, and this attribute is what the NEXUS HSE endeavours to facilitate.

This paper contributes to existing literature i) by providing a framework to describe HSEs and ii) by presenting an overview of a dynamic software system architecture, NEXUS, that enables the emergence of holonic synergy. The remainder of the paper is organized as follows: Section 2 presents the background for this work; Sections 3 and 4 present the HSE framework and NEXUS architecture, respectively; and Section 5 concludes the paper with a summary and a direction for future work.

II. Background

While there are many causes for organizational inefficiencies, they can be grouped along three lines: factors limiting i) the individual, ii) the organization, and iii) human-machine effectiveness. This section describes the limitations to achieving holonic synergy in HSEs in the context of existing literature.

A. *Individual Factors*

In terms of individual human factors that impact organizational effectiveness, the ones of interest to this paper relate to human cognitive limitations, including the problem of data overload.

Data explosion is a critical area of concern, especially for those who are called to sift through large volumes of data to uncover trends and make sense of a situation, and this problem is only expected to increase as the proliferation of technology continues to embed itself as an indispensable part of our civilization. Many researchers have examined the problem of data overload, including [9] who define it as "a condition where a domain practitioner, supported by artifacts and other human agents, finds it extremely challenging to focus in on, assemble, and synthesize the significant subset of data for the problem context into a coherent assessment of a situation." As part of their research, [9] have recommended different forms of technology that can assist the user in reducing the effects of data overload, including context-specific models and improved data visualization.

In addition to being easily overwhelmed by relatively small amounts of data, the human mind is also not well adapted to interpreting complex systems, which can comprise many nonlinear feedback loops [10]. However, technology in the form of computer simulation helps to overcome this limitation. According to [11], among other uses, computer simulation can help to explain phenomena, to guide data collection, to discover new questions, to demonstrate tradeoffs, to train practitioners, and to predict future states. In terms of the running example, EOC members can use simulation to better understand the situation on the ground, enhancing "what-if" analysis based on the complex dynamics of the environment as captured in simulation models (versus in the mind of the operator) and on the automatic incorporation of incoming, real-time data.

B. *Organizational Factors*

In addition to individual factors, factors at the organizational level also impact effectiveness, and this paper considers specifically the influence of structure.

Information today is more readily accessible than ever before, and, with an increasing spirit of interconnectedness and sharing, information hoarding and "stovepiping" are becoming characteristics of the past. The hierarchical structure in place in so many organizations has been used historically to create a "span of care" and to channel information into stovepipes so that specialized groups could address specific issues [1,2]. In part, this was a non-technical solution to the data overload problem. However, the recent change in the economy of information places an emphasis on building networks, rather than on traditional hierarchical structures, to capture the power of organizational information and to manage uncertainty [1-3,12,13] (see Fig. 1A and 1C). Through the promise of networks, organizations can promote information sharing, togetherness, and a shared vision, by distributing power across their entire structure and by redefining intra- and inter-organizational boundaries [1,3]. Consider two EOC members, *A* and *B*, that must share information: *A* requests information from *B*, but *B* is overloaded. In a traditional hierarchy, *A* must wait for *B* (which in a crisis situation could be catastrophic) or go through informal communication channels. In a networked organization, however, both *A* and *B* have access to the same information sources, so *A* no longer relies on *B* as an interface.

Even though there appears to be consensus with regards to the organizational structure needed to address complex, novel challenges, few organizations have adopted the network structure. Both [2] and [3] suggest this is due primarily to middle management and their reluctance to the notion of relinquishing control, while still maintaining responsibility. Moreover, there appears to be an unconscious, built-in notion

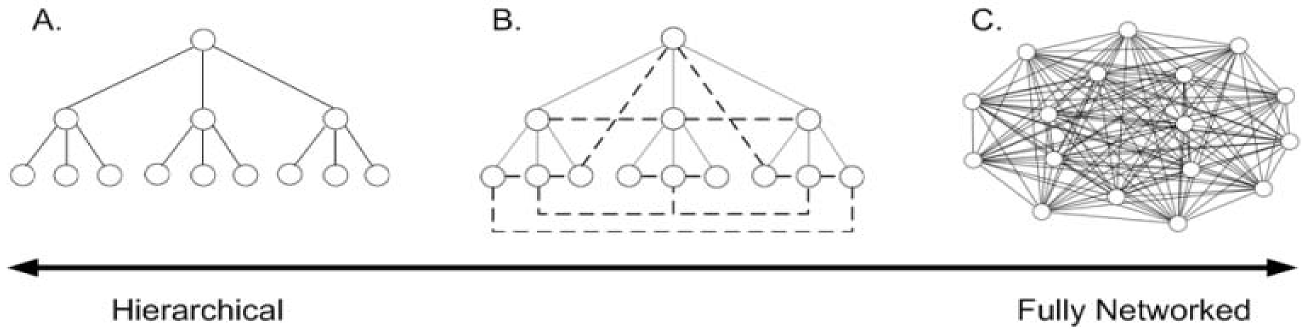

Figure 1. Three organizational structures, ranging from hierarchical ("A") to fully networked ("C"), with an intermediate structure "B" lying in between. Other structures such as small-world and scale-free would also fall along this spectrum. Dashed links in "B" represent formal technological links.

among managers that what has worked in the past will continue to work in the future [3]. What is needed is a method that preserves the stability of the hierarchy, while still being able to take advantage of the network [4], and a technological support strategy presents one possible solution to the reservations of middle management.

C. Human-Machine Effectiveness Factors

While the human-cognitive limitation of understanding complex situations may be alleviated by computer simulation, there are two other technologies that can have a great impact on the effectiveness of human-machine pairings in particular, and organizational effectiveness in general: Human-Computer Interaction (HCI) and Brain-Computer Interfaces (BCIs).

For many years, researchers have known of the challenges preventing users and their machines from acting as a cohesive unit. Particularly, research in the areas of socio-technical systems and ecological-interface design are replete with examples of human error resulting from poorly-designed interfaces [6]. Thus, one area that can improve the effectiveness of such pairings is the field of HCI. Specifically, an HCI that stresses "natural" interfaces is expected to facilitate usage of the software system. Recent efforts have focused on natural-language interfaces and visual analytics. Visual analytics present the "right" view of information to a user with an easily accessible presentation, while natural-language interfaces allow a user to interact with a computer system through speech commands [14]. Both provide users with tools to minimize their information loads, through improved visualization of data and speech-based communication that do not require full attention (versus the case when traditional peripherals, e.g., keyboards, are used).

In addition to effectively designed interfaces to streamline use of a system, it is beneficial to gain access to user context, especially user's internal mental states, and this can be achieved through brain-computer interfaces (BCIs). Having these mental states known to the system is useful for personalizing system responses to the user so as to allow for smart adaptation [16]. Wearable BCIs (e.g., EEG and fNIRS), with real-time signal processing and readily available software libraries, enable their use in detecting psycho-physiological factors, such as cognitive overload, attention, and stress [17]. The literature in the area shows many proofs-of-concept that recognize states (e.g., task load, error, attention, and emotion [18,19]). These aim to assist users by augmenting cognition through the minimization of negative states, such as increased cognitive load [20]. Traditionally, EOC members interact with computer systems via fixed, non-adaptive interfaces, resulting in inefficiencies (and potentially errors) when members are in suboptimal mental states (e.g., overloaded). In an augmented situation, visual analytics can be used to improve the adaptability of systems (e.g., increase font size and highlight critical information) based on user mental states identified through cognitive monitoring (BCI).

III. THE HUMAN-SERVICE ECOSYSTEM FRAMEWORK

As its name suggests, a Human-Service Ecosystem (HSE) comprises both humans and services as its base nodes and both social links (formal and informal) and technical links as its edges. Many different structures can be realized from distinct combinations of these nodes and edges. Furthermore, each edge can be attributed one of three directions: uni-directional (in either direction; e.g., from node *A* to node *B* or from node *B* to node *A*) or bi-directional (e.g., from node *A* to node *B* and from node *B* to node *A*). This provides insight into the interaction among the various component nodes. Ultimately, each edge functions as a type of messaging channel, obeying a specific protocol that governs the interaction across all edges. This system view, captured in Fig. 2, combines both social and technical aspects.

From a holonic perspective, this system view of the HSE can be expressed at different layers. A holon is any entity that participates in a whole-part relationship—that is, it functions as both a whole and a part at the same time. Each node represents a holon and participates at a specific level of organization. This holonic view is captured in the row names of Fig. 2. H1 denotes the individual level, which comprises one human and many software services; H2 denotes the team level, which comprises many nodes of H1; and H3 denotes the organization level, which comprises many nodes of H2. This holonic integration can continue indefinitely to incorporate higher-level meta-organizations, as seen for example in emergency response where multiple organizations come together to form a short-lived, meta-organization, and this meta-organization in turn can be part of a larger meta-meta organization, and so on. Each holonic layer in Fig. 2 is described below in more detail.

H1 represents the base level of the organization and comprises pairings of one human with many software services, which are shown under the nodes column. These nodes can be joined according to different structures. From graph theory, the total number of possible static structures, for a simple undirected labelled graph of n nodes, is as follows:

$$2^{\binom{n}{2}}. \tag{1}$$

Under the structures column for H1, four sample structures are shown (of the possible 64 structures for n = 4). Moreover, every edge in each static structure can take on one of three directions, as discussed previously. Thus, for each structure, the number of possible interactions is as follows:

$$3^{number\_of\_edges}. \tag{2}$$

Four sample interactions are shown for H1's interaction column (of the possible 243 for number of edges = 5), in which the same five edges are presented. Finally, for each interaction, an infinite number of protocols exist to govern the interaction dynamics. For graphical purposes, these are presented as sequence diagrams. At this layer, the protocol outlines the function of the human in concert with its services. Thus, it is here that an organization's roles are defined.

At the H2 level, nodes are represented as H1 holons. The structures and interactions at this layer are also governed by equations (1) and (2), but for space considerations only one example is shown. The edges at this layer represent social (solid lines) and technical (dashed lines) communication across nodes. This means that humans may be interacting with other humans and services with other services. As well, one instance protocol is shown for this layer, and it consists of those elements that interact at this layer. Thus, H2's protocol orchestrates the interaction between H1 holons, prescribing coordination, cooperation, or collaboration across the nodes.

The H3 layer is similar to H2's, except that its nodes now represent H2 holons. Once again, edges between nodes represent social and technical interactions, and this interaction is orchestrated by the protocol.

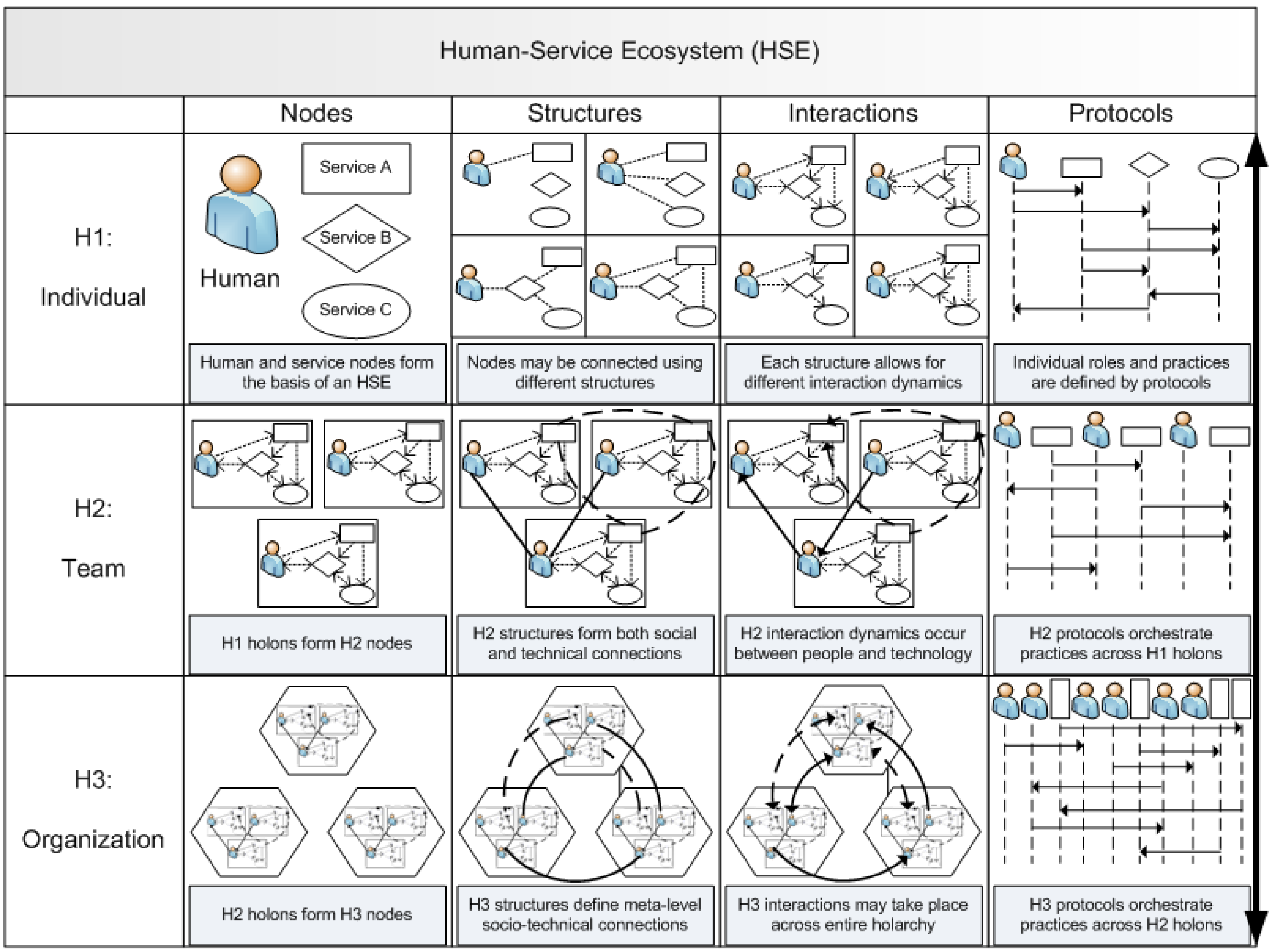

Figure 2. A holonic approach to a complex systems HSE, based on nodes, structures, interactions, and protocols. Emergent properties result across layers as a function of enacted protocols. An information system to support an HSE must adopt strategies that are designed for multiple layers as indicated by the spanning arrow on the right.

HSEs, like the EOC, are complex socio-technical systems, and frameworks to support them appear in two flavours: i) organizational systems science, which proposes norms for designing and influencing the behavioural protocols of individuals [21]; and ii) software engineering, which proposes methodologies for the design of interacting technological modules [22]. However, a merger of these two perspectives, a complex human-machine system-of-systems, is known to be difficult to engineer, due to the "human-factor" [22]. As a result, often social and software components are not considered together from this system view (i.e., nodes, structures, interactions, and protocols) across multiple holonic layers, which leads to inefficiencies as the possibility of linking the right people together with the right information to respond to novel situations in real-time is not built-in to the operating HSE protocol. This is the traditional approach, governed only by hierarchy. However, by enabling technical interactions, as well as social ones, benefits of a networked organization can be realized through technology. Such a technological solution is discussed in the following section.

IV. NEXUS – An Architecture for Holonic Synergy

In the world of emergency response, complex situational events can be thought of as a series of scenes—much like a movie. Together, these scenes provide the situational context. However, due to human limitations such as information overload, important aspects can often be overlooked or neglected. A more effective pairing of humans and intelligent technology, as discussed in the background, can be used to alleviate human limitations and augment human capabilities, thus enabling scenes and ultimately the situation to be better understood. This is the goal of NEXUS (networked experts understanding scenes): to increase the effectiveness of human-machine pairings and to enable synergy across holonic layers (see vertical arrow in Fig. 2).

The NEXUS architecture appears in Fig. 3 and consists of four nodes at the H1 layer—one human user and three services: HCI, Simulation, and BCI. The *HCI service* provides a natural interface with the user (e.g., natural-language processing), as well as the ability for the user to set specific parameters within the Simulation service. It further supports visual analytics, in which information is displayed to the user based on user preferences. The *Simulation service* provides a library of simulation models from which scenes are created. These may be created and used by a single user or shared across a team of users. This service constantly monitors the latest data and feeds this data into the simulation models, notifying the user (through the HCI service) if a particular scene's threshold has been met (e.g., one scene may be to monitor hospital occupancy levels in the city, and a threshold may be to notify the pertinent EOC member if any hospital's occupancy level exceeds 90%). This allows specific aspects of the situation to be offloaded to simulation, freeing the user to focus on other tasks. Finally, the *BCI service* monitors the user and prioritizes tasks (i.e., which scenes are of most importance to present to the user based on brain-context information). This service also reassigns scenes to other users if the current user's overload threshold has been exceeded (e.g., in the case of the EOC, if the hospital representative is overloaded, notification from the Simulation service regarding occupancy level could be sent to the EOC manager). Together, these services improve human-machine effectiveness by reducing the user's cognitive load (both through the Simulation and BCI services), as well as by improving the user's performance through the targeted visual analytics (provided by the HCI service). The architecture's H1 structure and interaction are shown in Fig. 3, as well, and coincide with the service descriptions presented previously.

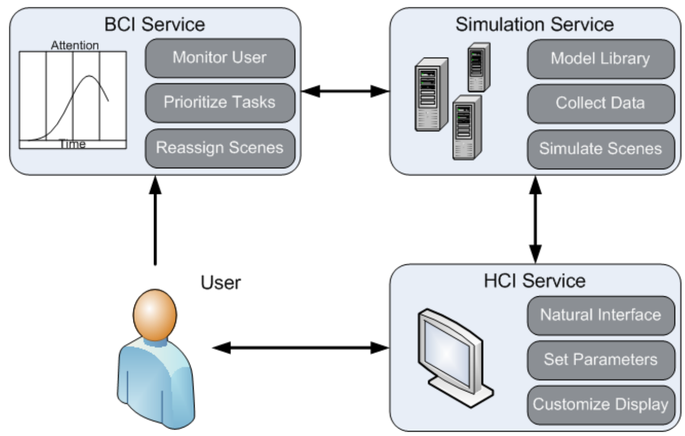

Figure 3. The NEXUS H1 architecture provides a BCI service for understanding implicit user states, a Simulation service for offloading processing of information, and an HCI service for improving the interaction between the user and the system.

At higher holonic layers (e.g., H2 and H3), NEXUS users are connected not only via the organization's formal and informal social structures, as occurs in a traditional organization, but also through technological structures, as the BCI service of one user is connected to the BCI service of all other users within the holonic structure (i.e., within the holarchy). The power of this approach is that it connects everyone across the ecosystem regardless of the formal organizational structure. In essence, it allows the organization to be more dynamic, as nodes interact on an as-needed basis, versus the alternative: a static formal structure with informal, undocumented social connections. The orchestrating protocol at these levels is based on users' current states, as well as on the specific contexts of the scenes to be reassigned. It is the degree to which these holonic protocols are able to integrate that guides the emergence of desired system-level properties, such as synergy. For example, by having similar protocols at H1, the NEXUS orchestrating protocols at H2 and H3 can essentially "plug and play" different scenes to different individuals. In theory, this means that a scene from one user can be reassigned to anyone else in the organization. However, in practice, specific protocols may be in place to preserve organizational policies such as "need-to-know" security clearances.

This "synergistic togetherness" across holonic layers is precisely what is needed today to solve emerging problems and to handle the issue of information overload [13]. Each participant node within the holarchy has its own protocol, which at the base level (i.e., H1) defines individual roles within the organization and at higher levels (i.e., H2 and H3) defines the orchestrating protocol. Within NEXUS, these protocols place decision-making power at the edge; that is, the decision-making power is vested primarily with the lowest-level elements—in this case, the BCI service in H1. This type of "robustly networked organization," suggested in [2], promoting the decentralization of authority, opens the possibility of implementing an agile organization that "self-organizes" around the needs of an evolving complex situation, such as those faced in emergency response [13], and NEXUS provides a glimpse into such a machine-assisted self-organization. The key lies in organizing the HSE nodes into the necessary structures, interactions, and protocols to allow desired system-level properties to emerge.

Continuing with the EOC example, as shown in Fig. 1, 1A represents the formal social structure, where the organization appears as a hierarchy, and 1C represents the technological structure, where the organization appears fully connected. Somewhere along this spectrum (1B) is the "active" structure enabled through NEXUS, representing a hybrid with both formal, hierarchical structure (solid lines) and technological, networked structure (dashed lines). This active structure changes dynamically, and 1B denotes only a single instance in time: in this case, where all the formal social connections are active, but only some of the possible technological connections are active.

V. Summary and Future Work

This paper introduced the concept of a Human-Service Ecosystem (HSE), which consists of both social and technical nodes, organized according to different structures, interactions, and protocols, across multiple holonic layers. It also explored the NEXUS architecture as a proof-of-concept. It was hypothesized that humans and services could be structured according to HSE principles in such a way as to improve the current levels of human-machine effectiveness and human-resource management, and, in so doing, improve the overall synergy of the organization and, thus, its fitness in achieving its goals. This was then presented in the context of a running emergency-response example, where the members of the EOC, supported by technology, could provide a better response through the simultaneous reduction in human limitations (e.g., through the BCI and Simulation services) and increase in human capabilities (e.g., through the HCI service and the benefits of a networked organization).

This work contributes to existing literature i) by providing a framework to describe HSEs and ii) by presenting an overview of a dynamic software system architecture, NEXUS, that enables the emergence of holonic synergy. As part of future work, the three NEXUS services described briefly in this paper will be implemented at the H1 level, and H2-level protocols will be explored so as to achieve holonic synergy within an organization. This is anticipated to result from a combination of improvements in two areas: i) human-machine effectiveness at H1, by providing technologies that reduce human limitations and augment human capabilities; and ii) human-resource management at H2, by reassigning scenes from overloaded individuals to individuals ready to address them. Thus, through the benefits of technology and an understanding of the holonic nature of organizations, NEXUS aims to create an HSE that unlocks and enables synergistic potential across an organization's holonic structure.

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